A QUALITATIVE PERFORMANCE MEASUREMENT APPROACH TO NEW PRODUCT DEVELOPMENT

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ABSTRACT

The main application of fuzzy logic in manufacturing has been through type-1 fuzzy sets leaving type-2 fuzzy sets behind. It is felt that type-2 fuzzy sets have the potential of being exploited on a similar scale to type-1 fuzzy sets, because of the additional advantages of containing more information about uncertainty.

The essence of type-2 is in capturing uncertainty in rule-bases by making the degrees of membership to fuzzy sets, fuzzy themselves. Type-2 fuzzy sets are used when (1) linguistic labels of fuzzy sets are uncertain, (2) there is more then one expert, (3) input data into the fuzzy model is uncertain, and (4) training data is uncertain for adaptive modelling. In this research (1) and (2) lead to the use of type-2 fuzzy sets for evaluating a New Product Introduction process. In particular the New Product Introduction Process is explored and documented in a high technology goods manufacturer. The work uses soft systems methodology, cause and effect diagrams, and process maps to document the use of and sharing of information and also to identify the causes of extended time to market.

Initially qualitative data is used to capture model structure by identifying linguistic variables and relationships between them. It is found that the variables can be arranged in a hierarchy to effectively reduce the potential number of rules. A questionnaire is prepared in order to capture further data to identify fuzzy set parameters and lead to type-2 fuzzy sets. The remainder of the paper finds some initial results and further illuminates the methodology of using type-2 fuzzy sets.

Keywords: Qualitative Performance Measurement, New Product Development.

INTRODUCTION

Fuzzy logic has been used in many successful applications, for example in control systems, economics, and process planning. These successes have predominantly used type-1 fuzzy logic. The aim of this research is to investigate methods of using qualitative data and expert judgement in the New Product Introduction process. One such method, type-2 fuzzy logic, is described and the sequence of steps in using it. The objectives of this research is to determine how to carry out knowledge acquisition and use it to build an accurate and robust type-2 fuzzy logic model. The general situation is that shown in Figure 1. Using accuracy as a metric, information is gleaned about what is "best practice" in knowledge acquisition for type-2 fuzzy logic.

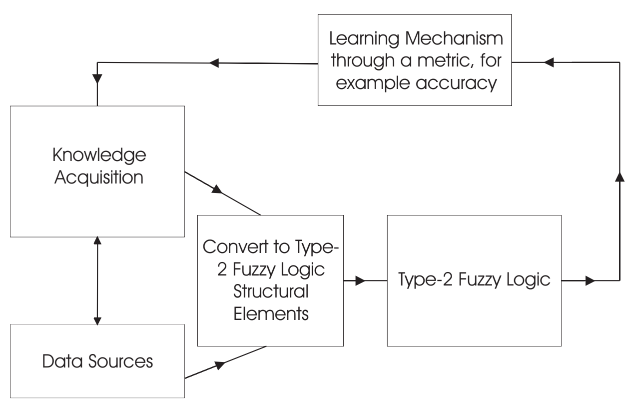

Figure 1. A General scheme for the use of Type-2 fuzzy logic.

1. New Product Introduction

The application of type-2 fuzzy logic in this research will be in the area of New Product Introduction (NPI), in particular NPI in lean and agile manufacture. There are many important aspects of lean engineering such as performance measurement, balanced scorecard and policy deployment. Performance measurements are a simple and easily measurable quantities used to rapidly assess operations, for example "dock to dock days" is the number of days from raw material delivery to product shipment from the factory (Maskell and Baggaley, 2003). Balanced score card (Bicheno, 1998) is a method of assessing performance from a balanced perspective of finance and the other perspectives of customer, internal business, and innovation and learning. Policy deployment is a method of defining productivity and quality goals and planning their attainment. Lean and agile manufacture require that processes such as design shall evolve through performance measures and redefine through policy deployment. It is essential that such evolution is capable of happening to respond to the customer. This research aims to link performance measurement to policy deployment through the use of type-2 fuzzy logic, and hence in this way allow evolutionary planning and response within the NPI process and corresponding work-flow. Further research will examine the methodology in a distributed collaborative design process.

