An Overview of Insurance Uses of Fuzzy Logic

Arnold F. Shapiro

Penn State University, Smeal College of Business, University Park, PA 16802, USA
Phone: 01-814-865-3961, Fax: 01-814-865-6284, E-mail: afs1@psu.edu

Abstract. This article presents an overview of insurance uses of fuzzy logic (FL). The two specific purposes of the article are to review the FL applications so as to document the unique characteristics of insurance as an application area and to document the FL technologies that have been employed in insurance-related areas.

Keywords: actuarial, fuzzy logic, fuzzy sets, fuzzy arithmetic, fuzzy inference systems, fuzzy clustering, insurance

Introduction

It has been twenty years since the first article on fuzzy logic (FL) in insurance [DeWit (1982)]. That article sought to quantify the fuzziness in underwriting. Since then, the universe of discourse has expanded considerably and now includes most areas of insurance.

This article presents an overview of these FL applications in insurance. The specific purposes of the article are twofold: first, to review the FL applications so as to document the unique characteristics of insurance as an application area; and, second, to document the FL technologies that have been employed in insurance-related areas.

Before continuing, the term FL needs to be clarified. In this article, we generally follow the lead of Zadeh (2000), and use the term FL in its wide sense, so that it embraces fuzzy set theory (FST), fuzzy numbers, fuzzy inference systems and fuzzy clustering.

The next section presents the overview of insurance applications of fuzzy logic. Subsections begin with an introduction to the application area and are followed by a chronological review of the FL applications in that area. The article ends with a comment on the future of FL in insurance.

Applications

There were six major insurance areas where FL has been implemented: classification, underwriting, projected liabilities, future and present values, pricing, and asset allocation and investments.

Classification

Classification is fundamental to insurance. On the one hand, classification is the prelude to the underwriting of potential coverage, while on the other hand, risks need to be properly classified and segregated for pricing purposes. This subsection provides an overview of FL applied to classification issues in insurance.

The classification articles include: Ebanks *et. al.* (1992), who showed how a fuzzy intersection operator or a FIS could be used to classify life insurance risks; Ostaszewski (1993, 47-67), who presented a detailed, yet simple, illustration of how fuzzy clustering can be used to classify insurance applicants; Manton et. al. (1994), who used FST and a grade of membership score to resolve statistical problems involving sparse, high dimensional data with categorical responses; Yoo et al (1994), who proposed an auto insurance claim processing system based on a fuzzy database, a rule based system, and a feed-forward NN learning mechanism; Cox (1995), who used an unsupervised NN for classification and a fuzzy model generated by a supervised NN to compare individual medical provider behavior to that of a peer group in order to isolate potential abuse in health insurance; Derrig and Ostaszewski (1995), who showed how fuzzy clustering can be used to classify insurance claims according to their suspected level of fraud; Hellman (1995), who used a fuzzy expert system to identify municipalities that were of average size and well managed, but whose insurance coverage was inadequate; McCauley-Bell and Badiru (1996), who discussed a two-phase fuzzy-linguistic expert system for quantifying and predicting the risk of occupational injury, the first phase of which used linguistic variables to qualify risk levels and the second phase used the analytic hierarchy process (AHP) to assign relative weights to the identified risk factors; McCauley-Bell et. al. (1999), who extended the foregoing studies by including a fuzzy linear regression model to predict the relationship of known risk factors to the onset of occupational injury; Verrall and Yakoubov (1999), who showed how fuzzy clustering could be used to specify a data-based procedure for investigating age groupings in general insurance; Peña-Reyes and Sipper (1999), who used a genetic algorithm based FISs to automatically produce diagnostic systems for breast cancer diagnosis; and Bentley (2000), who used an evolutionary-fuzzy approach to investigate suspicious home insurance claims.

Underwriting

Underwriting is the process of selection through which an insurer determines which of the risks offered to it should be accepted, and the conditions and amounts of the accepted risks. The goal of underwriting is to obtain a safe, yet profitable, distribution of risks. This subsection provides an overview of underwriting applications involving FL.

The underwriting articles include: DeWit (1982), who was the first to use a fuzzy expert system to analyze the internal logic of the intuitive part of insurance underwriting; Lemaire (1990), who used a fuzzy expert system to provide a flexible definition of a preferred policyholder in life insurance; Young (1993), who used a fuzzy expert systems to model the selection process in group health insurance; Erbach and Seah (1993), who discussed an early prototype life automated underwriter based on a mixture of fuzzy and other techniques; Carreno and Jani (1993), who developed a knowledge based system that combines fuzzy processing with a rule-based expert system in order to provide an improved decision aid for evaluating life insurance risks; Jablonowski (1996), who investigated the use of FST to represent uncertainty from the perspective of a risk manager and, to that end, conceptualized exposure analysis as being composed of a fuzzy representation of the perceived risk, as a contoured function of frequency and severity, the probability of loss, and the risk profile; Horgby *et. al.* (1997), who applied a FIS to medical underwriting of life insurance applicants; and Mosmans et. al. (2002), who developed a fuzzy multicriteria sorting procedure to investigate a health care budget using both global and detailed data.

