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Application of strategic fuzzy games to wage increase negotiation and decision problems

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ABSTRACT

We propose a flexible decision support scheme which could be used in managing the wage negotiation between employers and employees. This scheme uses fuzzy inference systems and game theory concepts in arriving at decisions on future wage increase which could be more mutually agreeable. For example, rather than specifying 5% *yearly increase* of wages, we propose that the uncertain factors which are mostly difficult to predict and that could affect wage decisions need to be taken into consideration by the wage formula. These include business revenues or (profit), inflation rate, number of competitors, cost of production, and other uncertain factors that may affect business operations. The accuracy of the fuzzy rule base and the game strategies will help to mitigate the adverse effects that a business may suffer from these uncertain factors. Based on our scheme, we propose that employers and employees should calculate their future wage by using a fuzzy rule base and strategies that take into consideration these uncertain variables. The proposed approach is illustrated with a case study and the procedure and methodology may be easily implemented by business organizations in their wage bargaining and decision processes.

1. Introduction

Wage negotiation has always caused persistent problems in business organizations (Gielen & van Ours, 2010; Holmwood, 10 Aug. 2010). On many occasions, there have been cases in which the entire workforce of countries embarked on industrial strikes that resulted from wage negotiation problems. Gielen and van Ours (2010) investigated what determines quits and layoffs that usually result as problems of poor wage negotiations by using a unique matched worker-firm dataset from the Netherlands. They concluded that in wage negotiation, the wage growth of a worker that stays in the firm is larger if that worker had a high quit probability and smaller when that worker had a high layoff probability.

In most cases, annual escalation clauses in employment contracts do specify future percentage increases in wages which are not tied to any index or rules. However, very often employers do find it difficult to meet these rigid (Aizenman, 1984; Dhillon & Petrakis, 2002; Holden, 1994) percentages and therefore, on various occasions, these have resulted into industrial disputes between employers and employees (or their unions) (Blanchflower & Millward, 1988; Corneo & Lucifora, 1997; Holden, 1994). The percentages are mostly based on predictions of future inflation which are often misleading and based on historical data.

Many authors have agreed that wages ought to be positively linked to financial performance of the business and some also have detected some links between wages and profits (Dhillon & Petrakis, 2002).

In this paper however, rather than pre-setting a rigid future and yearly percentage increase in wages, we propose a flexible scheme for employers and employees which they can use as a decision support system for their future salary increase. This scheme uses a fuzzy inference system in arriving at more mutually agreeable decisions on wage increase.

The root causes of wage negotiation (Fethke & Policano, 1987; Gielen & van Ours, 2010) disputes, in most cases, are often connected to the inability of either of the two parties involved (employers and employees' unions) to sustain or maintain the *status quo* contained in their earlier agreement on wage increase (Holden, 1994). This may be as a result of many uncertain factors that surround business environment such as *inflation* and change in *profit* of the business.

1.1. Decision making processes in a firm

A *decision* is a goal-directed behavior made by the individual, in response to a certain need, with the intention of satisfying the motive that the need occasions (McGrew & Wilson, 1982). The decision process begins with identification of a problem and ends

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with a *choice*. The problem arises when a sought-after goal can be obtained via alternative and sometimes competing avenues.

Decision makers in an organization are expected to be aware of and to be able to assess the information they generate and the potential use (or otherwise) of that information (Wisniewski, 1997). Nowadays, decision making (Vasara, Krebs, Peuhkuri, & Eloranta, 2003) processes are becoming increasingly very complex for managers (Wisniewski, 1997), therefore, the information needs of a manager are equally becoming more complex and highly demanding.

1.2. Employers' perspective

On the employers' part, a once prosperous business might have run into an economic turbulence as a result of diverse and adverse uncertainties that surround the business environment. Several of these cases were witnessed during the recent global economic recession which affected several businesses globally and during which many businesses went underground (closed).

Therefore, when the revenue of a business goes down, it may be economically impossible for management to sustain the earlier agreements signed when the revenues of the companies were booming. The same situation may occur if the rate of inflation adversely and grossly affects the cost of production (*CP*) in a firm without a corresponding increase in revenue.

1.2.1. Wage negotiation in developing nations

In developing nations (Pratap & Quintin, 2006) such as Nigeria, wage negotiation has always been a chronic problem (Oribabor, 2007; Owoye, 1994) and this menace has been directly and indirectly running down the nation's economy for many decades. This is because many trade unions have always insisted on international wage scales for their respective professions but irrespective of whether the revenues of the countries attain the standards on which those scales were designed.

For example, Medical Doctors, under the umbrella of the Nigeria Medical Association (NMA) (Okolie, 2010; Otobo, 1981) will always insist on World Health Organization (WHO) salary scales standard for their profession, not minding whether the revenues and resources of the nation match those expected by these standards.

Also the academic staff in the universities, under their union, Academic Staff Union of Universities (ASUU) (Okolie, 2010; Oribabor, 2007; Otobo, 1981), have always insisted on the international pension scale called universities superannuation scheme (USS) which may certainly be obtainable in developed nations like the United State of America (USA) and the United Kingdom (UK). However, the unions would never consider the fact that their country's revenues are *very far below* those of the developed nations mentioned.

1.3. Employees' perspectives

Generally in any country and on the side of the employees however, the rates of inflation in the country mighty have shot up astronomically such that earlier wage increase agreements becomes unrealistic. This is because inflation affects the purchasing powers of the consumers. Example of this high inflation otherwise known as hyperinflation is what is being currently experienced in Zimbabwe, a Southern African country.

1.4. Fuzzy logic and fuzzy sets

Fuzzy logic is a problem solving technique that was introduced by Zadeh (1965) to deal with vague or imprecise problems (Chen, Yang, Lin, & Yeh, 2008; Chinho & Ping-Jung, 2004; Dweiri & Kablan, 2006; Gungor & Arikan, 2000; Kahraman & Cebeci, 2004; Karsak & Tolga, 2001; Kim & Lee, 2001; Ngai & Wat, 2005; Royes & Bastos, 2006; Shuliang, 2000). A fuzzy set is a set containing elements that have varying degree of memberships in the set (Dweiri & Kablan, 2006; Irani, Sharif, Love, & Kahraman, 2002). It can simply be defined as a set with fuzzy boundary (Negnevitsky, 2005). Fuzzy sets are denoted by different symbols in different literatures, however, in this paper; a fuzzy set will be represented by a letter with a tilde on top of it. That is, fuzzy set A will be represented by $\widetilde{A}$ and membership of a set will be represented by μ. Therefore the functional mapping given by:

$$\mu_{\widetilde{A}}(x) \in [0, 1],$$

denotes the degree of membership of element x in fuzzy set $\widetilde{A}$. Therefore, $\mu_{\widetilde{A}}(x)$ is a value on the unit interval that measures the degree to which element x belongs to fuzzy set $\widetilde{A}$.

1.5. Fuzzy decision making system

In general, a fuzzy decision making system (FDMS) uses a collection of fuzzy membership functions (Fig. 7) and decision rules that are solicited from experts in the field to reason about data (Dweiri & Kablan, 2006). Typical components of a fuzzy decision making system are as shown in Fig. 1. The components of an FDMS, as shown in the figure are; a fuzzification section, a fuzzy rule base, fuzzy decision logic and defuzzification section (Oderanti & De Wilde, 2010a; Oderanti & Wilde, 2011).

