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Management Decision; 2004; 42, 1/2; ABI/INFORM Global
pg. 229

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The contribution of neural networks and genetic algorithms to business decision support

Academic myth or practical solution?

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Keywords *Neural net, Genetic engineering, Artificial intelligence, Business support services, Decision making*

Abstract *Managing large amounts of information and efficiently using this information in improved decision making has become increasingly challenging as businesses collect terabytes of data. Intelligent solutions, based on neural networks (NNs) and genetic algorithms (GAs), to solve complicated practical problems in various sectors are becoming more and more widespread nowadays. The current study provides an overview for the operations researcher of the neural networks and genetic algorithms methodology, as well as their historical and current use in business. The main aim is to present and focus on the wide range of business areas of NN and GA applications, avoiding an in-depth analysis of all the applications – with varying success – recorded in the literature. This review reveals that, although still regarded as a novel methodology, NN and GA are shown to have matured to the point of offering real practical benefits in many of their applications.*

1. Introduction

Applications of artificial intelligence (AI) techniques and modeling devices are attracting increasing interest in business literature. The main focus of attention so far has been expert systems (ES), which have been discussed by a number of authors (Wright and Rowe, 1992; Wong *et al.*, 1994; Jayaraman and Srivastava, 1996; Metaxiotis *et al.*, 2001; Metaxiotis and Psarras, 2003a). However, in the past decade there has also been a virtual explosion of interest in the fields of neural networks (NNs) and genetic algorithms (GAs). Appearing from seemingly out of nowhere, NNs and GAs have quickly evolved from an academic notion into proven and highly marketable products. They provide powerful and flexible means for obtaining solutions to a variety of problems that often cannot be dealt with by other, more traditional and orthodox methods. Nowadays their use is being proliferated to many sectors of our social life, while their applications are proved to be critical in the process of decision support and decision making.

This review bears witness to the enthusiastic application of NNs and GAs across a wide range of business-related problems with varying success. Certainly, this is not the first paper to review neural networks and genetic

Management Decision
Vol. 42 No. 2, 2004
pp. 229-242
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0025-1747
DOI 10.1108/00251740410518534

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algorithms. The developments in these fields have been reviewed by several authors from various points of view (Wong *et al.*, 2000; Metaxiotis and Psarras, 2003b; Cheng *et al.*, 1999; Man *et al.*, 2000). However, this paper has a different focus. Writing a fully comprehensive survey of business applications of NN and GA in a broad sense is objectively impracticable, mainly due to the amount recorded in literature. For this reason, our paper emphasizes the identification of the role of the operations researcher in the current environment by reviewing NN and GA developments in a series of application areas. This review thus aims to create a big knowledge base for the operations researcher, introducing him/her to specific areas of NN and GA applications and indicating other areas fertile for research. In parallel, it gives an answer to the following questions:

(1) Could an AI-based application support your company's business decision-making processes?

(2) Do we have success stories to prove that?

(3) Is this a practical solution or just an academic myth?

On the other hand, taking into consideration similar reviews concerning the use of expert systems in business (Metaxiotis and Psarras, 2003c) the authors wish to cultivate the ground for further comparative discussion on these three intelligent methodologies. A humorous but fully justified approach of this discussion has already been given by Liebowitz (2001) in the editorial of an issue of *Expert Systems with Applications*: "If you are a dog lover, build expert systems; if you are a cat lover, build neural networks".

The structure of the paper is as follows. The authors first present the scope of such a review and its merit for the readers. Sections 3 and 4 provide an overview for the operations research reader of the basic neural network techniques and genetic algorithms. In Section 5, a comprehensive review of NN and GA applications in various business areas is presented. Finally, concluding remarks are given and estimations on the future trends are recorded in Section 6.

2. Scope and merit of this review

A state-of-the-art review and analysis is an essential reading for researchers, practitioners, professionals, consultants and students in the framework of a specific area of knowledge. As presented in Figure 1, it forms an original, high-quality, reliable mean for all the above mentioned target groups to further explore the specific area of knowledge, update and advance their knowledge, benchmark their current practices against new developments or best practices and assess new prospects and promising directions for future work.

