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On the Relevance of Fuzzy Sets in Analytics

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The title of this contribution to *On Fuzziness* has a history and a reason that bridges the past, the present and the future. The history is a paper I wrote called "On the Relevance of Fuzzy Sets in Management Science Methodology" which was published in an edited book on *Fuzzy Sets and Decision Analysis* (H. J. Zimmermann, L. A. Zadeh and B. R. Gaines (eds.), in the TIMS Studies in Management Sciences series in 1984) [2]. This was a time when we tried to make the case for fuzzy sets in management science and as a support theory for managers who plan the future, and solve management problems and make decisions in their daily activities.

If we continue the history a bit, a first version of the paper had been presented and discussed at the 11th meeting of the EURO Working Group on Fuzzy Sets at the *European Institute for Advanced Studies in Management* in Brussels on February 19-20, 1981. The EIASM is the centre for serious research on management in Europe and getting an invitation to run a workshop on fuzzy sets took some negotiation; the EURO WG was the first organized activity on the study of fuzzy sets in Europe and was organized by Hans-Jürgen Zimmermann; I was the second chairman and was running the WG for a number of years, also at the time for the workshop at the EIASM in Brussels (Hans thought that I was a natural choice as my doctoral thesis was in management science and we believed that the break-through areas for fuzzy sets in Europe would be engineering and management).

Management science methodology – and especially operations research that applied the same methodology for engineering problems and theory development – had already in 1981 been under attack for more than a decade for failing to deal with the real world problems managers have to tackle, for oversimplifying decision problems and for spending too much time with mathematically interesting but practically irrelevant solutions to problems that had been simplified to be tractable with management science theory and methodology. The message was basically that management science methodology produced theory and methods that were irrelevant for handling actual management problems. The paper in 1984 (1981) argued that fuzzy sets when properly worked into management science methodology would make the models, the algorithms and the theory more relevant and better suited to deal with management problems in practice.

Now, thirty years later, we have to admit that we were not successful in bringing it about, that fuzzy sets remained a marginal development in management science and that we have been able to get fuzzy sets based methods accepted only for limited applications, such as multiple criteria optimisation, real options valuation, logistics

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optimisation, etc. for which there have been algorithmic benefits of allowing the use of fuzzy numbers.

Management science and operations research have also changed over the decades; two major organisations in the field – TIMS and ORSA – merged and became INFORMS to combine the applications oriented research (TIMS) with the algorithms and theory oriented research (ORSA); now the annual INFORMS conferences collect 2-3000 participants; in Europe the EURO Association is a sister organisation to INFORMS and the annual EURO conferences also collect 2-3000 participants. Both organisations run major, well-established journals with high impact factors (*Management Science* and *European Journal of Operations Research*, respectively) and there are dozens of journals publishing material produced guided by the management science methodology. The field is alive and well and promotes lively research that activates thousands of researchers. The context is there, then what is needed for fuzzy sets to be relevant (again) for the research that is carried out? We will work through some arguments in the following to build the promised bridge from the history to the present and future of fuzzy sets in management theory building and applications.

Analytics is gaining support as an important business function that adds value to management; this movement, that promotes data-driven and analytical decision making, is rather recent. Analytics builds on recent software improvements in information systems that has made data, information and knowledge available in real time in ways that were not possible for managers only a few years ago [3]. Now INFORMS has found out that the new movement represents both "potential opportunities" and "challenges" to management science and operations research professionals and published a study [4] in which the INFORMS membership was asked how they want their organisation to deal with analytics. The methods and the application cases worked out in the Davenport-Harris book[3] are very close to traditional text books on management science methodology, actually so close that a manager probably fails to see any differences, which is why INFORMS finds "challenges". Then it makes sense to work out the relevance of fuzzy sets in terms of the modern analytics movement - we will do this by comparing it with the points we made on the relevance of fuzzy sets for classical management science in 1984 (1981).

Liberatore and Luo [4] state that four factors drive the analytics movement: (i) availability of data, (ii) improved analytical software, (iii) the adoption of a process orientation by organisations, and (iv) technically literate managers and executives. Compared to the early 1980's the last factor is probably the most important driver – there is a new generation of managers and executives in charge of the corporations that are using information technology as part of their daily routines. They work with data, information and knowledge on a real time basis and they continuously hunt for better and better analytical tools to help give them competitive advantages. They do not necessarily recognize the analytical tools as classical management science algorithms because analytical software (cf. (ii)) has become user-friendly through graphical user interfaces and visualisation of results, which allows them to use analytical methods without knowing too much of the mathematical background. Information technology has made data available on a real time basis – in classical management science work off line and sufficient time always had to be allocated for collecting and processing data for the models and algorithms – which allows online planning, problem solving and decision making. Maybe “allow” is not the right verb as online management work in real time now is more of a necessity to keep up with the competition. The same driver also explains the adoption of a process orientation (cf. (iii)) as management work typically is group and team work online and in real time. Davenport and Harris [3] define analytics as “the extensive use of data, statistical and quantitative analysis, explanatory and predictive models and fact-based management to drive decisions and actions”. Liberatore and Luo [4] interpret this definition as representing three levels of modelling - descriptive, predictive and prescriptive – and stated that management science (they actually refer to OR, but here we do not make any difference between management science and operations research) typically would focus on advanced analytics, i.e. prescriptive modelling. Liberatore and Luo [4] also point out that analytics would focus on the managerial planning, problem solving and decision process, i.e. the transformation of data into actions through analysis and insight, which in their discussion contributes to the application cases of management science.