1. *Fuzzification section:* This is the section where the process of making a crisp quantity fuzzy (Ross, 2005) is carried out. This is done by simply recognizing that many of the quantities that we considered to be crisp and deterministic are actually not deterministic at all. They carry considerable uncertainty. If the form of uncertainty happens to arise because of imprecision, ambiguity, or vagueness, then the variable is probably fuzzy and can be represented by a membership function.
2. *Fuzzy rule base:* These rules are expressed in conventional antecedent-consequent form. The collection of such rules constitutes the fuzzy logic knowledge base that is used for inference of the decision agent. In a fuzzy system, if the antecedent is true to some degree, then the consequent is also true to that same degree. For a small number of inputs, there exists a compact form of representing a fuzzy rule-based system which consists of a tabular format with different partitions representing different inputs. This compact graphical form is called fuzzy associative memory table, or FAM table. The implication is implemented for each rule and in Matlab, many built-in methods are supported such as the functions that are used by the AND method: *min*(minimum), which truncates the output fuzzy set, *prod* (product), which scales the output fuzzy set. Here, the AND method was used and the centroid was computed using the Mamdani-type inference system which requires the output membership functions to be fuzzy sets after the aggregation process. It (Mamdani FIS) integrates, according to Eq. 1, across a two-dimensional function to find the centroid (Mamdani & Assilian, 1975).
3. The decision making logic (DML): The decision making logic is analogous to classical logic for reasoning (Ross, 2005) and it is similar to simulating human decision making in inferring fuzzy control actions based on the rules of inference in fuzzy logic (Dweiri & Kablan, 2006).
4. *Defuzzification process:* This is the procedure that converts the fuzzy results into a crisp output. It converts a fuzzy control action (a fuzzy output) into a non-fuzzy control action (a crisp output) (Dweiri & Kablan, 2006). Defuzzification has the result of reducing a fuzzy set to a crisp single-valued input, or to a crisp set; of converting a fuzzy matrix to a

crisp matrix; or making a fuzzy number a crisp number. Fuzziness helps to evaluate the rules, but the final output of a fuzzy system has to be a crisp number and the input for the defuzzification process is the aggregate output fuzzy set and the output is a single number (Negnevitsky, 2005). Mathematically, the defuzzification of a fuzzy set is the process of 'rounding off' from its location in the unit hypercube to the nearest (in a geometric sense) vertex. If one thinks of a fuzzy set as a collection of membership values, or a vector of values on the unit interval, defuzzification reduces this vector to a single scalar quantity – presumably to the most typical (prototype) or representative value (Ross, 2005).
Several defuzzification methods have been discussed in the literatures such as (Dweiri & Kablan, 2006; Negnevitsky, 2005; Ross, 2005). In this paper, we are using centroid method and we shall give a brief explanation on it.
Centroid defuzzification method: This method is also referred to as center of area (COA) or center of gravity (COG). It is the most commonly used (Dweiri & Kablan, 2006), most popular (Negnevitsky, 2005), most physically appealing (Ross, 2005) defuzzification technique and it finds the point where a vertical line would slice the aggregate set into two equal masses. In theory, the centroid method of defuzzification is calculated over a continuum of points in the aggregate output membership function but in practice, a reasonable estimate can be obtained by calculating it over a sample of points. Mathematically, the centroid method can be expressed as:

$$COG = \frac{\int \mu_{\tilde{A}}(x) * x \, dx}{\int \mu_{\tilde{A}}(x) \, dx} \tag{1}$$

$$COG = \frac{\sum \mu_{\tilde{A}}(x) * x}{\sum \mu_{\tilde{A}}(x)} \tag{2}$$

Fuzzy inference techniques: In general, fuzzy decision making system can be implemented using any of the three common methods of deductive inference for fuzzy systems based on linguistic rules (Ross, 2005) listed as follows: Mamdani system, Sugeno systems and Tsukamoto models.

In this work, the design and implementation of this fuzzy decision making system was achieved with the aid of Matlab software. Matlab is a menu driven software that allows the implementation of fuzzy constructs like membership functions and a database of decision rules (Dweiri & Kablan, 2006).

2. Game theory

Game theory is the study of the ways in which strategic interactions among rational players produce outcomes with respect to the preference (or utilities) of those players, none of which might have been intended by any of them (Ross, 2010). It is part of a large body of theories concerning decision making (Shubik, 1972). It deals with decision-making processes involving two or more parties, also known as players with partly or completely conflicting interest (Li, Karray, Hipel, & Kilgour, 2001; Shubik, 1955) and it is one of the methodologies designed for application to the social sciences. All situations in which at least one agent can act to maximize his utility through anticipating (either consciously, or just implicitly by his behavior) the responses to his actions by one or more other agents, are called games. Agents involved in games are referred to as players (Naylor & Vernon, 1969; Oderanti & De Wilde, 2010a, 2010b; Ross, 2010) and could represent people, military, firms, countries or other organizations (Braathen & Sendstad, 2004; Li et al., 2001).

For any game, there are three very important requirements and these are listed as follows (Tapan, 1997):

1. Players.
2. Strategies which are permitted with respect to the rules of the game and
3. Payoffs (that is, utilities or outcomes).

Further readings on game theory can be found in Li et al. (2001), Ross (2010), Kandel and Zhang (1998), Naylor and Vernon (1969), and Ross (2010).

3. Proposed fuzzy model for wage negotiation (FGAW)

Implementing our fuzzy reasoning (FGAW) model approach to wage negotiation will alleviate some of the concerns mentioned in Section 1 above. The model takes effective cognisance of the factors that affect wage negotiation and effectively grasps and captures the uncertainty therein using fuzzy rules solicited from experts in the field. That is, the model considers varying ranges of inflation trends as they affect both parties and also considers the varying ranges of possible revenue increase of the organization. It arrives at an agreed rate for wage increase which can be more sustainable for both the present and the future. This will also be more agreeable and acceptable to both parties.

For instance, rather than specifying 5% *yearly increase*, we propose a scheme such as:

IF Inflation is **very high** *AND Revenue is* **very low** *THEN Wage increase is* **medium**.

We verified this scheme and proved its validity with our algorithm and we discovered that it could be an invaluable tool in the hands of entrepreneurs. Details of the scheme are as explained in the sections that follow.

4. Justification for the scheme and contributions

- The scheme will reduce the level of industrial disputes and revenue or profit losses. This is because both the employers and the employees already know the factors on which their wage increases are based and both parties can calculate the expected wage increase for a particular year right from their own desk based on the factors specified in the fuzzy rule base.
- Rather than management pushing or driving workers to work hard, for the betterment or success of the firm, this scheme would indirectly rest these duties in the hands of the workers or their unions who will encourage employees to work hard so as to increase the revenues of the firm and hence, directly increase their wages.
- The scheme will reduce man hours lost on yearly wage negotiation.
- It puts fate of the workers regarding salary increase in their own hands. The harder they work, the better the firm's revenue and the better the increase in their wages.
- It will reduce unemployment rate. This is because firms will no longer embark on sudden staff cut (Gielen & van Ours, 2010) as a results of unregulated agitation for wage increase which firms are occasionally forced to pay.
- There will be no need for staff to take abrupt pay cuts (Holmwood, 10 Aug. 2010; Gielen & van Ours, 2010; Holden, 1994) in bids to keep the company afloat as was the case in Highland Airways (Miskelly, 2010), British Broadcasting Corporation (BBC) (Holmwood, 10 Aug. 2010) and many other companies during the 2009 economic recession.

5. Factors in wage negotiation

In competitive labor markets, wage rates are determined by the forces of supply and demand for labor (Griffiths & Wall, 2000). Even though, there may be many factors to be considered during wage negotiation, there are two major inevitable factors: inflation and revenue. These two concepts are as explained below.