The need for the implementation of a state-of-the-art study emerges when a specific area of knowledge is an active research area and research is ongoing. A state-of-the-art review provide answers to many questions as well as raising

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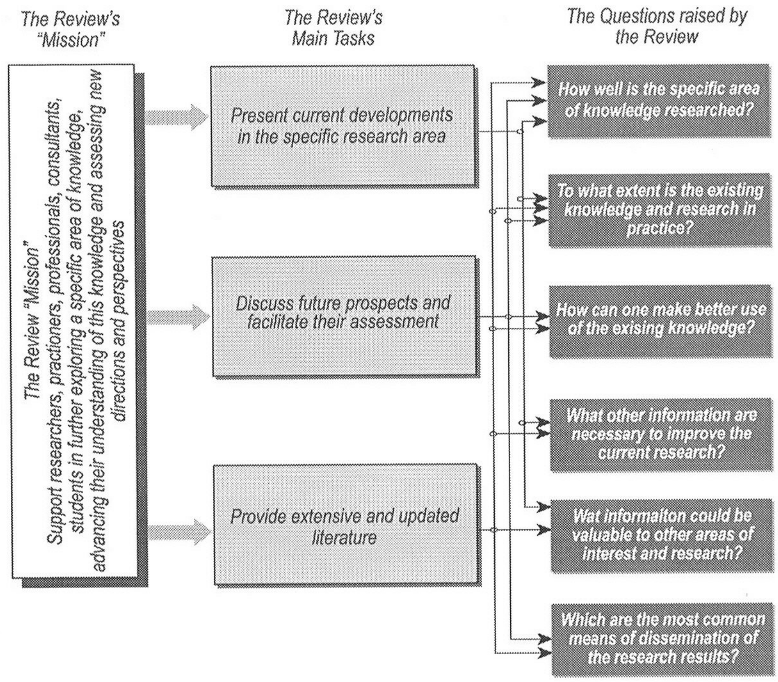

Figure 1. The review "mission"

new questions for further investigation, indicating both the sub-areas which are well researched and those where more research is needed.

Moreover, a state-of-the-art study prevents the above-mentioned target groups from research activities duplication and overlapping, while at the same time makes the identification of research gaps clear to them. In general, a high-quality state-of-the-art survey is always supported by an extensive and updated literature.

In this conceptual framework, this review has the aim to report the attempts of a number of researchers to apply the technology of NNs and GAs – main branches of artificial intelligence – to support business decision making. In a 1997 report, Stamford, Connecticut-based Gartner Group mentioned:

> Artificial intelligence is at the top of the five key technology areas that will clearly have a major impact across a wide range of industries within the next five to ten years.

The authors, fully agreeing with this estimation, describe research directions in the relative area in terms of both problem formulations and solution approaches, and discuss some perspectives on more promising directions for future work.

3. The neural network technology

Neural networks are an information processing technique based on the way biological nervous systems, such as the brain, process information. The fundamental concept of NNs is the structure of the information processing

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system. Composed of a large number of highly interconnected processing units (neurons) connected into networks, a neural network system uses the human-like technique of learning by example to resolve problems (Haykin, 1994). Every neuron applies an input, activation and an output function to its net input (sum of weighted input signals) to calculate its output. The neural network is configured for a specific application, such as data classification or pattern recognition, through a learning process called "training". Just as in biological systems, learning involves adjustments to the synaptic connections that exist between the neurons. In other words, the "learnt" information is stored in the form of numerical values, called "weights", which are assigned to the connections among the processing units of the network.

In general, NNs can differ on:

- the way their neurons are connected;
- the specific kinds of computations their neurons do;
- the way they transmit patterns of activity throughout the network; and
- the way they learn, including their learning rate.

With regard to the arrangement of the neurons, we distinguish between layered and unlayered networks. In layered networks the neurons are grouped in layers. Between the input and the output layer, which have external connections only, are one or more hidden layers. The input data are transmitted from the input layer via the hidden layers to the output layer. The signal flow in layered networks is forward directed (feedforward network), whereas unlayered networks have additional feedback loops (feedback network) which prevent a clear layer assignment.

The structure of the connections, the number of layers and the number of neurons therein determine the network architecture, which must be fixed prior to the use of an NN. The weights of the connections between neurons, and thus the activation states, do not have to be coded in advance. As illustrated in Figure 2, a typical NN usually consists of an input layer, one or more hidden layers and an output layer.