2. Type-2 Fuzzy Logic

Type-2 fuzzy logic is not a new idea, but is novel in that it has been infrequently used in research as opposed to type-1 fuzzy logic. (Mendel, 2001) found only 40 references, in a possible 27,000 including the word "fuzzy", concerning type-2 fuzzy sets. Applications of type-2 fuzzy logic have included executive decision making in design (Nojiri, 1982) and process time estimation in flat plate processing (Jahan-Shahi et al, 2001). A type-2 fuzzy set is shown in Figure 2, as compared to a type-1 fuzzy set shown in Figure 3. Type-2 fuzzy sets consist of "embedded" type-1 fuzzy sets in that each degree of membership of an element to a type-2 fuzzy set is a type-1 fuzzy set. The situation in which the degrees of membership of the "embedded" type-1 fuzzy sets are all 1, is one in which the fuzzy sets are termed interval-valued fuzzy sets. As shown in Figure 1 knowledge acquisition and a suitable "conversion" method, will produce type-2 fuzzy sets. These type-2 fuzzy sets are built so that meaning is imbued within the model through the use of degrees of membership. Research has proven that such a method of imbuing meaning is a sensible one. But previous research has introduced questions regarding the choice of fuzzy logic operators. It is fair to say that a model containing sensible fuzzy sets by way of defining degrees of membership, can produce responses that are not sensible through the use of inappropriate fuzzy logic operators. One example might be the use of the Smallest of Maximum defuzzification method providing a discontinuous response in a control application. Another such example is the suitability of aggregation operators for aggregating fuzzy sets in decision making. It was found by Yager (2003) that an aggregation operator must be required to form a better defined aggregated output fuzzy set when a large number of fuzzy sets are indeed being aggregated. Such a better definition is termed by Yager as "noble reinforcement" and was a research requirement considering existing operators.

3. Type Reduction

As well as type-2 fuzzy logic using type-2 fuzzy sets, a further difference between type-1 inferencing and type-2 inferencing is the step of type reduction from type-2 to type-1 fuzzy sets (Mendel, 2001). Type reduction is performed before defuzzification within Type-2 inferencing. Combining type-2 fuzzy sets using fuzzy logic operators is also more involved than for type-1 fuzzy sets. In summary the new information required to use type-2 fuzzy logic compared to type-1 fuzzy logic are:

1. How to construct type-2 fuzzy sets,

2. How to perform operations between type-2 fuzzy sets, for example maximum and minimum, and

3. How to perform type reduction.

It is important to justify all of these new types of operations from a subjective point of view in order to justify the use of type-2 fuzzy logic with expert opinion and knowledge acquisition.

4. Type-2 Fuzzy Logic Methodology

A type-2 fuzzy logic methodology is required in a vastly simplified form for use by, say, continuous improvement teams. The aim is to couch the type-2 fuzzy set theory jargon into familiar terms for shop-floor use as a new lean tool. This lean tool aims to join Bicheno's lean toolbox for quantifying such matters as process improvement, Single Minute Exchange of Die (SMED) implementation or Total Productive Maintenance (TPM) schedules, for example.

Type-2 fuzzy logic is a lean tool because it can lever teams' knowledge, and is better than type-1 just because of this ability to capture more knowledge and uncertainty (Bicheno, 1998).

Previous research in Table 1 has been conducted to find out how previous work has carried out the "convert to type-2 fuzzy logic structural elements" activity in Figure 1. Type-2 fuzzy logic is focussed on being able to better model uncertainty via the use of groups of experts to produce a Footprint of Uncertainty (FOU), as shown in Figure 2. The Footprint of Uncertainty is the blurring of type-1 fuzzy sets.

This research has initially used process maps for building a rule-base and a questionnaire for building type-2 fuzzy sets to produce a type-2 fuzzy logic model. An analogy with Program Evaluation Review Technique (PERT) for estimating project time has provided a pilot questionnaire as shown in an excerpt in Table 2. The analogy has brought forth the terms "pessimistic", "optimistic" and "most certain". "Most certain" is used instead of "most likely" as PERT uses probability theory for modelling uncertainty.

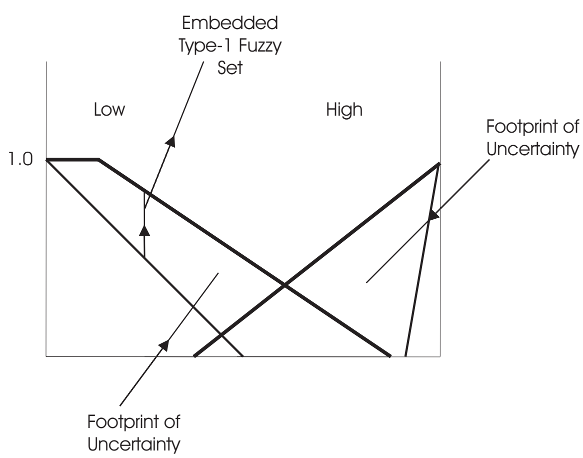

Figure 2. Examples of Type-2 fuzzy sets.