5.1. Inflation

Inflation in simple terms can be defined as a decline in the purchasing power of money for goods and services. It is a rise in the aggregate level of prices of goods and services in a particular economy over a certain period of time (Griffiths & Wall, 2000).

Inflation is one of the major factors that are usually considered in wage bargaining (den Butter & van de Wijngaert, 1992; Giordano, 2001). den Butter and van de Wijngaert (1992) defined *wage space* as the sum of price inflation and labor productivity growth. In economics, inflation is commonly calculated by using consumer price index (CPI) (Buesa, 2008). Raffaela Giordano in (Giordano, 2001) stated that the relationship between labor cost and inflation is statistically significant and quantitatively non-trivial.

5.2. Company's profit

On wage bargaining and company's profit, many authors have worked on the idea of profit (Net income) sharing schemes to replace simple wage rates. One of such is Ireland (1989) in which Norman Ireland explained the argument that profit sharing concerns microeconomic efficiency and relates to incentives in the place of work. He further explained that if workers see how their labor turns into profit from which they benefit, and particularly if they have some say in determining their work practices, then work will be better motivated, better performed and more highly valued.

Veugelers (1989) reports a model that applies a generalized Nash–Zeuthen-Harsanyi asymmetric bargaining theory (Crawford, 1980). She explained that the bargaining outcome from this scenario is that workers receive the competitive wage plus a fraction of the firm's price-cost margins.

6. Players' strategies in wage negotiation

A strategy is a decision rule that specifies how the player will act in every possible circumstance (Banerjee, 2006). It is a specific course of action taken by the firm. This will involve the firm allocating values to its policy variables (Griffiths & Wall, 2000).

In this experiment, we assume that the business has five units of initial resources (profit say £5M). Both the employer (represented as fuzzy player y) and the employees (represented as opponent player g) are deliberating on how this profit should be spent and also, how subsequent (future) profits generated by the company should be spent. Both players agreed on a three variable-vector $[C, W, M]$. This forms the strategies for both players. That is, employer (y) strategy is $[C_y, W_y, M_y]$ while that of the employee is $[C_g, W_g, M_g]$. The bone of contention is "what proportion of this £5M should be allocated to each of these strategic variables C, W and M?

In each round, the players may choose to allocate their resources to one of these three roles: *consolidation efforts* (C), *reserved wealth* (W) and *market expansion* (M). The allocations are denoted as a vector $[C, W, M]$ for each player and constitute the *strategy* of that player.

Consolidation efforts C refer to the proportion of the profit that adds to the wage increase of the employees and it is the most important variable to the employees as they would want to maximize this as much as they could. *Market expansion M* denotes the part of this profit designated for market expansion of the business including advertising, marketing and promotional campaigns. These are considered as the most important variables to the employers which they would like to maximize as much as they could. *Reserved wealth W* refers to part of the resources that are kept unused or those distributed to the firm's shareholders.

As examples of players' strategies, consider a case where the employer **Y** decides to allocate £4M out of the £5M on market expansion $M = 4$, and retaining £1M to be distributed to shareholders as shares, $W = 1$. This means that for that financial year, there would be no wage increase for (or to *consolidate* the) workers, $C = 0$. Then, employer strategy implies:

$$[C_y, W_y, M_y] = [0, 1, 4].$$

On the other hand, workers, represented by their union, may embark on negotiation with their employer with a proposal that £3M be allocated to wage increase ($C = 3$), £1M to shareholders ($W = 1$) and the remains on market or business expansion $M = 1$. Therefore, the workers' strategy becomes:

$$[C_g, W_g, M_g] = [3, 1, 1].$$

The variables in our models can be tailored to the business situations in the real world and therefore are not limited to those variables that we have used in designing the system. Therefore, this model can be applied to any real business situation and the variables can be adapted to suit the situation in question. The model can also work for systems that have more strategic variables than those that we have used in this model. The proposed decision model is as illustrated in Figs. 1 and 2.

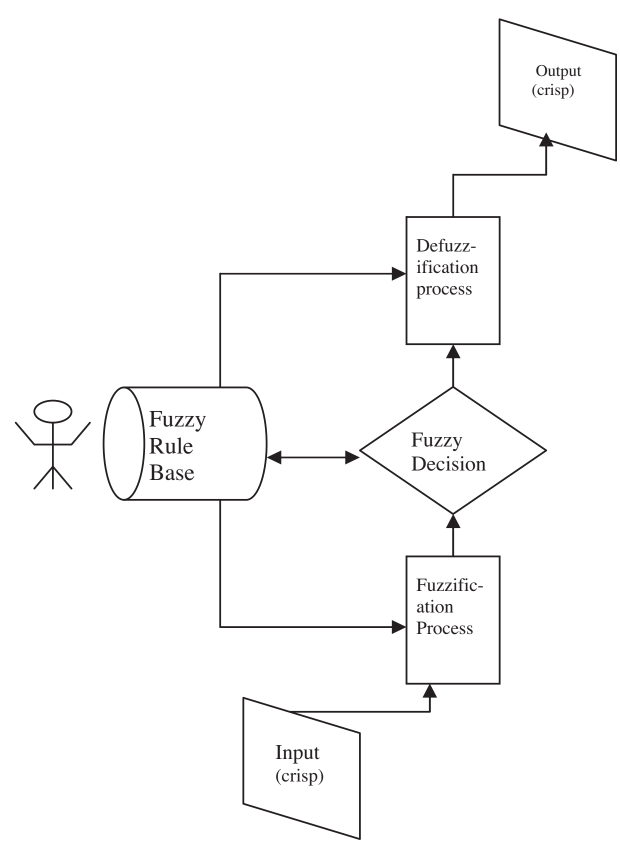

Fig. 1. Fuzzy decision making system (FDMS) for fuzzy inference. This is used as part of the components of the FGAW model shown in Fig. 2.

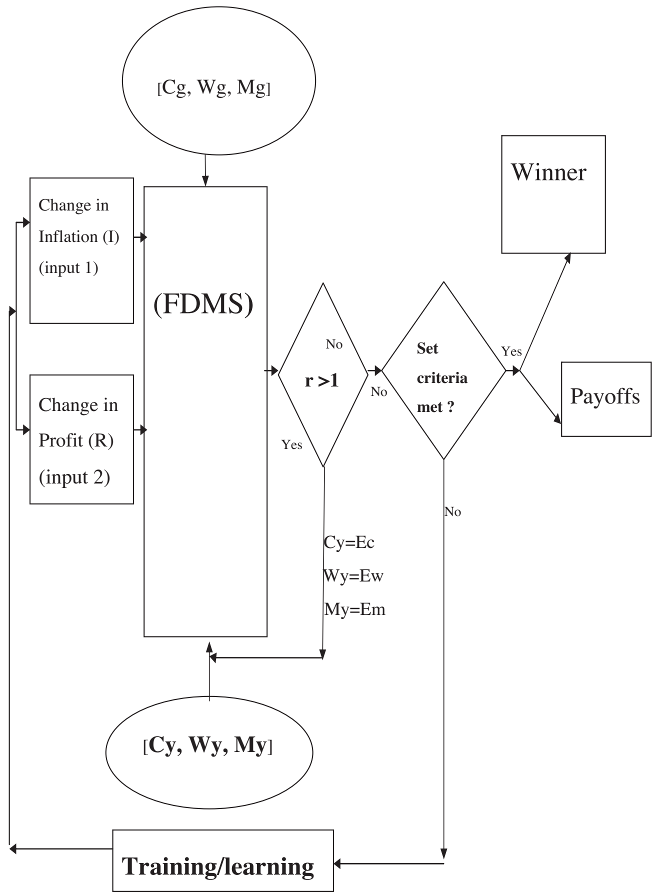

Fig. 2. A model of fuzzy game approach to wage negotiation (FGAW) game showing inputs, processes and outputs. The FDMS components are as shown in Fig. 1.