Before the network is trained, the weights are assigned small, randomly determined values. Through a training procedure, such as backpropagation, the network's weights are modified incrementally until the network is deemed to have learnt the relationship. This type of learning is a supervised type of learning. When a pattern is applied at the input layer, the stimulus is fed forward until final outputs are calculated at the output layer. The network's outputs are compared with the desired result for the pattern considered and the errors are computed. These errors are then propagated backwards through the network as feedback to the preceding layers to determine the changes in the connection weights to minimize the errors. A series of such input-output training examples is presented repeatedly, until the total sum of the squares of these errors is reduced to an acceptable minimum. At this point the network is considered "trained".

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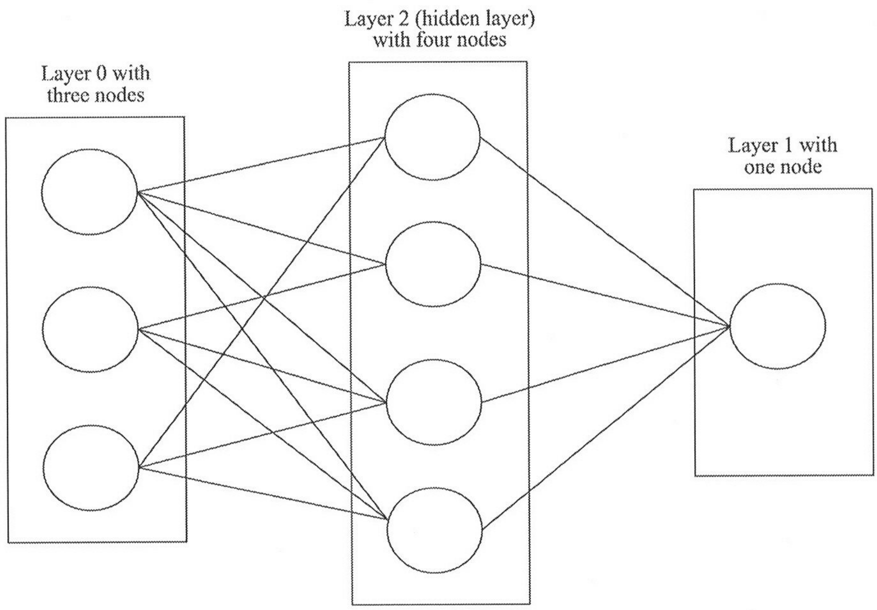

Figure 2. Typical ANN architecture

Application fields of NNs are problems:

- with an unknown correlation between the desired feature and the value of the variables of the decision problem belonging to it (in other words, the way to solve the problem is unknown);
- which have no efficient solution algorithm, i.e. which can not be solved formally with defensible expenditure; and
- which are characterized by incomplete data.

The main advantages of NNs are the ability to self-organize, the ability to learn, the ability to generalize and the fault tolerance (Fausett, 1994). On the other hand, the main disadvantage is the lack of self-explanation (i.e. the solution procedure loses transparency, resulting in problems of acceptability).

Concluding, we stress the fact that the selection of the right network paradigm and its configuration is of fundamental importance in ensuring sufficient performance.

4. The genetic algorithm technology

Genetic algorithms represent a powerful and robust approach for developing heuristics for large-scale combinatorial optimisation problems. The motivation underlying GAs can be expressed as follows: evolution has been remarkably successful in developing complex and well-adapted species through relatively simple evolutionary mechanisms. A natural question is the following: "what ideas can we adapt from our understanding of evolution theory so as to solve problems in other domains?" This fundamental question has many different

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answers because of the richness of evolutionary phenomenon. Holland (1975) and DeJong (1975) provided the first answer to this question by introducing the concept of GA as a general search technique which mimics biological evolution, with the survival of the fittest individuals and a structured, yet randomised, information exchange like in population genetics.

A GA encodes the problem into a set of strings, each of which is composed of several bits, then operates on the strings to simulate the process of evolution. In contrast to the local search algorithms, such as neighborhood search, tabu search and simulated annealing, which work only on one feasible solution, GAs consider a population of individuals. Working with a population allows us to be able to study the structures and the properties inherent in various kinds of individuals so that we can identify and explore good solutions more efficiently. During the execution, GAs select the strings which have higher fitness values to survive, eliminate those with lower fitness from the population, and combine the survivals with a structured but information exchange to generate new individuals and renew the population. Some basic concepts and operators of GAs are (Davis, 1991):

(1) *Chromosome.* A chromosome is a string consisting of a set of bits, which represents a point in the solution space. The set of bit symbols is called the alphabet. The most fundamental and popular representation of a chromosome is the string of binary numbers, 0 and 1. Considering, for example, the problem of purchasing a computer system, then it can be evaluated using speed (1: fast, 0: slow), equipment (1: well-equipped, 0: poorly-equipped) and price (1: low, 0: high). In this way, a fast, well-equipped computer system, in a high price can be expressed with string 110. The bits in the string are called genes.

