Trust and cooperation from a fuzzy perspective

M.S. Al-Mutairi a,*, K.W. Hipel a,1, M.S. Kamel b,2

a Department of Systems Design Engineering, University of Waterloo, Waterloo, Ontario, Canada N2L 3G1
b Department of Electrical and Computer Engineering, University of Waterloo, Waterloo, Ontario, Canada N2L 3G1

Available online 8 April 2007

Abstract

The well-known game of Prisoner’s Dilemma, which reflects a basic situation in which one must decide whether or not to cooperate with a competitor, is systematically solved using a fuzzy approach to modeling trust. When involved in a dispute, two or more parties need to make decisions with fully or partially conflicting objectives. In situations where reaching a more favorable outcome depends upon cooperation and trust between the two conflicting parties, some of the mental and subjective attitudes of the decision makers must be considered. While the decision to cooperate with others bears some risks due to uncertainty and loss of control, not cooperating means giving up potential benefits. In practice, decisions must be made under risk, uncertainty, and incomplete or fuzzy information. Because it is able to work well with vague, ambiguous, imprecise, noisy or missing information, the fuzzy approach is effective for modeling such multicriteria conflicting situations. The fuzzy procedure is used to take into account some of the subjective attitudes of the decision makers, especially with respect to trust, that are difficult to model using game theory. © 2007 IMACS. Published by Elsevier B.V. All rights reserved.

Keywords: Cooperative games; Fuzzy logic; Decision making; Prisoner’s dilemma; Trust

1. Introduction

Game theory is a widely accepted procedure for addressing problems arising in engineering, economics, psychology, biology, business, and politics [7,13,18,22,27,44]. The modern development of game theory dates back to the year 1944 when von Neumann and Morgenstern published their seminal book entitled The Theory of Games and Economic Behavior [49]. John Nash [39], who introduced the concept of a Nash Equilibrium into classical game theory, won the Nobel Prize in Economics for this insightful concept.

When a group of decision makers or agents (referred to as players in game theory) interact with each other, they are faced with conflicting objectives. While they are trying to maximize their profits or minimize their costs, it might be in their interest to help others achieve their goals. This could be as a result of expecting to be reciprocated in future interactions or to achieve a better situation that seems unachievable without the others’ assistance.

Cooperation is the situation in which people work together to achieve their individual goals that without some type of unified action would not be reached or reached but with less rewards. When engaging in a cooperative action, the chances of success are dependent on joint actions and the number of partners involved. This creates risks and

* Corresponding author. Present address: Hafer Albatin Community College, PO Box 1803, Hafer Albatin, 31991 Saudi Arabia.
Tel.: +1 519 888 4567x7736 (Canada); fax: +1 519 746 4791 (Canada).
E-mail addresses: mutairims@gmail.com (M.S. Al-Mutairi), kwhipel@uwaterloo.ca (K.W. Hipel), mkamel@pami.uwaterloo.ca (M.S. Kamel).

1 Tel.: +1 519 888 4567x2830; fax: +1 519 746 4791.
2 Tel.: +1 519 888 4567x5761; fax: +1 519 746 3077.

0378-4754/$32.00 © 2007 IMACS. Published by Elsevier B.V. All rights reserved.
doi:10.1016/j.matcom.2007.04.006
uncertainties. Thus, it could be claimed that trust is a necessary condition for cooperation and that it is a product of successful cooperative actions [36]. Trust is a good way of motivating cooperative actions but might not be sufficient alone. Besides trust, there should be some sort of common goals, shared values, or even a kind of reciprocation. The role of trust in the case of cooperation is mainly in the elimination of fear of being betrayed or not being reciprocated [32]. The two main conditions to be met besides trust to facilitate cooperative actions are [32,34]:

1. Having a common goal or sharing some values.
2. Expecting others to cooperate.

If any of the above two conditions is not satisfied, the chances for cooperation are relatively low. In general, one could say that cooperation occurs when there is a non-mutually exclusive goal in which everyone wants to reach a better situation. On the other hand, the presence of distrust could eliminate any chances for cooperation. In his book of 2000, Gambetta, on page 219, states that “if distrust is complete, cooperation will fail among free agents” [23].