The modern movement of analytics appears to offer interesting possibilities and opportunities for building on fuzzy sets; the movement is data-driven which will require tools for handling imprecision; the movement is focused on managers who need to deal with real world problems, for which available data, information and knowledge are incomplete, imprecise and uncertain and should allow for fast, often intuitive conclusions; the movement builds on improved analytical software that can easily incorporate various tools using fuzzy sets (fuzzy numbers, fuzzy optimisation algorithms, linguistic modelling, etc.).

Let us then go back to the insights of 1984 (1981) and find out in what way the relevance of fuzzy sets in management science still could apply for the analytics of the 2012.

The composing of the management science methodology follows some principles, and some rules. The classical approach is to aim for either a logico-deductive or an inductive system and select the methods accordingly; the logico-deductive system is favoured in the sciences and has been favoured also for management science methodology. One of the pioneers, Russel L. Ackoff [1], outlined the system as a problem-solving methodology that handles research problems (here summarized):

i Formulate the problem; listing alternative activities that could be carried out, expected outcomes and formulating a set of criteria for comparing the outcomes;
ii Construct or select a model; describing the problem formulation in (i) with the help of a set of formal and stringent concepts;
iii Select a system of measurement; quantifying the concepts introduced in (ii) through some appropriate system of measurement and delimiting activity and solution spaces;

iv Test the model; checking the technical performance of the quantitative model in (iii) and carrying out a preliminary validation;
v Derive a solution from the model; deriving numerical values for the elements of the model in (iii); this constitutes a definite choice of a set of activities, which could be the "best" one possible;
vi Validate the model and the solution; testing and controlling both the model and the solution in order to make certain that the model is a formally valid and reliable representation of the problem and that the solution is formally correct;
vii Carry out experiments with the model, implement and control the solution; testing the applicability and relevance of both the model and the solution to the problem; continue until the model is either accepted or rejected, or modified and developed in order to better correspond to the formulation and the needs of the real world problem.

Each step in this methodology should form a deductive system: (a) a set of undefined and defined concepts to form the framework, which is developed and specified by (b) a set of assumptions, from which is deduced (c) a set of more or less formal theorems, which are confronted with (d) sets of more or less explicit facts (cf. [1]). Such a system will allow us to proceed from general and undefined concepts to specific and defined, from loose and preliminary assumptions to precise and stringent, from general theorems to specific, and from loose heaps of facts to well-structured, theory-oriented sets of facts. This corresponds quite closely to the ideal form for a scientific process and we are assured by the methodology that the solution to (for instance) a management problem will be scientifically valid, formally correct and operationally acceptable as a solution to the original real world problem.

Throughout the history of management science it has been accepted that the methodology described is – in principle – the correct and best way to find solutions to managerial problems. The methodology has been much used to explain great breakthroughs in industry and important innovations in business; it has also been useful for explaining and proving that everything necessary and relevant had been done when unexpected events have caused disasters. The typical thing is, however, that these explanations have been given *after* the processes have been carried out, not online and in real time when they would have been most needed and useful. The reasons given have been that data was not available and that there was no time to build and use the necessary decision models through the methodology summarized in (i)-(vii). Thus the end result has typically been that everybody seems to accept that management science methodology is the best way to tackle and handle management problems but that nobody uses it for practical planning, problem solving and decision making in management.

This is where we made a case for fuzzy sets in the 1984 (1981) paper [2]. First of all, the science methodology applies very well to modelling based on fuzzy sets and we do not have to make any special provisions for fuzzy modelling. The theory of fuzzy sets is developed for a domain in which descriptions of activities and observations are “fuzzy”, in the sense that there are no well-defined boundaries of the set of activities or observations to which the descriptions apply.