Projected Liabilities

The evaluation of projected liabilities is fundamental to the insurance industry but many of the underlying parameters are fuzzy, so it is not surprising that FL is being applied in this area.

Articles which deal with projected liabilities included: Boissonnade (1984), who used pattern recognition, where a discriminative function was developed using Bayes' criterion, and FL in the evaluation of seismic intensity and damage forecasting, and for the development of models to estimate earthquake insurance premium rates and insurance strategies; Cummins and Derrig (1993), who studied fuzzy trends in property-liability insurance claim costs by focusing on the selection of a "good" forecast, where goodness was defined using multiple criteria that may be vague or fuzzy, rather than a good forecasting model; Zhao (1996), who used fuzzy programming methods to build decision making simulation models for maritime collision prevention; Chen and He (1997), who used the AHP, along with entropy theory and FST to derive an overall disability index for measuring an individual's disability; and Sánchez and Gómez (2003), who developed a claims runoff model based on possibilistic regression.

Future and Present Values

Buckley (1987) appears to have been the first author to address the fuzzy time-value-of-money aspects of insurance pricing, when he investigated the fuzzy future and present values of fuzzy cash amounts, using fuzzy interest rates, and both crisp and fuzzy periods. Subsequent studies included: Lemaire (1990), who, using Buckley (1987) as a model, discussed the computation of the fuzzy premium for a pure endowment policy using fuzzy arithmetic; Ostaszewski (1993: 29-38), who extended the pure endowment analysis of Lemaire (1990) by introducing a fuzzy interest rate whose fuzziness was a function of duration and investigating the more challenging situation of a net single premium for a term insurance, where the progressive fuzzification of rates plays a major role; and, along the same lines, Terceno et. al. (1996), who explored the membership functions associated with the net single premium of some basic life insurance products assuming a crisp morality rate and a fuzzy interest rate.

Pricing

In the conclusion of DeWit's (1982) article, he recognized the limitations of his analysis and he speculated that "[E]ventually we may arrive, for branches where risk theory offers insufficient possibilities, at fuzzy premium calculation." He was right, of course, and since then we have seen FL applied to a host of pricing-related problems. This subsection presents an overview of these studies.

Articles on pricing included: Lemaire (1990), who envisioned the decision-making procedure in the selection of an optimal excess of loss retention in a reinsurance program as essentially a maximin technique, similar to the selection of an optimum strategy in noncooperative game theory; Ostaszewski and Karwowski (1992), who explored the use of fuzzy clustering methods as an alternate tool for estimating credibility; Krasteva et. al. (1994), who in a study of life insurance sales as a response to price changes, sketched out the essence of a fuzzy regression model applied to the S-shaped response curve; Young (1996), who described the use of a FIS for making pricing decisions in group health insurance; Young (1997), who described step-by-step how an actuary/decision maker could use FL to adjust workers compensation insurance rates; Cummins and Derrig (1997), who used the inverse membership function of Buckley to fuzzify a well-known insurance financial pricing model in order to address the financial pricing of property-liability insurance contracts; Carretero and Viejo (2000), who investigated the use of fuzzy mathematical programming for insurance pricing decisions with respect to a rating system in automobile insurance; and Lu et. al. (2001), who focused on the linguistic operators of importance and superiority in order to investigate the use of game theory to decide on a product line in a competitive situation.

Asset Allocation and Investments

The analysis of assets and investments is a major component in the management of an insurance enterprise. Beyond the general studies of any financial intermediary, FL studies related to insurance have involved bonds, cash flow matching, immunization, optimal asset allocation, insurance company taxation, and market forecasting. An overview of these studies follows.

Asset and investment studies included: an early discussion of fuzzy cash flows by Buckley (1987: 268), whose focus was on the development of a method of comparing fuzzy net cash flows in order to rank fuzzy investment alternatives; Hosler (1992), who showed how membership functions could be used to describe the risk of call of a bond; Buehlmann and Berliner (1992), who developed a cash-flow matching approximation based on a technique they called "fuzzy zooming," whereby cash flows of assets and liabilities due at different times and in different amounts can be replaced by a single fuzzy payment; Guo and Huang (1996), who used a possibilistic linear programming method for optimal asset allocation based on simultaneously maximizing the portfolio return, minimizing the portfolio risk and maximizing the possibility of reaching higher returns; Bouet and Dalaud (1996), who investigated the use of Zadeh's extension principle for transforming crisp financial concepts into fuzzy ones and the application of the methodology to cash-flow matching; Derrig and Ostaszewski (1997), who illustrated how FL can be used to estimate the effective tax rate and after-tax rate of return on the asset and liability portfolio of a property-liability insurance company; Chang (2003), who developed fuzzy mathematical analogues of the classical immunization theory and the matching of assets and liabilities; and Sánchez and Gómez (2003), who used possibilitic regression to analyze the term structure of interest rates.