(2) *Population.* Population is the set consisting of a certain number of chromosomes randomly selected. The number of the chromosomes, known as population size, is an important parameter of GA.

(3) *Fitness.* Fitness is the performance evaluation of individuals in the population. The higher the fitness, the better the performance of the individual and the greater the probability of its survival.

The most frequently employed operators in GA are:

(1) *Reproduction.* Reproduction is the process in which individuals copy themselves, according to the probabilities that are proportional to their fitness values. As result, individuals with higher fitness values will have higher probabilities of producing their offspring in the next generation.

(2) *Crossover.* Crossover is the operator that produces two new chromosomes (offspring) by exchanging some bits of a couple of randomly selected chromosomes (parents).

(3) *Mutation.* Mutation operates on a single chromosome with a very small probability. With this operation, one or more bits are chosen at random

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from the chromosome and are changed into a different symbol of the alphabet.

The best chromosome from the final population is taken as the solution to the problem.

5. Overview of business applications

After gaining some background in NNs and GAs and their development, we can now identify key business areas of their applications, leading simultaneously the operations researcher to other "promising islands" for future NN and GA development. Thus, the next sections will highlight the kinds of business problems (areas in substance) to which these technologies are suited, with a brief discussion of some of the reported studies relevant to each area. As it is mentioned in the introductory section, this paper is focused on the use of NNs and GAs. Concerning the use of expert systems, readers can address themselves to the survey of Metaxiotis and Psarras (2003c).

5.1. Marketing

In general, marketing is an area which is not well understood and can be characterized as involving high uncertainty, loose casual structure and incomplete and dispersed knowledge. Most decision-making and problem-solving tasks are unstructured or semi-structured. Because of these reasons the development of NNs and GAs in marketing has been proved more difficult than in other domains.

In 1991, Curry and Moutinho discussed the role of artificial intelligence in marketing and analyzed competitive positioning by means of the object-oriented methodology. Ellis *et al.* (1991) reported the development of a working NN model dealing with transportation backhaul pricing, while Proctor (1992) presented how NN technology can be used to learn marketing data patterns and help build up marketing decision support systems. Curry and Moutinho (1993) used the NN technology in order to model consumer responses to advertising stimuli. This model was suggested to show how the NN can be employed to shed light on the way in which consumers respond to stimuli contained in advertising messages, with particular emphasis on the stimuli which are implicit or embedded in these messages rather than being overtly measurable.

Wray *et al.* (1994) made use of neural network analysis to quantify the factors contributing to buyer-seller relationship quality. A NN was developed with two outcome components of relationship quality (relationship satisfaction and trust) and five input antecedents (the salesperson's sales orientation, customer orientation, expertise, ethics and the relationship's duration). In a comparison of multiple regression and NN techniques, the latter was found to give statistically more significant outcomes.

On the other hand, Hurley *et al.* (1995) discussed the use of GAs in solving marketing optimization problems. According to their study, the range of

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potential applications of GAs in marketing is quite considerable, as can be seen in the following list:

(1) *Consumer behaviour:*
   - learning models of consumer choice;
   - consumer information processing; and
   - reference group influence.

(2) *Segmentation, targeting and positioning:*
   - optimization of product-market structures;
   - analysis of key buying factors; and
   - product positioning.

(3) *Managing the marketing mix:*
   - optimization of the product life cycle;
   - product design;
   - advertising strategy and media planning; and
   - sales management.

Greene and Smith (1987) developed a genetic system for learning models of consumer choice, while Tang and Holak (1992) developed a conceptual framework linking marketing concepts to Darwin's evolution mechanism. Balakrishman and Jacob (1992) presented a GA-based decision support system for optional product design. Finally, we can also report the development of the following systems:

- STRATEX – a knowledge-based system with the aim to support the selection of marketing segments (Borch and Hartvigsen, 1991).
- ADDUCE – a system for reasoning about consumer response to advertising by searching for relevant past advertising experiments (Burke, 1991).
- COMSTRAT – a system for strategic marketing decisions with a special emphasis on competitive positioning (Moutinho *et al.*, 1993).
- MarStra – a hybrid intelligent system for developing marketing strategy and assessing strategic marketing factors (Li, 2000).
- GloStra – a hybrid intelligent system for developing global marketing strategy and associated Internet marketing strategy (Li and Davies, 2001).