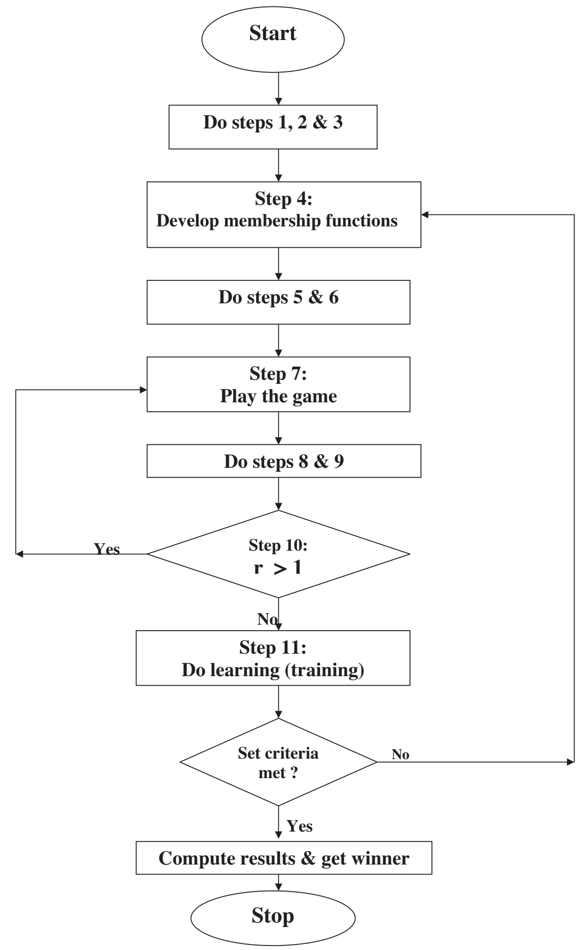

Fig. 3. Chart showing the two loops of the wage game. The first loop stops when $r = 1$ (this means the fifth round of the game) and the second loop represents learning of the fuzzy player and it stops when the set performance criteria have been met as explained in step 11.

7. Assumptions

In this simulation, while we are considering only inflationary trends and business revenue as the most important factors in determining wage increase, we are assuming that other factors remain constant and that decision makers are rational in their views. These other factors that are kept constant include the labor force and the market trends.

We are also assuming that the labor force of the organizations are represented jointly by their unions and that all necessary information about the company (such as the company account details) are available to both the union and the employer's representatives in the decision processes.

Further more, the fuzzy rules ought to be solicited from experts in the field in order to implement the model more accurately and effectively in a real system. In this paper, due to time limitation and other factors, we have relied on assumed fuzzy rules which are based on heuristic and from our business knowledge.

8. Methodology and a case study of the fuzzy game approach to wage negotiation (FGAW)

We assume that the company has initial resources (say £5M) profit. These resources are being deliberated upon by the two parties namely:

1. Employer (represented as fuzzy player (*yellow*) y).
2. Employees (or their union as representative, represented as player (*green*) g).

These resources are to be allocated initially between three variables [C, W, M] that form the strategy of each player. The subsequent allocation will follow the outcome of the fuzzy rules from the fuzzy inference system formulated by each party and the expected outcome will determine the winner.

The procedures necessary for implementing the proposed FGAW automatic decision system are as listed in the steps below:

1. List all uncertain (fuzzy) factors that will be considered in taking the business decision: the uncertain or fuzzy information we are taking into consideration are changes in business profit R and in the inflation I.
2. Determining the strategy: the game strategies are as explained in Section 6. The business has five units of initial resources (profit say £5M). Both the employer (represented as fuzzy player y) and the employees (represented as opponent player g) are deliberating on how this profit should be spent and also, how subsequent profits generated by the company should hence be spent. Both players agreed on three variable-vector [C, W, M]. This forms the strategies for both players. That is, employer (y) strategy is [C_y, W_y, M_y] while that of the employees is [C_g, W_g, M_g]. The bone of contention is "what proportion of this £5M should be allocated to each of these strategic variables C, W and M? Further details on player strategies are as explained in Section 6.

3. Determine the input and output variables of *FGAW* FIS: The inputs are the values of *change in inflation* (ΔI), and *change in business profit* (ΔR) and the outputs are *expected wage increase* (*consolidation efforts*) (E_c), expected wealth (E_w) and expected market expansion efforts (E_m) where: $E_m = 5 - (E_w + E_c)$ because the total (expected) resource of each player at any point is five. The variables E_c,E_w, and E_m relate to the fuzzy player y, and we will not index them by y.
4. Develop fuzzy sets, subsets and membership functions for all the input and output variables. This can be accomplished by soliciting knowledge from the experts or searching through literature data. Our adopted fuzzy sets, subsets and membership functions are as shown in Figs. 5 and 7.
5. Formulate decision rules for the rule base. These also ought to be solicited from experts (Shuliang, 2000). The rules shown in Figs. 5 and 7 also depict our adopted decision rules.
6. Establish relationships between input values and their fuzzy sets and apply the decision rules using the relationships shown in Figs. 5 and 7. The fuzzy rule base was coded into a Fuzzy Inference System (FIS) using the Matlab toolbox.
7. Play the game: Procedures for playing the game are as follows: The game state is represented as vector $S = [g, y, A_w, r]$, where g represents the green player's amount of resources, y represents the fuzzy player (yellow) amount of resources, A_w represents opponents' accumulated wealth (profit) and r is the number of rounds that the game is played. Both the green and fuzzy player strategy are as stated in step 2 above.

- Initial state of the game is [5, 5, 0, 5] (i.e according to vector $[g, y, A_w, r]$).
- At every state $[g, y, A_w, r]$, green chooses his move by allocating to his strategies $[C_g, W_g, M_g]$ where: $C_g + W_g + M_g = g = 5$ and yellow who is the fuzzy player chooses his strategy $[C_y, W_y, M_y]$ where $C_y + W_y + M_y = y = 5$.
- The game changes states as follows:

$$r = r - 1, \tag{3}$$

$$A_w = A_w + W_g - W_y, \tag{4}$$

$$g = g + C_g + M_g r - (y + C_y + M_y r), \tag{5}$$

$$y = y + C_y + M_y r - (g + C_g + M_g r), \tag{6}$$

$$temp = A_w + g - y, \tag{7}$$

where *temp* represents game payoff. Then,

$$E_m = 5 - (E_w + E_c). \tag{8}$$

This is because the total or expected resources of each player at any point amount to five. Now, the outputs of each round of the game are *expected wage increase* (*consolidation efforts*) (E_c), expected wealth (E_w) and expected market expansion efforts (E_m). This then forms the input strategies for the fuzzy player in the subsequent rounds of the game.