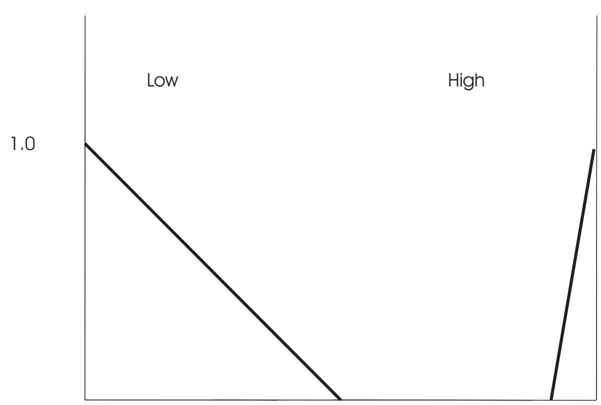

Figure 3. Examples of type-1 fuzzy sets.

Applications Using Type-2 Fuzzy Sets	"Convert to type-2 fuzzy logic structural elements"activity
Knowledge mining (Mendel, 2001)	A survey found how many respondents agreed with a predefined rule-base. Also a survey established the Footprint of Uncertainty, for example through asking about typical intervals for fuzzy sets to many people. The "conversion" occurred through frequency charts.
Last and Kandel (2002)	Perceptions were used to analyse histograms of experimental data for the manufacture of semiconductors. Exponentially shaped functions were chosen according to the psychology literature to model human perception. By allowing the parameters of the fuzzy sets to vary in a range type-2 fuzzy sets were produced.
Jahan-Shahi et al (2001)	Type-2 fuzzy sets were produced from type-1 fuzzy sets by using hedges to find the square and then the square root of the degrees of membership of the type-1 fuzzy set. This led to an interval valued fuzzy set.

Table 1. Previous research into producing type-2 fuzzy sets.

Factor Name	Most Pessim-istic Value	Most certain Value	Most Optim-istic Value	Range of Most Pessimistic (e.g. Most pessimistic is between x and y)	Range of Most Optimistic (e.g. Most Optimistic is between x and y)	Range of Most certain (e.g. Most Likely is between x and y)
e.g"Medium" "Amount of User Feedback" in number of users	24	16	10	Between 20 and 28	Between 9 and 14	Between 16 and 16 (i.e. zero range)

Table 2. Excerpt from the questionnaire to build type-2 fuzzy sets.

We have seen examples of how to construct type-2 fuzzy sets. The next step in the paper is to show how operations between type-2 fuzzy sets work so that inference can be carried out as usual. Let a rule be: "if Amount of User Feedback is Low and Product Power is High then Market Evaluation is good". The rule has been created by examining process maps of a New Product Introduction process. "Product Power" or power of the product is part of the product specification, and "User Feedback" refers to customer feedback, in this case when the customer has knowledge of the "Product Power" specification. Only the premise of the rule is considered, that uses the connective, "and". Consider equation (1) (Nojiri, 1982).

$$A \cap B \Leftrightarrow \mu_{A\cap B}(z) = \mu_A(x) \cap \mu_B(y) = \left(\sum_i \frac{f(u_i)}{u_i}\right) \cap \left(\sum_j \frac{g(w_j)}{w_j}\right) = \sum_{i,j} \frac{f(u_i) \cap g(w_j)}{u_i \cap w_j} \quad (1)$$

$\mu_A(x)$ refers to the embedded type-1 fuzzy set at x ("Amount of User Feedback") and $\mu_B(y)$ refers to the