5.2. Banking and finance

The most frequently cited applications for NNs and GAs in banking and finance are: credit applications, financial analysis, financial investments, analysis of stock exchange market. A lot of researchers have discussed the

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issue of the effective application of these technologies in banking and finance (Duchessi *et al.*, 1988; Hartvigsen, 1992; Mui and McCarthy, 1987). In 1993, Tafti and Nikbakht (1993) discussed the use of NNs by financial institutions and corporations for a variety of new applications from credit scoring to bond rating to detection of credit card fraud. Tan and Dihardjo (2001) extended an earlier study using NN to predict financial distress in Australian credit unions by extending the forecast period of the models. They compared the results with probit model results and found NN models generally at least as good as the probit.

On the other hand, various GA applications in this field have been reported in the business literature: the selection of strategies in an oligopolistic market (Marks, 1989), the development of financial investment strategies (Bauer, 1994), the search for technical rules in order to operate in the capital market (Karjalainen, 1994); or the analysis of insolvency risk in banking (Varetto, 1998). In addition, Allen and Karjalainen (1999) used GAs to find technical trading rules, while Andrada *et al.* (1999) used GAs to make technical analysis in the Madrid stock exchange.

Other well-known financial NN/GA-based systems recorded in literature are the following:

- KABAL – a knowledge-based system for financial analysis in banking, used protocol analysis to elicit knowledge from the expert financial analysts of a Norwegian bank (Hartvigsen, 1990).
- CREDEX – a system for credit assessment (Pinson, 1992).
- FINEVA – a multicriteria knowledge-based decision support system for the assessment of corporate performance and viability (Zopounidis *et al.*, 1996).

5.3. Forecasting

Forecasting is one of the oldest management – and business in general – activities. In biblical times there were frequent allusions to seers and prophets. In more recent times, a successful manager has often been credited with possessing the virtues of experience and judgement. From experience he/she has been able to predict the future and his/her judgement enables him/her to take the most appropriate decision in anticipation of that future.

Metaxiotis *et al.* (2003) made a state-of-the-art survey concerning the use of artificial intelligence in the short term electric load forecasting (STELF). What emerged from this study is that AI-based systems are becoming more and more common decision-making tools in STELF. AI methods for forecasting have shown ability to give better performance in dealing with the nonlinearities and other difficulties in modeling of the time series.

Rahman and Bhatnagar (1988) presented an expert system approach to short-term power load forecasting, while Chiu *et al.* (1997) combined a neural network with a rule-based expert system approach for the same problem in Taiwan. The work of Connellan and James (1998) showed that it is possible to

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link various economic and property attributes to the value of a commercial property over time in a particular market, and arrive at a valuation pattern which can be used to give a short-term forecast of valuation fluctuations by using NN approach.

Finally, from the review of the relative literature we can conclude that research in this specific area using neural networks is more abundant that the one using genetic algorithms (Fletcher and Goss, 1993; Gorr, 1994; Hill *et al.*, 1994; Zhang *et al.*, 1998).

5.4. Other business areas

Until this section we have examined various applications of NNs and GAs to the key business sectors: marketing, banking and finance, forecasting. Of course there are many other business areas which have benefited to a less extent from NNs and GAs over the last decade or can be benefited in future. For instance, we can indicatively mention the use of NNs in the hotel industry (Law, 1998), property valuation (Lenk *et al.*, 1997), forecast inflation (Aiken, 1999). In addition, it is obvious that we have not considered other sectors (e.g. manufacturing, heavy industry, energy, construction) as business areas in the narrow sense, in which relative research is really abundant.

5.5 Benefits reported from the use of these AI technologies

Concerning the benefits reported from the use of these AI technologies, researchers have mentioned that they have received from their NN- or GA-based systems:

- Better customer service.
- Reduction in time to complete tasks.
- Increases in production.
- More effective use of resources.
- Better consistency in decision making.