In order to calculate inflation (input for FIS) for a particular year, we simply calculate the percentage change of consumer price index (CPI) as follows:

$$Inflation(I) = \frac{CPI_1 - CPI_0}{CPI_0} * \frac{100}{1}, \tag{9}$$

where CPI_0 is the initial value and CPI_1 is the final value.
However, an entrepreneur may want to base his own inflation on the changes in the cost of production (*CP*) of his goods or services such that inflation is calculated as:

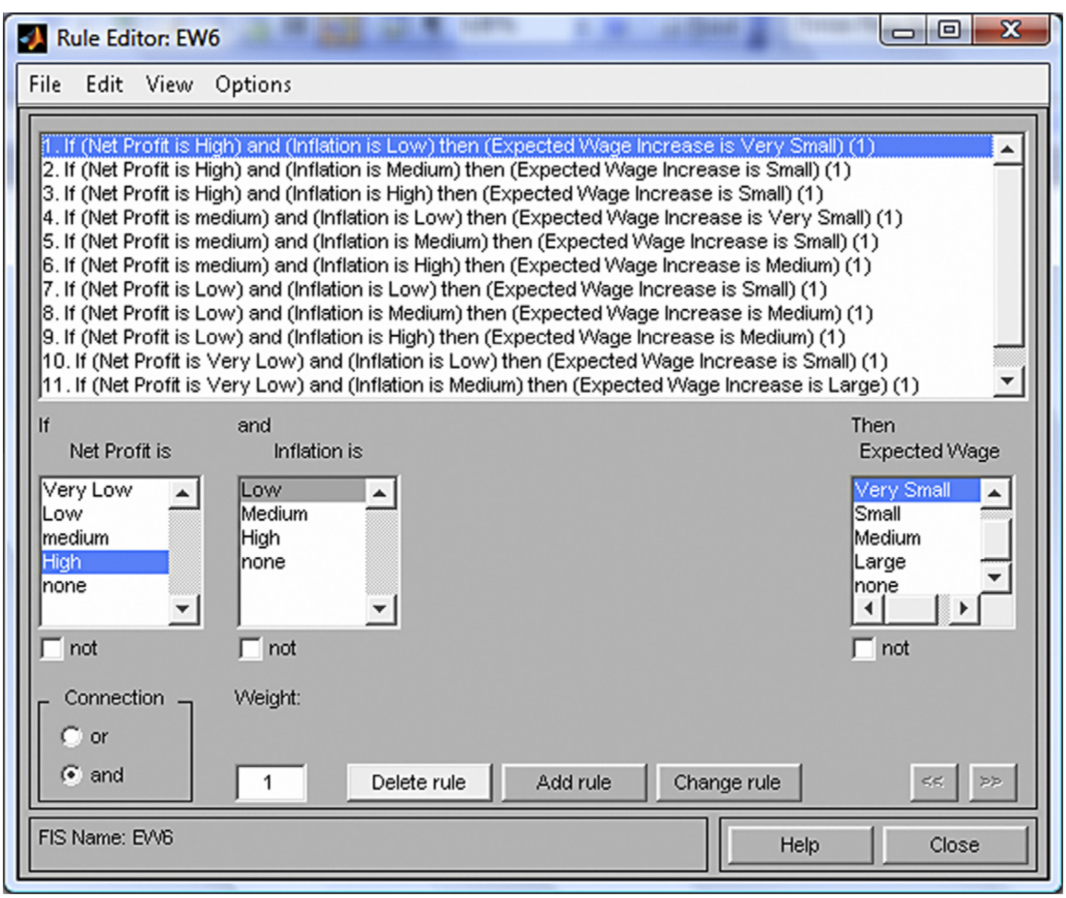

Fig. 4. The rule base for the inflation rate and business profit coded using Matlab software.

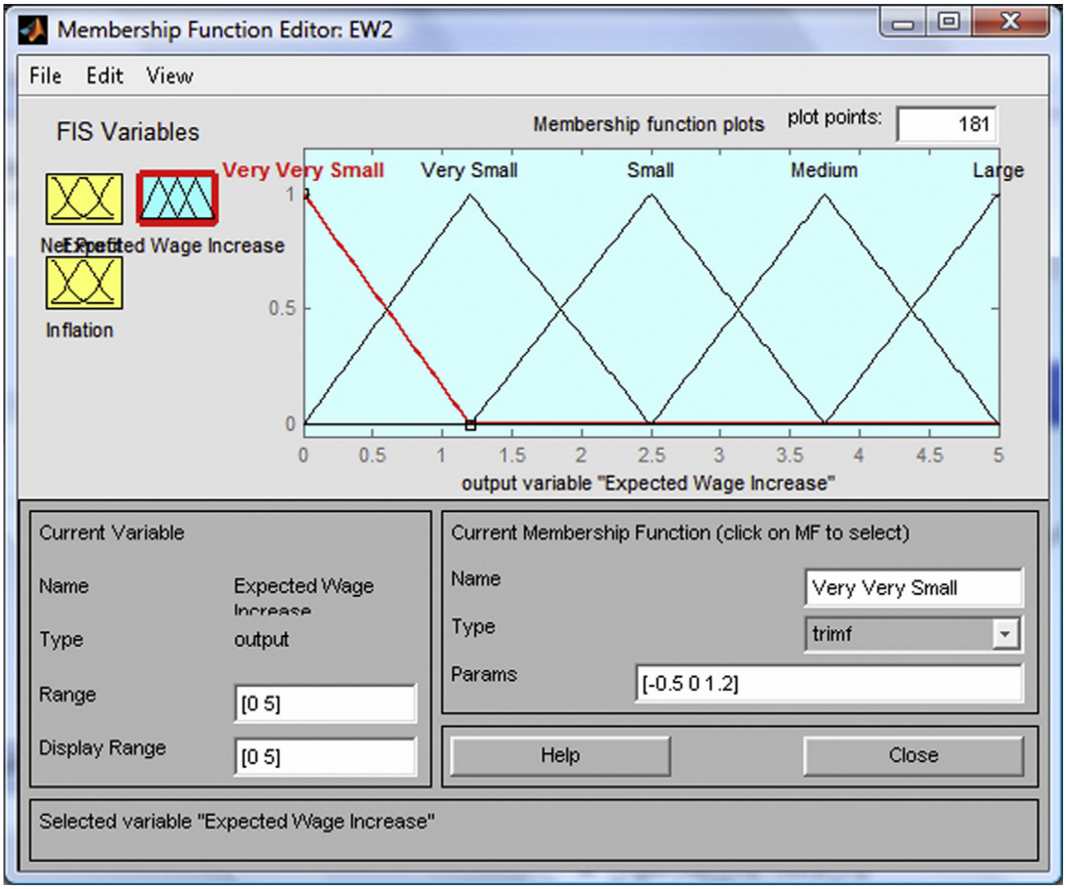

Fig. 5. FIS interface for the membership functions of the output variable *Expected Wage Increase or consolidation* (E_c).

$$Inflation(I) = \frac{CP_1 - CP_0}{CP_0} * \frac{100}{1}, \tag{10}$$

where CP_0 is the initial value and CP_1 is the final value.
And change in profit (ΔR) of the business is calculated as

$$\Delta R = \frac{R_1 - R_0}{R_0} * \frac{100}{1}, \tag{11}$$

where R_0 is the initial profit value and R_1 is the final value.

The game ends when $r = 0$ and if *temp* is greater than zero ($temp > 0$), the green player (the employees) wins, if less than zero ($temp < 0$), then the fuzzy player (yellow or employer) wins else, the game is a draw (i.e. if $temp = 0$).
Sample rules of the fuzzy inference system are as copied below:

Rule Base 1:

(a) If (Net Profit is High) and (Inflation is Medium) then (Expected Wage Increase is Medium).
(b) If (Net Profit is Medium) and (Inflation is Low) then (Expected Wage Increase is Small).
(c) If (Net Profit is Medium) and (Inflation is Medium) then (Expected Wage Increase is Medium).
(d) If (Net Profit is Medium) and (Inflation is High) then (Expected Wage Increase is Large).
(e) If (Net Profit is Low) and (Inflation is Low) then (Expected Wage Increase is Medium).