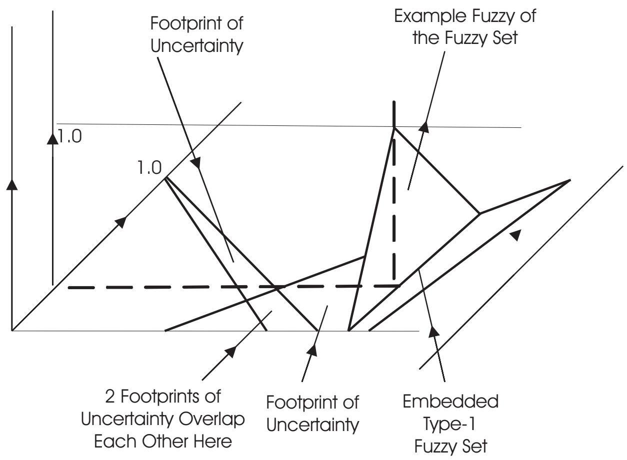

Figure 4. A 3 dimensional view of 1 of the uncountably many "fuzzy of the fuzzy" sets.

embedded type-1 fuzzy set at y ("Power"). For a visual example of an embedded type-1 fuzzy set see Figures 2 and 4. In Figure 4 an example embedded type-1 fuzzy set is shown coming out of the paper and is labelled, "fuzzy of the fuzzy". There are uncountably many of these embedded type-1 fuzzy sets in continuous type-2 fuzzy sets. $\mu_{A\cap B}$ (z) ("Market Evaluation") refers to the resulting type-2 fuzzy set when x and y are varied. For testing a rule then $\mu_{A\cap B}$(z) will be a type-1 fuzzy set for each z. In Equation (1) u_i refers to the range (indexed by iif u_i is discrete) of the degree of membership of x in $\mu_A(x)$,and is a range because of the uncertainty in the degree of membership. $f(u_i)$ refers to the "fuzzy of the fuzzy", i.e. the degree of membership of range of the degree of membership u_i. Equation (1) works by the extension principle. The type-2 fuzzy sets per fired rule are aggregated using an equation like equation (2) (Nojiri 1982). The equation is similar to Equation (1) but includes union instead of intersection because it is aggregation.

$$A\cup B \Leftrightarrow \mu_{A\cup B}(z) = \mu_A(x)\cup\mu_B(y) =$$

$$\left(\sum_i \frac{f(u_i)}{u_i}\right)\cup\left(\sum_j \frac{g(w_j)}{w_j}\right) = \sum_{i,j}\frac{f(u_i)\cap g(w_j)}{u_i\cup w_j} \qquad (2)$$

5. Final Steps

The final step is type reduction and defuzzification. Type reduction by Mendel (Mendel, 2001) is a complex process. The type-2 fuzzy set to be type reduced is first made to consist of discretised points. These points are then used to refer to several possible embedded type-1 fuzzy sets. These are used to come up with a type-1 fuzzy set that is finally defuzzified.

A path must be found that is reasonable and intuitive through the described steps that make type-2 fuzzy sets a reasonable and intuitive method for knowledge