6. Conclusions

Over the last decade neural networks and genetic algorithms have reached into a wide range of business related applications. This situation has been reflected in previous reviews. Instead, this paper is focused on the research applied to pure business areas, with special attention to marketing, banking, finance and forecasting. It intends to be a useful reference and search tool as well as a critical account of the up-to-date use of NNs and GAs in business applications.

What emerges from this discussion is the complete diversity of the application areas which are reaping the advantages and benefits of NNs and GAs. These two technologies are becoming more and more common decision-making tools in many organizations. The benefits reported from the use of NNs and GAs in business include more accurate decisions, time gains, flexibility, improved quality, effective training and minimization of human

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inconsistencies. Researchers have shown that NNs, and especially GAs, have better performance than heuristics in large problems (by 6-10 per cent) and near-to-optimal in small problems, and other GAs achieved around 40 per cent reduction in cost.

It is our belief that the usefulness of NNs and GAs will gain more recognition if they are properly integrated with other intelligent technologies (e.g. expert systems, intelligent agents, fuzzy logic) and operations research (OR) techniques, especially simulation. Most of the NNs and GAs that have been discussed and developed are essentially stand-alone systems. However, it is very likely that in the near future a large portion of the NNs and GAs developed will be embedded systems, that is, systems which form a part of the overall software package. Hybrid NNs and GAs are one example of such an approach (e.g. neuro-fuzzy systems, GA-based expert systems, etc.). Since most operations management problems – in general – are not isolated problems by their nature, isolated NNs and GAs can not solve exactly the problem of the business manager.

The work outlined in this article is ongoing. In particular, the authors are involved currently in the following two areas of research:

(1) Having conducted a primary investigation into using genetic algorithms in business decision problems, work is planned for an in-depth study of the benefits of using GAs in marketing optimization problems. Issues that arise include, for example, whether alternative fitness functions improve the quality of the solutions; the need for a comparison of results with previous real-life decisions; whether to use real market data or artificially generated data to the test the algorithms.

(2) Comparisons between using NNs, GAs and expert systems (ES) in business are needed, as well as direct comparisons with other techniques such as Tabu search and simulated annealing, in order to identify advantages and disadvantages of each technology.

References

Aiken, M. (1999), "Using a neural network to forecast inflation", *Industrial Management & Data Systems*, Vol. 99 No. 7, pp. 296-301.

Allen, F. and Karjalainen, R. (1999), "Using genetic algorithms to find technical trading rules", *Journal of Financial Economics*, Vol. 51, pp. 245-71.

Andrada, J., Fernadez, F. and Sosvilla, S. (1999), "Technical analysis in the Madrid stock exchange", Working Paper 99-05, FEDEA, Madrid.

Balakrishman, P. and Jacob, V. (1992), "A genetic algorithm-based decision support system for optional product design", paper presented at the TIMS Annual Conference, 13-14 July, London Business School, London.

Bauer, R. (1994), *Genetic Algorithms and Investment Strategies*, John Wiley & Sons, New York, NY.

Borch, O. and Hartvigsen, G. (1991), "Knowledge-based systems for strategic market planning in small firms", *Decision Support Systems*, Vol. 7 No. 2, pp. 145-57.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Burke, R. (1991), "Reasoning with empirical marketing knowledge", *International Journal of Research in Marketing*, Vol. 8 No. 1, pp. 75-90.

Cheng, R., Gen, M. and Tsujimura, Y. (1999), "A tutorial survey of job-shop scheduling problems using genetic algorithms, part II: hybrid genetic search strategies", *Computers & Industrial Engineering*, Vol. 36, pp. 343-64.

Chiu, C., Kao, L. and Cook, D. (1997), "Combining a neural network with a rule-based expert system approach for short-term power load forecasting in Taiwan", *Expert Systems with Applications*, Vol. 13 No. 4, pp. 299-305.

Connellan, O. and James, H. (1998), "Estimated realization price (ERP) by neural networks: forecasting commercial property values", *Journal of Property Valuation and Investment*, Vol. 16 No. 1, pp. 71-86.

Curry, B. and Moutinho, L. (1991), "Artificial intelligence in marketing: an application to strategic analysis", in Gilly, M.C. and Dwyer, R. (Eds), *Enhancing Knowledge Development in Marketing*, American Marketing Association, Chicago, IL.