When trying to maximize his or her expected payoff, a person investigates the possibility of cooperating or joining a coalition that promises enhanced individual expectations. In such a highly subjective occurrence, nothing is guaranteed. The situation is subject to many unpredictable and hard-to-evaluate factors. Not being able to predict the commitment of the game players, the influences of the surrounding environment, and the game roles, one is unlikely to be able to forecast the outcomes. Such uncertainty, imprecision, or vagueness is best modeled through the use of fuzzy logic.

Fuzzy set theory [52] is appropriate for employment when dealing with vague, imprecise, noisy or missing information. Instead of using the Boolean \{0, 1\} values, fuzzy sets try to map the degree to which an element belongs to a certain group in a continuous scale between [0, 1].

When interacting with someone in a conflicting or cooperative situation, it is vitally important to know some of the mental and social characteristics of the opponent. Since such subjective characteristics are difficult to estimate using crisp values (whether experimentally or in real life), a fuzzy procedure is employed to overcome this problem.

This research is an enhancement and expansion of the earlier work of Al-Mutairi et al. [1]. The current research focuses on exploring the close relationship between trust and cooperative behavior. It also uses a fuzzy logic approach to study the attitudes of the decision makers in an attempt to incorporate it into an operational concept for describing human behavior under conflict.

Section 2 reviews the well-known Prisoners’ Dilemma game which constitutes a basic cooperative situation. In Section 3, the repeated version of the Prisoners’ Dilemma along with some of its well-known strategies are reviewed. Section 4 acknowledges and highlights the close relationship between trust and cooperative actions. The evaluation process of risk in Prisoners’ Dilemma using a fuzzy approach to trust is introduced in Section 5. The results of a stability analysis of the Prisoner’s Dilemma game using the solution concepts of Nash, general metarational, symmetric metarational and sequential stability, are presented in Section 6. A real-world groundwater dispute referred to as the Elmira Conflict is studied in Section 7 using the new developments presented in this paper while some concluding remarks and insights are given in Section 8.

2. Prisoner’s dilemma

In 1984, Axelrod [3] analyzed cooperation by means of a $2 \times 2$ non-zero-sum game called “Prisoner’s Dilemma”. In this game, the two players have two strategies: either “cooperate” (called strategy C) or “defect” (labeled as strategy D). While both gain equally when cooperating, if one of them cooperates, the other one who defects, will gain more. If both defect, both lose (or gain very little). Table 1 summarizes the complete game situation and its different states or outcomes. Notice in this table that player 1, or prisoner 1, controls the row strategies while player 2 controls the column strategies. When each player selects a strategy, an outcome or state is formed, which is represented by a cell in the matrix. The double letters given at the top of a cell represent the strategies of the players where the letters on the left and right stand for the strategies of players 1 and 2, respectively. Hence, the cell given as CD is the state in which player 1 cooperates and player 2 defects. The two numbers given in parentheses in the middle of a cell represent the preferences of player 1 (left entry) and player 2 (right entry), where a higher number means more preferred. The hypothetical negative quantities given in parentheses at the bottom of a cell are meant to represent the years in prison where the left and right entries are for players 1 and 2, respectively. They are represented using negative signs since staying in prison is not a desirable situation.
Table 1
Prisoner’s Dilemma in normal form

<table>
<thead>
<tr>
<th>Prisoner 1</th>
<th>Prisoner 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooperate (C)</td>
<td>Cooperate (C)</td>
</tr>
<tr>
<td>Cooperate (C)</td>
<td>Defect (D)</td>
</tr>
<tr>
<td>Defect (D)</td>
<td>Cooperate (C)</td>
</tr>
<tr>
<td>Defect (D)</td>
<td>Defect (D)</td>
</tr>
</tbody>
</table>

The following hypothetical situation is the reason behind the game’s name. Two criminals have been arrested under the suspicion of having committed a crime together. Due to lack of evidence, the police cannot convict them. While keeping them separated, the police separately offer each of them a deal. The one helping the police to convict the other one will be set free. If they cooperate with each other (by rejecting the police’s offer), both of them will be jailed for a short time and they both gain the same amount. However, each has an incentive to confess to the police in order to be set free. In this case, the defector will gain more, since he or she is freed; the one who remained silent, on the other hand, will receive the full punishment. If both comply with the police’s request, both will be jailed, but by less of an amount of time than if one had refused to talk and the other confessed. The dilemma arises because each prisoner needs to make a good decision which is not possible without knowing the other’s choice.