Rule Base 2:

(a) If (Net Profit is High) and (Inflation is Medium) then (Expected Market Expansion is High).
(b) If (Net Profit is Medium) and (Inflation is Medium) then (Expected Market Expansion is Medium).

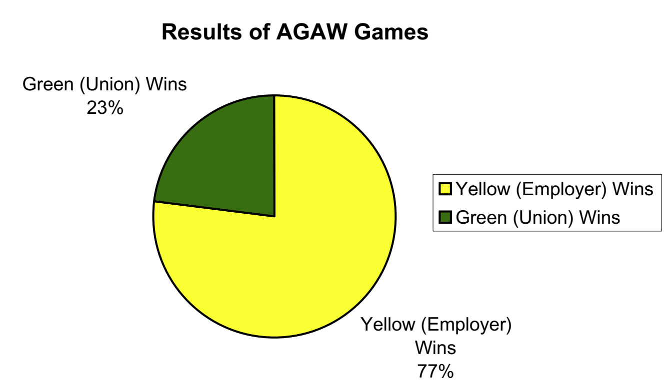

Fig. 6. This chart summarizes the performances of the fuzzy player (employer) and the union in the FGAW simulations shown in Table 1.

(c) If (Net Profit is Medium) and (Inflation is High) then (Expected Market Expansion is Low).
(d) If (Net Profit is Low) and (Inflation is Medium) then (Expected Market Expansion is Very High).

These rules are as coded in Fig. 4. The output interface for *Expected Wage Increase (consolidation)* is as shown in Fig. 5.

8. Evaluate the fuzzy inference system (FIS): using Matlab fuzzy toolbox, all the fuzzy inputs are passed into the Mamdani type FIS.
9. Get the defuzzified output from the FIS: the crisp output for the FGAW is computed using center of gravity method (COG) method. Fig. 5 shows the FIS interface for the output variable of *Expected Wage Increase or consolidation* (E_c) while

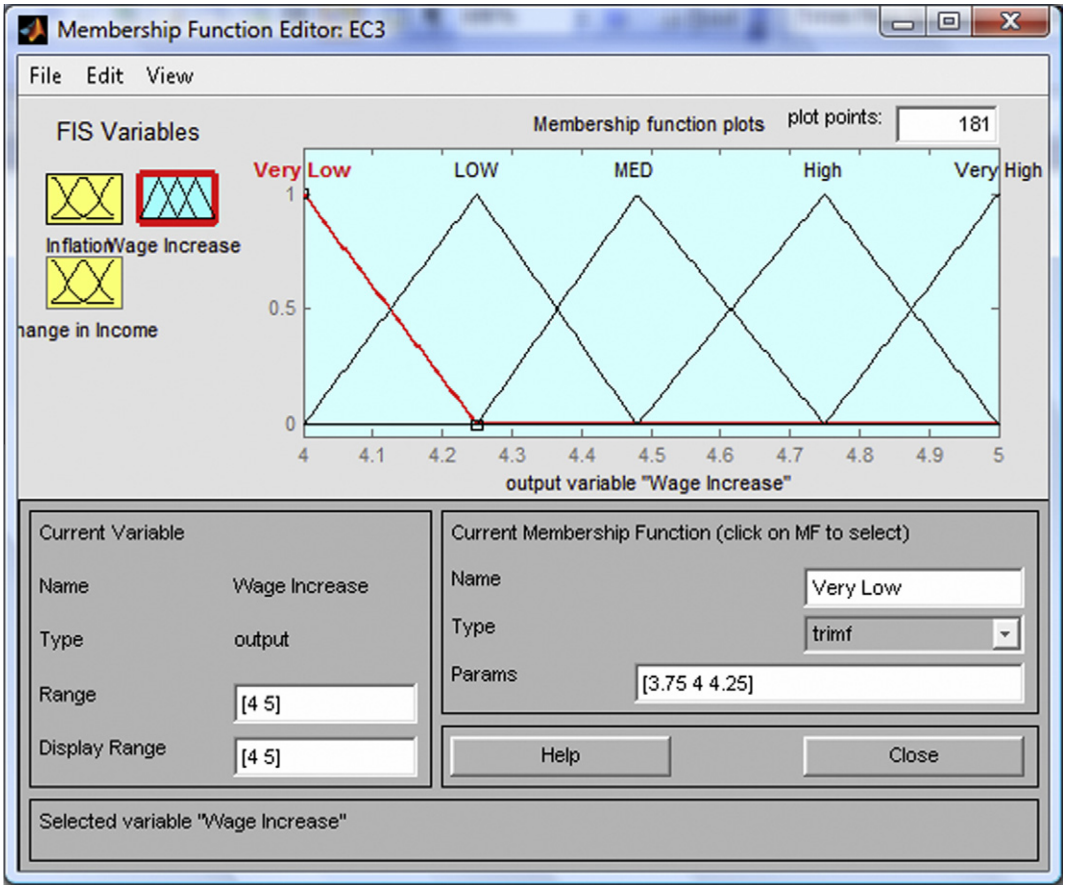

Fig. 7. FIS interface for the membership functions of the output variable *Expected Wage Increase* for HWU case study.

Fig. 7 shows the output interface for the HWU case study and a defuzzified (crisp) output interface is as shown in Fig. 8.

10. Determine whether the conditions for the end of the game have been met: in this case study, the condition for the end of the game is when the number of rounds r reaches 1 counting down from 5 (i.e. when $r = 1$).
11. Training and performance evaluation: training and learning of the *FGAW* decision agent was accomplished through the optimization of the fuzzy logic parameters while using the game payoff as the basis for the performance measure after playing a series of the game as in Braathen and Sendstad (2004). This training or learning of the fuzzy agent to optimize its performance was achieved through the use of the *fminsearch* function in Matlab having considered other optimization algorithms such as gradient descent and genetic algorithm.
Fminsearch uses the Nelder-Mead Simplex Search Method for finding the local minimum x of an unconstrained multivariable function $f(x)$ using derivative-free method and starting at an initial estimate. This is generally referred to as unconstrained non-linear optimization. If n is the length of x, a simplex in n-dimensional space is characterized by the $n + 1$ distinct vectors that are its vertices. In two-space, a simplex is a triangle; in three-space, it is a pyramid. At each step of the search, a new point in or near the current simplex is generated. The function value at the new point is compared with the function's values at the vertices of the simplex and, usually, one of the vertices is replaced by the new point, giving a new simplex. This step is repeated until the diameter of the simplex is less than the specified tolerance (Lagarias, Reeds, Wright, & Wright, 1998). We maximized the fuzzy agent's payoff based on the fuzzy membership functions (MFs) and therefore, algorithm stops when opponent's wealth is minimized. However, during the optimization, the membership functions need to retain a valid shape.

All these steps that are necessary for playing this game are as summarized in the flowchart shown in Fig. 3.

9. FGAW case study of Heriot-Watt University

As a case study for this model, we considered Heriot-Watt University (HWU) Wage bargaining processes for consecutive five years. The figures of UK inflation, HWU university's revenue, revenue increase and the wage increase for its staff from year 2005 to 2009 are as shown in columns two, three, four and five of Table 2. Column six of Table 2 shows the expected wage increase for each year according to our FGAW model that uses fuzzy reasoning.

Fig. 7 shows the FIS interface for the output variable *Expected Wage Increase* and a defuzzified (crisp) output interface is as shown in Fig. 8.