Curry, B. and Moutinho, L. (1993), "Neural networks in marketing: modelling consumer responses to advertising stimuli", *European Journal of Marketing*, Vol. 27 No. 7, pp. 5-20.

Davis, L. (1991), *Handbook of Genetic Algorithm*, Van Nostrand-Reinhold, New York, NY.

DeJong, K.A. (1975), "An analysis of the behaviour of a class of genetic adaptive systems", doctoral dissertation, University of Michigan, Ann Arbor, MI.

Duchessi, P., Shawky, H. and Seagle, J. (1988), "A knowledge-engineered system for commercial loan decisions", *Financial Management*, Vol. 17 No. 3, pp. 57-65.

Ellis, R., LeMay, S. and Arnold, D. (1991), "A transportation backhaul pricing model: an application of neural network technology", in Johnson, C., Karakaya, F. and Laric, M. (Eds), *Proceedings of the 1991 AMA Micro Computers in the Marketing Education Conference*, American Marketing Association, Chicago, IL.

Fausett, L. (1994), *Fundamentals of Neural Networks. Architectures, Algorithms and Applications*, Prentice-Hall, Englewood Cliffs, NJ.

Fletcher, D. and Goss, E. (1993), "Forecasting with neural networks: an application using bankruptcy data", *Information & Management*, Vol. 24, pp. 159-67.

Gorr, W. (1994), "Research prospective on neural network forecasting", *International Journal of Forecasting*, Vol. 10, pp. 1-4.

Greene, D. and Smith, S. (1987), "A genetic system for learning models of consumer choice", in Grefenstette, J. (Ed.), *Genetic Algorithms and Their Applications, Proceedings of the 2nd International Conference on Genetic Algorithms, MIT, Cambridge, 28-31 July*, Hillsdale, NY.

Hartvigsen, G. (1990), "KABAL: a knowledge-based system for financial analysis in banking", *Expert Systems for Information Management*, Vol. 3 No. 3, pp. 213-31.

Hartvigsen, G. (1992), "Limitations of knowledge-based systems for financial analysis in banking", *Expert Systems with Applications*, Vol. 4, pp. 19-32.

Haykin, S. (1994), *Neural Networks: A Comprehensive Foundation*, Macmillan, Basingstoke.

Hill, T., Marquez, L., O'Connor, M. and Remus, W. (1994), "Artificial neural network models for forecasting and decision making", *International Journal of Forecasting*, Vol. 10, pp. 5-15.

Holland, J. (1975), *Adaption in Natural and Artificial Systems*, University of Michigan Press, Ann Arbor, MI.

Hurley, S., Moutinho, L. and Stephens, N. (1995), "Solving marketing optimization problems using genetic algorithms", *European Journal of Marketing*, Vol. 29 No.4, pp. 39-56.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Jayaraman, V. and Srivastava, R. (1996), "Expert systems in production and operations management", *International Journal of Operations & Production Management*, Vol. 16 No. 12, pp. 27-44.

Karjalainen, R. (1994), "Using genetic algorithms to find technical trading rules in financial markets", dissertation, University Microfilms International, Ann Arbor, MI.

Law, R. (1998), "Room occupancy rate forecasting: a neural network approach", *International Journal of Contemporary Hospitality Management*, Vol. 10 No. 6, pp. 234-9.

Lenk, M., Worzala, E. and Silva, A. (1997), "High-tech valuation: should artificial neural networks bypass the human valuer?", *Journal of Property Valuation & Investment*, Vol. 15 No. 1, pp. 8-26.

Li, S. (2000), "Developing marketing strategy with MarStra: the support system and the real-world tests", *Marketing Intelligence & Planning*, Vol. 18 No. 3, pp. 135-43.

Li, S. and Davies, B. (2001), "GloStra – a hybrid system for developing global strategy and associated Internet strategy", *Industrial Management & Data Systems*, Vol. 101 No. 3, pp. 132-40.

Liebowitz, J. (2001), "If you are a dog lover, build expert systems; if you are a cat lover, build neural networks", Editorial, *Expert Systems with Applications*, Vol. 21, p. 63.

Man, K.F., Tang, K.S., Kwong, S. and Ip, W.H. (2000), "Genetic algorithm planning and scheduling problems for manufacturing systems", *Production Planning and Control*, Vol. 11, No. 5, pp. 443-58.