In many real life situations, one can encounter such distributions of gains and losses. While the cooperator, whose action is not reciprocated, will lose resources to the defector, neither of them will be able to get the additional gain coming from their cooperation. The gain for mutual cooperation in Prisoner’s Dilemma is kept smaller than the gain for one-sided defection so that there would always be an incentive to defect, though this assumption might not be generally valid. For example, it is better when two hunters hunt for a stag together rather than hunt individually as they would for a hare. Even if one of them hunts a hare and gave it to the other one, the hunter who did nothing would still have gained less compared to the case in which he had helped his companion to hunt a stag.

When knowing nothing about any future interactions, Prisoner’s Dilemma is a generic way for studying short term decision-making. Assuming the evolution of experience is a cumulative process, long term cooperation can only evolve after short term ones have been selected, thereby adding small improvements upon each other but without blindly making major blunders.

One of the problems associated with Prisoner’s Dilemma is rationality. If both players were purely rational, they would never cooperate. A rational decision-making process means that a particular player makes the decision which is best for him or her regardless of the other player’s choices. If the other player decided to defect, then it is rational for the given player to defect. While not gaining by doing so, the initial player still is avoiding the maximum stay in prison. On the other hand, if the other player decided to cooperate, the rational choice for the particular player is to defect so he or she will gain more. If both are rational, both will decide to defect, and neither of them will gain anything. On the other hand, if both would “irrationally” decide to cooperate, both would spend less time in jail. The problem now is to find the appropriate mix between the two situations.

3. Repeated Prisoner’s Dilemma

Despite the rationalism and the inherent selfishness of people and organizations [16], some sort of cooperative behavior may occur among different individuals. The motives for these cooperative actions could be based on, but not limited to, some type of trust, expectancy of reciprocation, or conditional behaviors such as “you do this and I will do that”. To better model such cooperative behavior, researchers examine what is called repeated Prisoner’s Dilemma. This will eventually enable them to track the evolution of such behavior [5,6,21].

In a single encounter of Prisoner’s Dilemma, if the first prisoner defects, the second will defect in response to the first one’s defection. On the other hand, if the first one cooperates, the second will defect to get a better payoff. In
general, the second player always has an incentive to defect. It could also be claimed that the first player is better to defect in the first place to avoid betrayal by the second one. However, if they both decided to defect regardless of the other’s choice, they will always end up in a less preferred situation compared to both cooperating.

When having repeated encounters of the Prisoner’s Dilemma game, players have to decide between the value of the current encounter and future ones. Players who place a higher value on the current encounter are motivated to defect in favor of a short term benefit. On the other hand, players seeking a long lasting relationship would be more motivated to build a good, positive reputation and a trusting relationship [29]. In the following sub-sections, some of the well-known strategies for repeated encounters are explained [3,4,8,9,11,12,26,29,30,35,37,38,41–43,45–47].

3.1. Tit for tat (TFT)

Tit for tat (TFT) is a deterministic strategy. In this strategy, one player starts with a cooperative action and then behaves the same as the other in future steps. In other words, one will defect in the current step if the opponent defected in the previous one. Likewise, one will cooperate in the current step if the opponent did so in the previous step. This strategy is the most well known and has been shown to give the best results in most of the cases. This could be interpreted as a kind of reciprocal cooperation, meaning that one will cooperate based on the expectancy that the other will cooperate too. This is the safest and most rewarding strategy in repeated encounter situations [4,26,35].

3.2. Generous tit for tat (GTFT)

As implied by its name, this strategy is a slightly modified and more generous version of the original deterministic TFT strategy. It is mainly based on the assumption of the presence of some noise or misperception. Mistakes in the application of some choices and misperceptions are two common characteristics of human behavior. When implementing this strategy, a player is more forgiving in case of small mistakes or defections in the absence of strong evidence that it was intentional. Adding some generosity will contribute to more cooperative actions [37,42].

3.3. Contrite tit for tat (CTFT)

This is another modified version of the famous deterministic TFT strategy. It has three main attitudes namely, contrite, content and provoked. The initiating player begins with cooperation and keeps cooperating unless there is a defection from the other player. If a player defects while content, the victim player becomes provoked and defects until cooperation from the other player causes him or her to become content again. If the other player is content and the remaining player defects, this player becomes contrite and should cooperate. When contrite, he or she becomes content only after he or she has successfully cooperated [9,11].