Also, this model could also be applied in determining the wage increase for the public sector of a nation's economy by taking all the necessary factors as inputs to the fuzzy model in determining the wage increase of workers for a particular year. The public sector workers receive wage directly from the governments. For example, In determining the estimated wage increase for the public sector workers in UK, the government might consider the nation's gross domestic product (GDP) and inflation as key factors and inputs in determining wage increase of workers as shown in

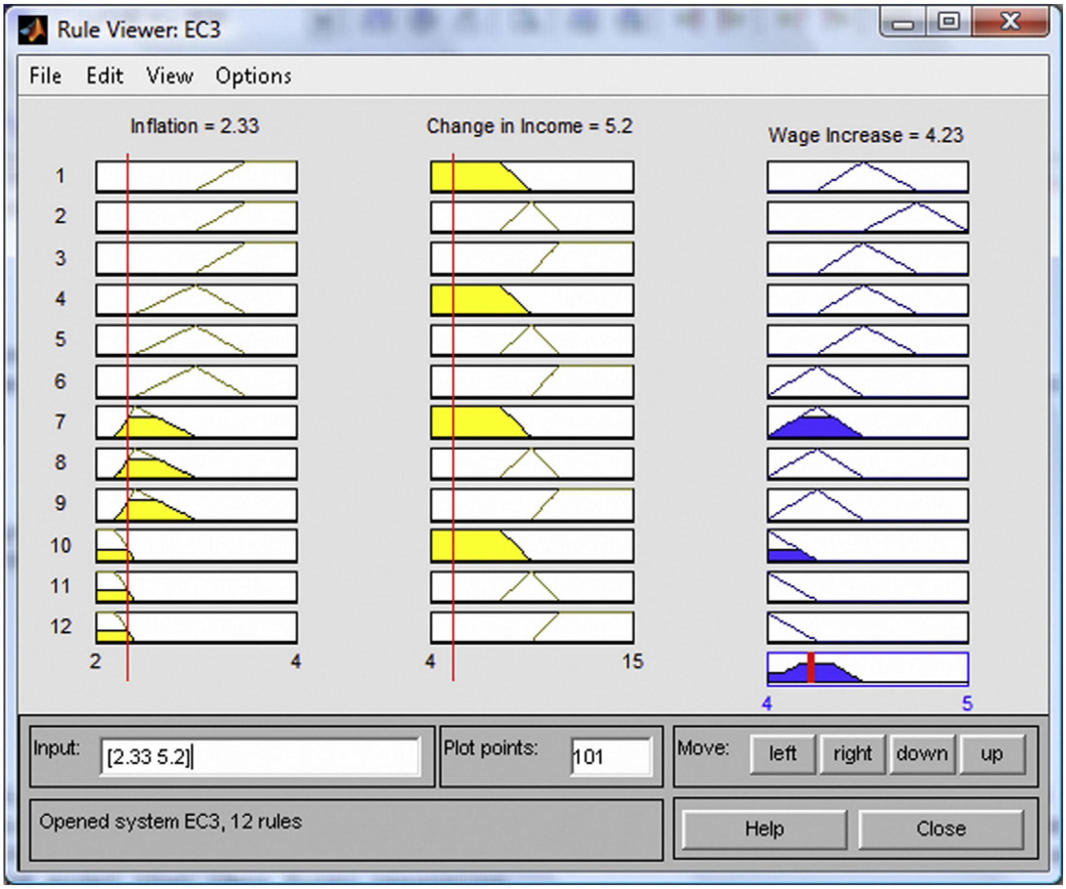

Fig. 8. Defuzzified (crisp) values for *Expected Wage Increase* at inputs $I = 2.33$ and $\Delta R = 5.2$ for HWU case study.

Table 1
Results of the FGAW game decision system.

S/N	Player moves		Control expmt		FGAW players	
	Green	Yellow	Winner	Payoff	Winner	Payoff
1	1,1,3	1,0,4	Yellow	−22.0	Yellow	−63.9
2	2,1,2	1,1,3	Yellow	−52.7	Yellow	−94.8
3	3,0,2	2,0,3	Yellow	−26.7	Yellow	−68.8
4	4,0,1	4,0,1	Green	40.8	Yellow	−8.2
5	1,0,4	2,0,3	Green	351.6	Green	302.2
6	3,1,1	4,0,1	Yellow	−16.1	Yellow	−65.2
7	3,0,2	2,1,2	Green	136.8	Green	94.9
8	3,1,1	3,1,1	Green	14.8	Yellow	−34.2
9	3,1,1	2,0,3	Yellow	−289.3	Yellow	−305.0
10	0,5,0	1,4,0	Yellow	−99.8	Yellow	−142.2
11	0,5,0	0,1,4	Yellow	−704.8	Yellow	−747.2
12	0,0,5	0,5,0	Green	1054.5	Green	1012.0
13	0,5,0	0,0,5	Yellow	−863.8	Yellow	−906.2

l[1] From the table, the first column shows the serial numbers of the iterations, the second column contains player *green's* strategies while the third column contains that of *yellow*. For example, in the first iteration, *green's* strategy shows [1,1,3], this indicates how resources are allocated to green strategy [*C*, *W*, *M*]: $C = 1$, $W = 1$ and $M = 3$. The fourth and fifth columns contain the control experiments in which the business management did not use fuzzy rules in the wage negotiation. The sixth and seventh columns show FGAW players and the results, that is, the simulations in which the business uses fuzzy rules in taking its decisions. Detailed results are discussed in Section 10 and are as further summarized in the pie chart of Fig. 6.

Table 3. Columns four and five give the general (mostly applicable to the private sector) minimum wage for the nation for those years. Fig. 9 shows a sampled expected FGAW output wage increase for UK public sector workers at inputs: *Inflation* = 3.35 and *GDP* = 1.33.

Table 2
Results of the FGAW decision system case study.

Year	Inflation	Revenue (£m)	Revenue Inc. (%)	Wage Inc. (%)	FGAW Inc. (%)
2005	2.05	94.6	4.1	4.3	4.08
2006	2.33	99.5	5.2	4.6	4.23
2007	2.32	110.7	11.3	4.8	4.22
2008	3.61	117.8	6.4	5.0	4.49
2009	2.17	134.5	14.2	5.0	4.08

l[1] From the table, the first column shows the years, second column shows inflation rate in UK, third column shows the revenue, fourth columns shows the revenue increase and the fifth column shows the calculated wage increase of Heriot-Watt University staff while the sixth column shows the recommended wage increase as output of the FGAW iterations. The results shows the similarity of the organization's calculated wage increase and the FGAW modeled wage increase. After training (Section 8 step 2), the model performs much better and closer to the negotiated increase.

10. Results discussion for fuzzy game approach to wage negotiation

Based on the procedures highlighted in Section 8 above and from the results in Table 1, the results of the game show that yellow (employer) wins more often than green (employees' union) because the business wage decision was based on the output of fuzzy reasoning from the fuzzy inference system (FIS) and learning was used. This shows the extent to which fuzzy reasoning can help a business if it wants to make use of fuzzy rules plus learning for their decision support tools. Fuzzy rules make the wage negotiation more flexible and were able to capture both the present and the future uncertainty inherent in the business environment.

Table 3
FGAW simulation for UK public sector wage increase.

Year	Inflation	GDP £ tr	ΔGDP (%)	Mini wage £	Wage Inc. (%)	FGAW Inc. (%)
2005	2.05	1.25	4.2	4.85	7.7	1.0
2006	2.33	1.33	6.4	5.05	4.1	1.2
2007	2.32	1.40	5.3	5.35	5.9	1.1
2008	3.61	1.45	3.6	5.35	0.0	2.5
2009	2.17	1.39	−4.1	5.73	7.1	1.0

l[1] From the table, the first column shows the years, second column shows inflation rate in UK, third column shows GDP of UK for the years, fourth column shows change (increase) in GDP while the fifth column shows the **general** minimum wage in the country. Column six shows the percentage wage increase (for the **general** or **private** sector) and columns seven shows the FGAW model output wage increase for each year that are recommended for the **public sector** workers. We got Details about UK GDP from IMF web sites and we also got UK minimum wages as well as inflation rates from Office for National Statistics web sites.