In the context of managerial planning, problem solving and decision making we have learned over the years that “fuzziness” differs from “generality”, which is the application of one description to a (well-defined) set of activities or observations; it differs also from "ambiguity", which refers to the use of several, competing (but well-defined) descriptions of a set of activities or observations. “Fuzziness” is not “uncertainty” in the sense of subjective probability theory – because it does not use its axioms – nor in the sense of classical probability theory as it does not build on the frequencies of events, activities, observations, etc. (we have of course fuzzy probability theory in order to make the world interesting). In the managerial world we quite often look for general principles to guide the development of business models and we have to deal with ambiguity and uncertainty when we work out strategic plans. In many cases management theory recommends that ambiguity and uncertainty should be handled with (subjective) probability theory even if none of the events, activities, observations, etc. is recurring. “Fuzziness” is “vagueness” or “imprecision” (but not in the sense of tolerance analysis as the tolerance interval is not sharp), which makes it a central element in human thought and perceptions, as well as in human language. Why is this important? It is a well-known fact that it is virtually impossible to give an exact description of any real physical situation; needless to say this holds also for any managerial problem situation, especially as many of these problems relate to an unknown future. A science-oriented methodology knows only exact, well-defined activities, outcomes, external activities and goals – and functional relationships. The reason for that has been the nature of and the limitations of the concepts applied in management science methodology: it has not been possible to give an adequate representation of “fuzziness” – or as Lotfi Zadeh wrote “..., *we need a radically different kind of mathematics, the mathematics of fuzzy or cloudy quantities which are not describable in terms of probability distributions*.”

The theory of fuzzy sets allows us to structure and describe activities and observations which differ from each other only vaguely, to formulate them in models and to use these models for various purposes in managerial problem solving and decision making. This is ability we have as human beings but which is not supported by any science-oriented methodology. We are trained as scientists to use precise concepts and sharp definitions in order to be able to build precise and elegant models, to use mathematically well-defined algorithms so that we can give distinct descriptions, precise explanations and concise predictions; we are also trained as managers to use precise concepts and sharp definitions so that we can give distinct descriptions of business events, precise explanations of business opportunities and concise predictions of the outcomes when using resources to achieve business ends (at least we strive towards these ideals). The experience we now have (which is also supported by analytics) is that this ability is not the most important one for handling managerial problems.

The human brain is said to think and reason in imprecise, non-quantitative, vague terms which (for instance) gives us the ability to decipher sloppy handwriting and understand distorted speech. It also gives us the ability to summarize and to focus on relevant information and knowledge and to concentrate on essential aspects when handling very large amounts of data and information (a by-product of the information technology revolution). These last-mentioned three capabilities are often cited as "essential" for managers-to-be.

Over the last 30 years we have found in a number of industrial and business cases that fuzzy sets has been a very useful tool for handling imprecision, uncertainty and vagueness without undue simplifications. We have found that we can get a consistent representation of linguistically formulated knowledge that allows the use of precise operators and algorithms. We have worked with fuzzy multi-goal models, fuzzy linear programming and fuzzy multiple criteria optimization and found that fuzzy modelling offers flexibility to deal with very complex problems and the means to include subjective judgment and inexact knowledge to deal with difficult problems that include the needs to resolve future expectations. We have also found that inexactness, or fuzziness, is useful as it helps to convey sufficient information with less effort. We have found the theory of fuzzy sets helpful for carrying out the emphasis on synthesis, expansionism, adaptation and learning (in group and team work), and we have found relevance in the contention that fuzzy modelling in management will contribute to the handling of complex, real-life managerial problems.

Analytics has the same agenda as management science and is working with the same industrial and business context to support managerial planning, problem solving and decision making. Analytics has a broader scope in terms of methods - besides models and algorithms it also works with statistical methods and advanced technology for handling data, information and knowledge. The software used for analytics is several generations more advanced than the software used for management science in 1984. The managers for whom analytics support is developed is a generation more advanced in using information technology and modelling tools. Data, information and knowledge are available in real time for online use to support fast moving business operations. Davenport and Harris [3] argue that "*sophisticated quantitative and statistical analysis and predictive modelling supported by data-savvy senior leaders and powerful information technology*" are the key elements of competitive strategies that make the difference between winning and losing business.

We believe that fuzzy sets will be even more relevant for analytics than for management sci-ence as we (i) will have to deal with (often incomplete, imprecise) large data sets (now called "big data"), (ii) have much better software that can incorporate fuzzy modelling modules, (iii) have to work out support online and in real time where sufficient precision may be more im-portant than full precision, and (iv) have data-savvy users with the insight and knowledge to build on results from fuzzy modelling.

References

1. Ackoff, R.L.: Scientific Method. Optimizing Applied Research Decisions. J. Wiley & Sons, New York (1968)
2. Carlsson, C.: On the Relevance of Fuzzy Sets in Management Science Methodology. In: Zimmermann, H.-J., Zadeh, L.A., Gaines, B.R. (eds.) Fuzzy Sets and Decision Analysis. TIMS Studies in Management Sciences, pp. 11–28. North-Holland, Amsterdam (1984)
3. Davenport, T.H., Harris, J.G.: Competing on Analytics. The New Science of Winning. Harvard Business School Press, Boston (2007)
4. Liberatore, M.J., Luo, W.: INFORMS and the Analytics Movement: The View of the Membership. Interfaces 41(6), 578–589 (2011)