3.4. Suspicious tit for tat (STFT)

This is also a modified version of the deterministic TFT. It is based on total distrust. To be on the safe side and avoid any chances of betrayal, a player will defect on the first move; otherwise he or she will do the same as the other player did last. If one makes the first move and defects against TFT, the result is continuous defection thereafter [12,29].

3.5. Tit for two tats (TF2T or TFTT)

In this strategy, a player is trying to stay neutral (not going to any of the two extremes). Based on the expectancy of an unintentional error or misperception, the player will cooperate on the first move and defect after two consecutive defections by the opponent. It is a more tolerant strategy but very exploitable by a strategy which alternately cooperates and defects [3,29].

3.6. PAVLOV

Pavlov is a stochastic simple win-stay, lose-shift strategy. In brief, if the player’s payoff is below a certain level, he or she will change his or her action. Otherwise, the player keeps repeating the previous one. A Pavlov player tries to
divide game results in each step into two groups: success or defeat. If his last result belongs to the success category, he or she plays the same move; otherwise he or she chooses another move. A player will cooperate if and only if both the protagonist and opponent played identically in the last round. Pavlov success is based on two main advantages: it can correct occasional mistakes and exploit unconditional cooperators [30,43].

3.7. Prudent PAVLOV (P-PAVLOV)

This is a modified version of the well-known PAVLOV strategy. The main distinction lies in the fact that a player will only resume cooperation after two rounds of mutual defection. The key advantage of this strategy is that it will allow one to recover from an opponent’s erroneous or unintentional defection or a misperceived defection [9].

3.8. Remorse

The remorse strategy is the complement of the forgiving one. A player practicing remorse switches to cooperation after defecting or being in a “bad standing” or if both players cooperated in the last round. Maintaining a record of the opponent’s “standing” can be of help recovering from an opponent’s erroneous defection. One can call this strategy an error-correcting one [9].

3.9. Always cooperate (ALLC)

This strategy is based on blind trust. Regardless of the other player’s behavior, the one implementing ALLC will always cooperate. A player employing such a strategy is exploited by others and is vulnerable to defection.

3.10. Always defect (ALLD)

While ALLC is based on blind trust, ALLD is founded on extreme suspicion (trust no one). In this case, one will always defect regardless of the other’s choice. It might benefit a player in a single encounter but certainly not in the long run or in repeated encounters.

3.11. GRIM

GRIM is an unforgiving strategy that starts with cooperation until the opponent defects once, and then defects for the rest of the game. It will cooperate if both players cooperated previously but will revert to ALLD if the other player defects. The biggest disadvantage is that it cannot recover from an erroneous or misperceived defection [8,9].

4. Trust and cooperative actions

The foregoing analysis of repeated Prisoners’ Dilemma shows the strong relationship between trust and cooperative actions and how one’s attitudes and actions change when realizing the fact that one is being trusted or trusting someone else. Generally speaking, one could say that the presence of complete distrust will eliminate any chance for cooperation [23,34].

The different strategies developed for dealing with repeated Prisoner’s Dilemma discussed in the previous section are ideal for hypothetical situations but are not sufficient for explaining real life circumstances. In reality, most games are played once. Even when engaging in iterative or repeated encounters, it is not known in advance, nor after how many iterations, the encounter will be terminated. Even if one knows that he or she is having repeated encounters with another party, one uses some mental shortcuts like trust to reduce the situation’s complexity and the chances for risks thereafter.

When trying to explain cooperative actions, it cannot be studied in isolation of other influential factors like trust, importance of the situation, risk involved, and sharing some common goals. The presence of trust will eliminate or decrease fears of betrayal when engaging in a cooperative situation. Other factors like low risks and the importance of the situation could complement and support low levels of trust. On the other hand, having a high level of risk and having low importance when combined with a low level of trust will reduce the chances of cooperation.
Luhmann [33, p. 36] wrote, “trust rests on illusion. In actuality, there is less information available than would be required to give assurance of success. The actor willingly surmounts this deficit of information”. In favor of an inner confidence, a person in this illusory state of trust simplifies the complexity of the outer world and removes any external uncertainty. As a result of lack of information and a deceptive sense, the trustful individual finds a possibility of comprehending new experiences and carrying out actions that were previously undesirable or unachievable.