Marks, R. (1989), "Breeding hybrid strategies: optimal behaviour for oligopolist", in Schaffer, J.D (Ed.), *Proceedings of the 3rd International Conference on Genetic Algorithms*, Morgan Kaufmann Publishers, Inc., San Mateo, CA, pp. 198-207.

Metaxiotis, K. and Psarras, J. (2003a), "Expert systems in business: applications and future directions for the operations researcher", *International Management & Data Systems*, Vol. 103 No. 5, pp. 361-8.

Metaxiotis, K. and Psarras, J. (2003b), "Neural networks in production scheduling: intelligent solutions and future promises", *Applied Artificial Intelligence*, Vol. 17 No. 4, pp. 361-73.

Metaxiotis, K. and Psarras, J. (2003c), "Expert systems in business: applications and future directions for the operations researcher", *Industrial Management & Data Systems*, Vol. 3 No. 5, pp. 361-8.

Metaxiotis, K., Askounis, D. and Psarras, J. (2001), "Expert systems in production planning and scheduling: a state-of-the-art survey", *Journal of Intelligent Manufacturing*, Vol. 13, pp. 253-60.

Metaxiotis, K., Kagiannas, A., Askounis, D. and Psarras, J. (2003), "Artificial intelligence in short term electric load forecasting", *Energy Conversion and Management*, Vol. 44, pp. 1525-34.

Moutinho, L., Curry, B. and Davies, F. (1993), "The COMSTRAT model: development of an expert system in strategic marketing", *Journal of General Marketing*, Vol. 19 No. 1, pp. 32-47.

Mui, G. and McCarthy, W. (1987), "FSA: Applying AI techniques to the familiarization phase of financial decision making", *IEEE Expert*, Vol. 2, pp. 33-41.

Pinson, S. (1992), "A multi-expert architecture for credit risk assessment: the CREDEX system", in O'Leary, D.E. and Watkins, P.R. (Eds), *Expert Systems in Finance*, Elsevier Science Publishers, Oxford, pp. 37-64.

Proctor, R. (1992), "Marketing decision support systems: a role for neural networking", *Marketing Intelligence & Planning*, Vol. 10 No. 1.

Rahman, S. and Bhatnagar, R. (1988), "An expert system based algorithm for short-term load forecast", *IEEE Transactions on Power Systems*, Vol. 3 No. 2, pp. 392-9.

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Tafti, M. and Nikbakht, E. (1993), "Neural networks and expert systems: new horizons in business finance applications", *Information Management and Computer Security*, Vol. 1 No. 1.

Tan, C. and Dihardjo, H. (2001), "A study of using artificial neural networks to develop an early warning predictor for credit union financial distress with comparison to the probit model", *Managerial Finance*, Vol. 27 No. 4, pp. 56-77.

Tang, Y. and Holak, S. (1992), "A dynamic model of the product evolutionary cycle: applying a biological mechanism to dynamics of product-markets", paper presented at the TIMS Annual Conference, 13-14 July, London Business School, London.

Varetto, F. (1998), "Genetic algorithms applications in the analysis of insolvency risk", *Journal of Banking and Finance*, Vol. 22, pp. 1421-39.

Wong, B.K., Chong, J.K.S. and Park, J. (1994),"Utilization and benefits of expert systems in manufacturing: a study of large American industrial corporations", *International Journal of Operations & Production Management*, Vol. 14 No. 1, pp. 38-49.

Wong, B., Lai, V. and Lam, J. (2000), "A bibliography of neural network business application research: 1994-1998", *Computers and Operations Research*, Vol. 27 No. 11/12, pp. 1045-76.

Wray, B., Palmer, A. and Bejou, D. (1994), "Using neural network analysis to evaluate buyer-seller relationships", *European Journal of Marketing*, Vol. 28 No. 10, pp. 32-48.

Wright, G. and Rowe, G. (1992), "Expert systems in marketing: current trends and an alternative scenario", *Marketing Intelligence & Planning*, Vol. 10 No. 6.

Zhang, G., Patuwo, B. and Hu, M. (1998), "Forecasting with artificial neural networks: the state of the art", *International Journal of Forecasting*, Vol. 14 No. 1, pp. 35-62.

Zopounidis, C., Matsatsinis, N. and Doumpos, M. (1996), "Developing a multicriteria knowledge-based decision support system for the assessment of corporate performance and viability: the FINEVA system", *Fuzzy Economic Review*, Vol. 1 No. 2, pp. 35-53.

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