Conclusions

The overviews presented in this article verify that FL has been successfully implemented in insurance. Given this success, and the fact that there are many more insurance problems that could be resolved using fuzzy systems, we are likely to see a number of new applications emerge. There are at least two reasons for this. One reason is that the industry should now have a greater appreciation of potential areas of application, to wit, areas that are characterized by qualitative conditions for which a mathematical model is needed that reflects those conditions. The second reason is that, while fuzzy systems have made inroads into many facets of the business, in most instances the applications did not capitalized on the synergies between the SC technologies and, as a consequence, there are opportunities to extend the studies. These things considered, FL applications in insurance and related areas should be a fruitful area for exploration for the foreseeable future.

Acknowledgments

This work was supported in part by the Robert G. Schwartz Faculty Fellowship and the Smeal Research Grants Program at the Penn State University. The assistance of Asheesh Choudhary, Bharath Nemali, Laura E. Campbell and Michelle L. Fultz is gratefully acknowledged.

References

Bentley, P. J. (2000). "Evolutionary, my dear Watson. Investigating Committee-based Evolution of Fuzzy Rules for the Detection of Suspicious Insurance Claims", Proceedings of the second Genetic and Evolutionary Computation Conference (GECCO), 8-12.

Boissonnade, A. C. (1984). "Earthquake Damage and Insurance Risk", Ph.D. Dissertation, Stanford University.

Bouet, G. and Dalaud, R. (1996). "Extension de Concepts Financiers en Calcul Flou et Application á l' Adossement de Flux", AFIR, 2,827-843.

Buckley, J. J. (1987). "The Fuzzy Mathematics of Finance", FS&S, 21: 257-273.

Buehlmann, N. and Berliner, B. (1992). "Fuzzy Zooming of Cash Flows", TICA, 6: 437-453.

Carreno, L.A. and Jani, Y. (1993). "A Fuzzy Expert System Approach to Insurance Risk Assessment Using FuzzyCLIPS", WESCON Conference Record, 536-541.

Carretero, R.C. (2003). "Fuzzy Logic Techniques in the Non-Life Insurance Industry," in Shapiro, A. F. and Jain, L. C. (Eds) Intelligent and Other Computational Techniques in Insurance: Theory and Applications, World Scientific Publishing Company, River Edge, NJ, pp. 229-257.

Carretero, R.C. and Viejo, A.S. (2000). "A Bonus-Malus System in the Fuzzy Set Theory [insurance pricing decisions]", IEEE Int. Conference on Fuzzy Systems 2, 1033-1036.

Chang, C. (2003). "A Fuzzy Set Theoretical approach to Asset and Liability Management and Decision