5. Fuzzy risk in Prisoner’s Dilemma

When trusting, one is actually accepting risk and trying to deal with it. The general framework for fuzzy risk in a decision situation such as Prisoner’s Dilemma is displayed in Fig. 1. It consists of three main modules: a given decision maker, the assessment, and the fuzzy evaluation. The decision maker tries to make sensible and wise decisions based on some information. The nature of this information could be incomplete, imprecise, or vague. To cope with the missing information and the uncertainty in such situations, one tends to trust. Having some common goals, shared values, and good reputation could complement the missing information and hence enhance the chances for trust. In the assessment module, each of the criteria in the decision maker module is assessed using appropriate values. With qualitative criteria, it might be simpler to express the values using natural linguistic terms. Each decision maker has a different threshold for the acceptable level of the values for a given criterion. What might seem to be important for a particular decision maker might not be of the same importance for another decision maker. The conversion between linguistic terms and fuzzy intervals representing the linguistic terms is done using some predefined scales, as will be explained in the next few sub-sections. In the fuzzy evaluation module, based on the fuzzy values and weights for each criterion, some fuzzy calculations are executed and the final answer is translated back into a matching linguistic term using some predefined scales [10,17,24,50,51]. Since the final fuzzy value might not exactly overlap with one of the intervals on the predefined fuzzy scale, it has to be approximated using an appropriate technique [2]. Based on fuzzy computations and the judgment of the decision maker, the final cooperative decision can be made.

5.1. Preliminaries

Following the procedure of Chen and Chen [14] and based on the concepts of fuzzy numbers and their arithmetic [15,40], a generalized trapezoidal fuzzy number is represented as \( A = (a, b, c, d; w) \) (see Fig. 2), where \( 0 < w \leq 1 \), and \( a, b, c \) and \( d \) are real numbers. If \( w = 1 \), then the generalized fuzzy number \( A \) is called a normal trapezoidal fuzzy number denoted as \( A = (a, b, c, d) \). If \( a = b \) and \( c = d \), then \( A \) is called a crisp interval. If \( b = c \), then \( A \) is called a generalized triangular fuzzy number. If \( a = b = c = d \) and \( w = 1 \), then \( A \) is called a real number. For any value \( x \) on the real line, there is a corresponding membership \( \mu_x \) where \( 0 \leq \mu_x \leq 1 \).

5.2. Fuzzy numbers arithmetic

The arithmetic operations between the generalized trapezoidal fuzzy numbers \( A_1 \) and \( A_2 \) are as follows:

1. Fuzzy number addition:

\[
A_1 \oplus A_2 = (a_1, b_1, c_1, d_1; w_1) \oplus (a_2, b_2, c_2, d_2; w_2) = (a_1 + a_2, b_1 + b_2, c_1 + c_2, d_1 + d_2; \min(w_1, w_2)),
\]

where \( a_1, b_1, c_1, d_1, a_2, b_2, c_2, \) and \( d_2 \) are real numbers.

2. Fuzzy number subtraction:

\[
A_1 \ominus A_2 = (a_1, b_1, c_1, d_1; w_1) \ominus (a_2, b_2, c_2, d_2; w_2) = (a_1 - d_2, b_1 - c_2, c_1 - b_2, d_1 - a_2; \min(w_1, w_2)),
\]

where \( a_1, b_1, c_1, d_1, a_2, b_2, c_2 \) and \( d_2 \) are real numbers.

3. Fuzzy number multiplication:

\[
A_1 \odot A_2 = (a, b, c, d; \min(w_1, w_2)),
\]
where \( a = \min(a_1 \times a_2, a_1 \times d_2, d_1 \times a_2, d_1 \times d_2) \), \( b = \min(b_1 \times b_2, b_1 \times c_2, c_1 \times b_2, c_1 \times c_2) \), \( c = \max(b_1 \times b_2, b_1 \times c_2, c_1 \times b_2, c_1 \times c_2) \), and \( d = \max(a_1 \times a_2, a_1 \times d_2, d_1 \times a_2, d_1 \times d_2) \). It is obvious that if \( a_1, b_1, c_1, d_1, a_2, b_2, c_2, \) and \( d_2 \) are all positive real numbers, then

\[
A_1 \otimes A_2 = (a_1 \times a_2, b_1 \times b_2, c_1 \times c_2, d_1 \times d_2; \min(w_1, w_2))
\]