These results on Table 1 (columns 6 and 7) show that the fuzzy player (**Yellow** which represents the employer) in FGAW iterations was able to win more often than the employees' union (**Green**) because the management of the business made use of the fuzzy inference system in making the business decisions. Out of the thirteen FGAW iterations on the table, yellow won a total of 10 iterations.

The results of the control experiments in columns four and five of the table (in which business did not use fuzzy rules to make decisions) show that green wins as often as yellow does. These two results (the FGAW games and the control experiment simulations) are as summarized in the pie chart of Fig. 6. The results of the control experiment (where fuzzy rules were not used) may be considered dangerous for the business. This is because if employees continue to win and wages continue to grow without corresponding market expansion, the trend may lead to gradual demise of the business.

We also observed, as shown in the table, that the stronger the strategy, the higher the payoff. This means that the more the yellow player allocates to market expansion, the better the payoffs. That is, for the business to continue to survive, decision makers may need to allocate more resources to marketing.

The results of the FGAW case study of HWU in Section 9 show that the wage increase results of our FGAW model moves closer to the agreed negotiated wages and the management agreed that the variation is due to additional factors which are taking into consideration during wage increase negotiation such as tax. When implementing this model in a real system, these additional factors would also be incorporated into the model as additional input variables.

We therefore observed that this model could be more acceptable to both employers and employees in determining future wage increase for the workers. That is, for example, rather than specifying a rigid 5% *yearly increase* of wages, our model has recommended that the future wage increase fomular needs to take into consideration some of the business factors which are difficult to predict with certainty and these could be accomplished by using this FGAW model which uses fuzzy rules that we have demonstrated in this paper.

After training, the fuzzy player performs better with higher payoffs. This shows that the learning is important as the fuzzy player is able to adapt with fuzzy reasoning over time.

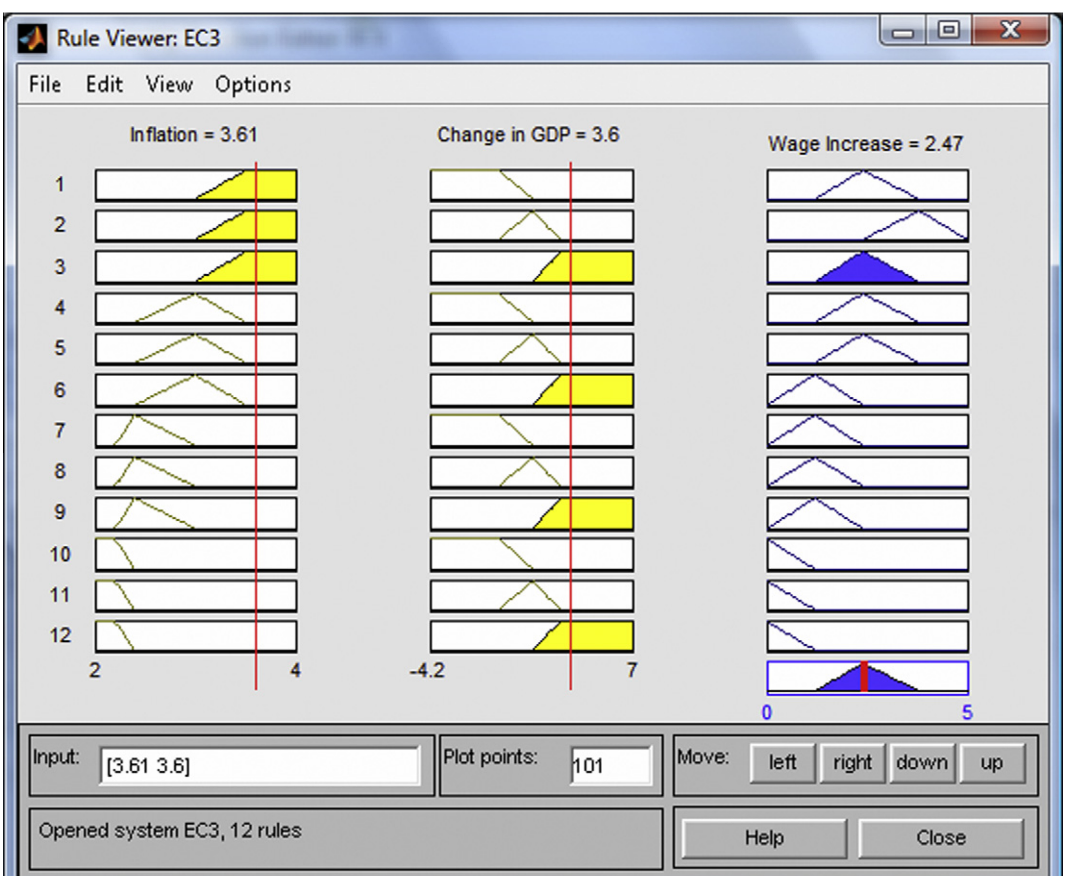

Fig. 9. Defuzzified (crisp) values for the *Expected Wage Increase* for UK Public Sector workers in 2008 at inputs $I = 3.61$ and ΔI GDP $= 3.6$.

11. Conclusion

We have used a fuzzy inference system in designing an effective and efficient decision system that models wage bargaining processes in organizations. The model took effective cognisance of the aims of the two parties involved and effectively captures the uncertainty therein using fuzzy rules solicited from experts in the field. The model considers varying ranges of inflation trends as it affects both parties and also considers the varying ranges of possible revenue increase of the organization. It arrives at an agreed rate for wage increase which may be sustainable for both present and in the future. This may also be more agreeable and acceptable to both parties.

The result of the general model showed that the employer wins most often because the management implemented fuzzy rule base and used learning in taking their wage decisions. This helped to formulate sustainable wage agreements between employers and employees.

However, the fact that the employer wins most often may not necessarily mean that the employees are cheated but rather guarantees the continue survival of their firm (or organization) and therefore guarantees the continuity of their jobs. If our scheme could be employed by entrepreneurs, it would help to greatly reduce deadlocks that usually plague wage negotiations between employers and employees (or their union) and will therefore increase productivities.

Also, the results of the model demonstrated in the Heriot-Watt University case study in Section 9 showed that the outcomes of the FGAW simulations draw closer to the yearly negotiated wages increase of the organization and therefore, the management agreed that this automatic model could be used to automate the wage negotiation processes and therefore save time that they spend on yearly wage negotiation. This also helped to formulate sustainable wage agreements between employers and employees as the fuzzy rule base was able to capture both the present as well as the future uncertainty that surrounds the business environment. The management also agreed that the slight variation in the results is due to additional factors which are taking into consideration during wage increase negotiation such as tax and in a real system, these additional factors would also be incorporated into the model as additional input variables.

12. Future research

We will apply this model in a wider range of micro and macroeconomic models that are targeted to specific industries and international trades among countries. We will do experiments to determine the actual duration and number of steps in the business games. We plan to apply the model to other different strategic games and to replace the adaptation of the membership functions by operations on type-2 fuzzy sets (Méndez & Hernandez, 2008). Also, the model can be applied for optimizing bidding in auctions and in a variety of human resource allocation decisions. It could also be applied for pension negotiations in determining what percentages the employers and employees should contribute toward their pension pots.

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