Making," in Shapiro, A. F. and Jain, L. C. (Eds) Intelligent and Other Computational Techniques in Insurance: Theory and Applications, 301-33.
Chen, J.J.G. and He, Z. (1997). "Using Analytic Hierarchy Process and Fuzzy Set Theory to Rate and Rank the Disability", FS&S, 88: 1-22.
Cox, E. (1995). "A Fuzzy System for Detecting Anomalous Behaviors in Healthcare Provider Claims", Intelligent Systems for Finance and Business, edited by Goonatilake, S. and Treleven, P. John Wiley & Sons, Chichester, England, 111-135.
Cummins, J. D. and Derrig, R. A. (1993). "Fuzzy Trends in Property-Liability Insurance Claim Costs", JRI, Vol. 60, 429-465.
Cummins, J. D. and Derrig, R. A. (1997). "Fuzzy Financial Pricing of Property-Liability Insurance", NAAJ, Vol 1, No. 4, 21-44.
Derrig, R. A. and Ostaszewski, K. M. (1995). "Fuzzy Techniques of Pattern Recognition in Risk and Claim Classification", JRI 62, 447-482.
Derrig, R. A. and Ostaszewski, K. M. (1997). "Managing the Tax Liability of a Property-Liability Insurance Company" JRI 64(4), 695-711.
DeWit, G. W. (1982). "Underwriting and Uncertainty", I:M&E, Vol. 1, 277-285.
Ebanks, B., Kanvowski, W. and Ostaszewski, K. M. (1992). "Application of Measures of Fuzziness to Risk Classification in Insurance", Computing and Information, IEEE Computer Society Press, Los Alamitos, California, 290-291.
Erbach, D. W. and Seah, E. (1993). Discussion of "The Application of Fuzzy Sets to Group Health Underwriting" by Young, V. R. TSA 45, 585-87.
Guo, L. and Huang, Z. (1996). "A Possibilistic Linear Programming Method for Asset Allocation", JAP, 2: 67-90.
Hellman, A. (1995). "A Fuzzy Expert System for Evaluation of Municipalities - an Application", 25h TICA, 1: 159-187.
Horgby, P., Lohse, R. and Sittaro, N. (1997). "Fuzzy Underwriting: An Application of Fuzzy Logic to Medical Underwriting", JAP, 5(1), 79-104.
Hosler, V. R. (1992) "The Application of Fuzzy Sets to Group Health Underwriting", ARCH 2, 1-63.
Jablonowski, M. (1996). "A New Perspective on Risk", Chartered Property and Casualty Underwriters Journal 49 (4), 225-236.
Krasteva, E. B., Singh, M. G., Sotirov, G. R., Bennavail, J. C. and Mincoff, N. C. (1994). "Model Building for Pricing Decision Making in an Uncertain Environment", Systems, Man, and Cybernetics, IEEE Int. Conference on Humans, Information and Technology, 1, 194-199.
Lemaire, J. (1990). "Fuzzy Insurance", ASTIN Bulletin, Vol. 20, No. 1, 33-55.
Lu, Y., Zhang, L., Guan, Z. and Shang, H. (2001). "Fuzzy Mathematics Applied to Insurance Game", IFSA World Congress and 20th NAFIPS International Conference, Vol. 2: 941-945.
Manton, K. G., Woodbury, M. A. and Tolley, H. D. (1994). Statistical Applications Using Fuzzy Sets, John Wiley & Sons, Inc., New York.
McCauley-Bell, P. R. and Badiru, A. (1996). "Fuzzy Modelling and Analytic Hierarchy Processing to Quantify Risk Levels Associated with Occupational Injuries", Part I and II, IEEE Transactions on Fuzzy Systems, 4: 124-138.
McCauley-Bell, P. R., Crumpton, L. L. and Wang, H. (1999). "Measurement of Cumulative Trauma Disorder Risk in Clerical Tasks Using Fuzzy Linear Regression", IEEE Transactions On Systems, Man, And Cybernetics - Part C: Applications And Reviews, 29(1), pp. 1-14.
Mosmans, A., Praet, J.-C. and Dumont, C. (2002). "A Decision Support System for the Budgeting of the Belgian Health Care System", European Journal of Operational Research, 139(2) 449-460
Ostaszewski, K. (1993). Fuzzy Set Methods in Actuarial Science, SOA, Schaumburg, IL.
Ostaszewski, K. and Karwowski, W. (1992). "An Analysis of Possible Applications of Fuzzy Set Theory to the Actuarial Credibility Theory", Proc. of the Annual Meeting of the NA Fuzzy Information Processing Society, Puerto Vallaria.
Peña-Reyes, C. A. and Sipper, M. (1999). "A Fuzzy-Genetic Approach to Breast Cancer Diagnosis", Artificial Intelligence in Medicine 17, 131-155.
Sánchez, J. de A. and Gómez, A. T. (2003) "Applications Of Fuzzy Regression In Actuarial Analysis," JRI, 70(4), 665-699
Terceno, A., De Andres, J., Belvis, C. and Barbera, G. (1996). "Fuzzy Methods Incorporated to the Study of Personal Insurances", International Symposium on Neuro-Fuzzy Systems, 187-202.
Verrall, R. J. and Yakoubov, Y. H. (1999). "A Fuzzy Approach to Grouping by Policyholder Age in General Insurance", JAP, 7, 181-203.
Yoo, J-H, Kang, B-H and Choi, J-U. (1994). "A Hybrid Approach to Auto-insurance Claim Processing System", IEEE Int. Conference on Systems, Man, and Cybernetics 1, 537-542.
Young, V. R. (1993). "The Application of Fuzzy Sets to Group Health Underwriting", TSA, Vol. 45, 551-590.
Young, V. R. (1996). "Insurance Rate Changing: a Fuzzy Logic Approach", JRI 63, 461–83.
Young, V. R. (1997). "Adjusting Indicated Insurance Rates: Fuzzy Rules that Consider Both Experience and Auxiliary Data", Proceedings of the Casualty Actuarial Society, 84, 734-765.
Zadeh, L. (2000) Foreword of *Fundamentals of Fuzzy Sets*, Volume 1, Dubois D., Prade H., eds. Kluwer Acad. Publ.
Zhao, J. (1996) "Maritime Collision and Liability." Ph.D. Dissertation, University of Southampton.