4. Fuzzy number division
The inverse of the fuzzy number $A_2$ is $1/A_2 = (1/d_2, 1/c_2, 1/b_2, 1/a_2; w_2)$, where $a_2, b_2, c_2,$ and $d_2$ are all nonzero positive real numbers or all nonzero negative real numbers. If $a_1, b_1, c_1, d_1, a_2, b_2, c_2,$ and $d_2$ are all nonzero positive real numbers, then the division of $A_1$ and $A_2$ is

$$A_1\theta A_2 = (a_1, b_1, c_1, d_1; w_1)\theta(a_2, b_2, c_2, d_2; w_2) = (a_1/d_2, b_1/c_2, c_1/b_2, d_1/a_2; \min(w_1, w_2))$$

5.3. Trust and cooperation criteria

Cooperation is closely tied to trust. It is difficult trying to explain cooperation in isolation of trust, as discussed in Section 4. Thus, it could be claimed that trust is a prerequisite for cooperation and without trust, there will be no cooperation [23,48]. Yet trust is complex and multidimensional in nature and could go beyond sensible factors [2]. Risk is activated by our actions, the choices we make, and the decisions we take. Trusting is actually making a decision in a risky and uncertain situation. In some circumstances, regardless of the level of risk and uncertainty, one tends to trust simply based on sharing some common goals or having some common background like family and friend relationships. The availability of some alternatives, such as how much one values something and how important it is to achieve it, all make the trust situation dependent. The same person might be trusted in a particular situation but not in others depending on the different circumstances. In the end, it is up to the decision maker’s own judgment (based on the attractiveness of the situation and how one feels about it) whether it is worth trusting and cooperating with someone or not. The main factors that could positively or negatively influence trust and cooperative actions are outlined in Fig. 3 [2].
5.4. Fuzzy values and weights

Due to the subjective nature of the evaluation criteria as well as the vague and imprecise nature of the available information, it is easier to express the values and the weights in natural language terms rather than using crisp values. These linguistic terms could be assessed through the use of fuzzy logic. Many scales have been proposed in the literature to represent linguistic terms using fuzzy intervals. It is widely agreed that the use of 5–9 intervals is sufficient depending on how much overlapping is required [10,17,24,50,51]. For this research, five and six linguistic terms and their corresponding fuzzy values for the values and weights are given in Tables 2 and 3, respectively.

By analyzing the Prisoner’s Dilemma game shown in Table 1, one can claim that it is important for both players to cooperate since they will get 2 years in prison compared to 6 if they do not cooperate. This also could serve as an indication of a common goal (spending less time in prison for both). On the other hand, this cooperation could trigger some risks since it is advantageous for both to deviate from that cooperative action and go free compared to spending 2 years in prison.

5.5. Fuzzy computation

To consolidate the fuzzy values and fuzzy weights of all the important trust and cooperation factors into one fuzzy attractiveness ratio (FAR), one can follow the procedure of Lin and Chen [31]. The higher the FAR value, the more promising the cooperation is. Let $R_j$ and $W_j$, where $j = 1, 2, \ldots, n$, be the fuzzy rating and fuzzy weighting given to factor $j$, respectively. Then, the fuzzy attractiveness ratio is computed as

$$\text{FAR} = \frac{\sum_{j=1}^{n} (W_j \otimes R_j)}{\sum_{j=1}^{n} W_j}$$

(5)

Once the FAR has been calculated, this value can be approximated by a similar close linguistic term (LT) from the fuzzy values predefined scale in Table 2. Several methods for approximating the FAR with an appropriate corresponding linguistic term have been proposed. The Euclidean distance will be used since it is the most intuitive from the human perception of approximation and the most commonly used method. The distance between FAR and each fuzzy number member of LT can be calculated as follows:

$$D(\text{FAR}, \text{LT}_i) = \left\{ \sum_{x=1}^{4} \left( f_{\text{FAR}}(x) - f_{\text{LT}_i}(x) \right)^2 \right\}^{1/2}$$