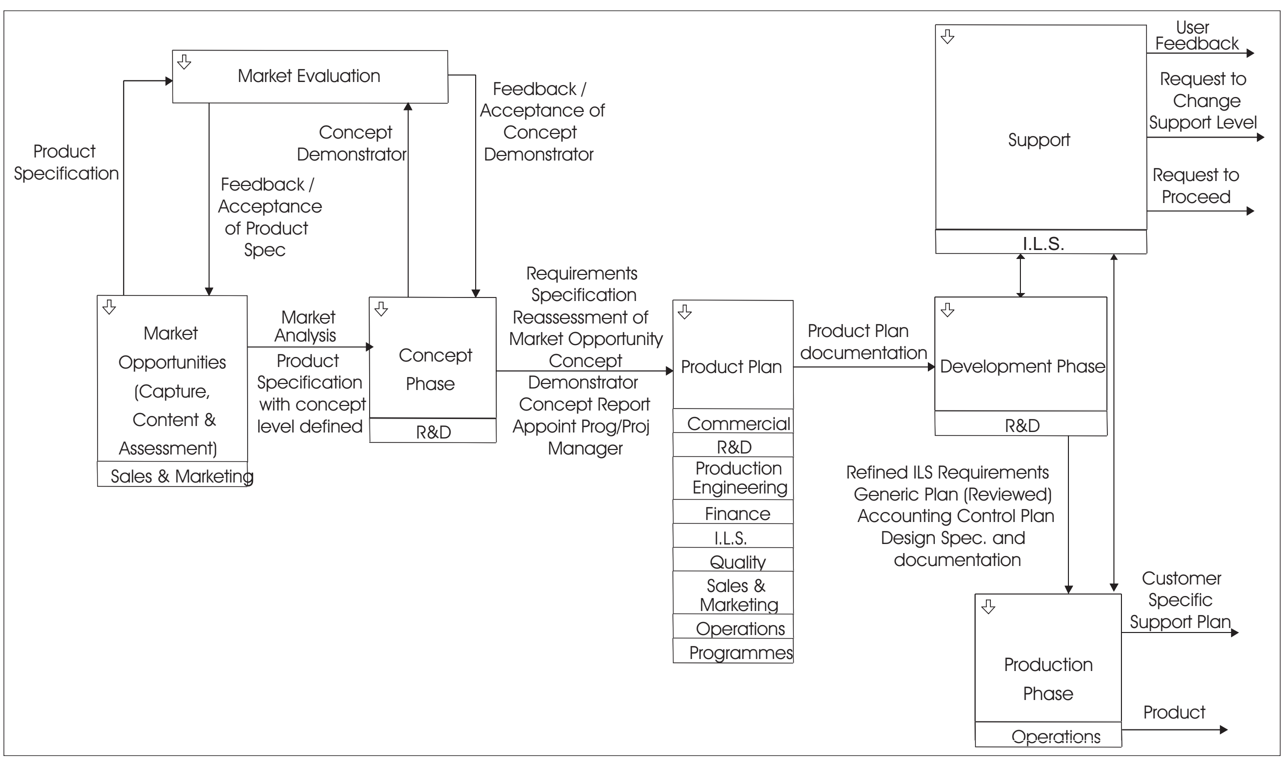

Figure 5. Process map of the New Product Introduction process (Koliza et al 2003).

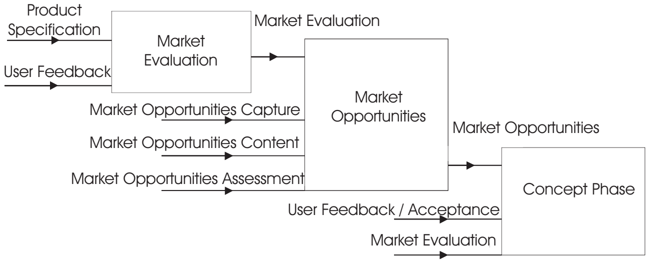

Figure 6. Excerpt from a hierarchy of sub-models.

acquisition and manipulation as a lean tool. This path must of course be backed up with results from the model. Further research shall therefore be involved with mapping knowledge, the described paths through building the model, and the learning process that changes the model.

6. Initial Work

Initial work has converted a process map as shown in Figure 5 into a number of sub-models as shown in Figure 6. Each box in Figure 6 shows a number of inputs and a subsequent output. Within the hierarchy the output is used as an input into the next sub-model. This is a way of avoiding a large model with an impractically large rule-base.

Conclusion

Type-2 fuzzy logic has been introduced. Type-2 fuzzy logic is designed as a generalization of type-1 fuzzy logic. Mendel (2001) uses an analogy from probability and statistics in that the variance generalises from the mean of a probability density function, i.e. type-2 generalises from type-1 fuzzy sets. The main reason for using type-2 fuzzy sets in this research is that "words mean different things to different people". In particular type-2 fuzzy sets are proposed as a lean tool for quantifying knowledge, for example the effects of continuous improvement. Initial work on an NPI process has produced a structure of several sub-models from qualitative data, i.e. a process map.

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Tom Page is currently working as a Lecturer of Electronic Product Design in the Department of Design & Technology at Loughborough University, England. He graduated from Napier in 1988 with a degree in 'Technology with Industrial Studies' and started employment with Ferranti Defence Systems Ltd., as a Design Engineer from 1988 to 1990. In 1990, he returned to Napier Polytechnic as a Research Assistant and worked between there and the Engineering Design Research Centre (EDRC) at the University of Glasgow. In 1992, he attained a M.Phil by research in Engineering design methodology for his work at the Engineering Design Research Centre. On completion of this work, Tom took up a teaching post in Computer-Aided Engineering at the University of Hertfordshire. In 1995, he became a Chartered Engineer with full membership of the Institution of Electrical Engineers (IEE) and was promoted to Senior Lecturer in Computer-Aided Design and Manufacturing. Whilst at Hertfordshire, Tom pursued his research interests in Electronics Design for Manufacturing and Assembly which led to the award of a PhD in 2001. He is also a Full member of the Institute of Learning & Teaching (ILT). His research interests include electronics design tools, electronics design for manufacturing and assembly and engineering/ technological education. To date he has over two hundred research publications in these areas.