(6)
Table 4
Main and sub-criteria for trust and their fuzzy values and weights

<table>
<thead>
<tr>
<th>Sub-criteria</th>
<th>Fuzzy values</th>
<th>Fuzzy weights</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trust</td>
<td>(0.8, 0.9, 1.0, 1.0; 1.0)</td>
<td>(0.7, 0.8, 0.9, 1.0)</td>
</tr>
<tr>
<td>Risk</td>
<td>(0.6, 0.7, 0.8, 0.9; 1.0)</td>
<td>(0.7, 0.8, 0.9, 1.0)</td>
</tr>
<tr>
<td>Uncertainty</td>
<td>(0.8, 0.9, 1.0, 1.0; 1.0)</td>
<td>(0.5, 0.6, 0.7, 0.8)</td>
</tr>
<tr>
<td>Common goals</td>
<td>(0.4, 0.5, 0.6, 0.7; 1.0)</td>
<td>(0.7, 0.8, 0.9, 1.0)</td>
</tr>
<tr>
<td>Shared values</td>
<td>(0.7, 0.8, 0.9, 1.0; 1.0)</td>
<td>(0.5, 0.6, 0.7, 0.8)</td>
</tr>
<tr>
<td>Circumstances</td>
<td>(0.6, 0.7, 0.8, 0.9; 1.0)</td>
<td>(0.5, 0.6, 0.7, 0.8)</td>
</tr>
<tr>
<td>Importance</td>
<td>(0.8, 0.9, 1.0, 1.0; 1.0)</td>
<td>(0.7, 0.8, 0.9, 1.0)</td>
</tr>
<tr>
<td>Value</td>
<td>(0.6, 0.7, 0.8, 0.9; 1.0)</td>
<td>(0.5, 0.6, 0.7, 0.8)</td>
</tr>
<tr>
<td>Alternatives</td>
<td>(0.4, 0.5, 0.6, 0.7; 1.0)</td>
<td>(0.7, 0.8, 0.9, 1.0)</td>
</tr>
<tr>
<td>Judgment</td>
<td>(0.7, 0.8, 0.9, 1.0; 1.0)</td>
<td>(0.5, 0.6, 0.7, 0.8)</td>
</tr>
<tr>
<td>Attractiveness</td>
<td>(0.6, 0.7, 0.8, 0.9; 1.0)</td>
<td>(0.7, 0.8, 0.9, 1.0)</td>
</tr>
<tr>
<td>Feelings and emotions</td>
<td>(0.4, 0.5, 0.6, 0.7; 1.0)</td>
<td>(0.3, 0.4, 0.5, 0.6)</td>
</tr>
</tbody>
</table>

Then the distance from FAR to each of the members of the set LT can be calculated and the closest linguistic expression is the one with minimal distance value.

Table 4 shows the main factors and sub-factors for trust and cooperation along with their corresponding fuzzy values and weights. Originally, most of these values are expressed in natural linguistic terms like saying the risk for this situation is high. From Table 2, one can see that the matching fuzzy interval for high is (0.8, 0.9, 1.0, 1.0; 1.0). Different decision makers would have different weights for the different factors. Using the information in Table 4 and employing Eq. (5), one obtains the fuzzy values for the main criteria shown in Fig. 3 as follows:

- trust = (0.306, 0.522, 0.858, 1.308),
- circumstances = (0.312, 0.543, 0.909, 1.435),
- judgment = (0.236, 0.434, 0.765, 1.320).

Computing the fuzzy attractiveness value using Eq. (5), one obtains: FAR = (0.285, 0.555, 1.055, 1.935).

By using Eq. (6), the Euclidean distance from FAR to each member in the set LT at \( \alpha \)-cut = 0 is calculated to be:

\[ D(FAR, L) = 1.921, \quad D(FAR, FL) = 1.600, \quad D(FAR, M) = 1.322, \quad D(FAR, FH) = 1.121, \quad \text{and} \quad D(FAR, H) = 1.123. \]

Then, by matching the linguistic term with the minimum distance (\( D \)), the value corresponds to the linguistic term fairly high. Expressing the trust and cooperation value over a set of values rather than a single crisp value gives the decision maker greater flexibility and fewer chances for making a wrong trusting decision.

6. Stability analysis

Prisoners’ Dilemma can be solved using different solution concepts like Nash stability, general metarationality (GMR), symmetric metarationality (SMR), and sequential stability (SEQ) (see Fang et al. [18] for precise definitions of these solution concepts along with original references). The results obtained using these different solution concepts are provided in Table 5. In this table, a “U” stands for a state that is unstable for a particular player. In other words, a player could move unilaterally to another state that will produce a better payoff without a credible sanction being levied by the opponent player. An “S” stands for a state that is stable for a particular player. It could be stable because there are no unilateral improvements by that particular player or for any unilateral improvement the opponent player can invoke a sanction according to the way a sanction is defined for a given solution concept. A state that is stable for both players constitutes an equilibrium state denoted by \( E \).

According to Nash stability, the equilibrium point will be DD. A Nash equilibrium is the situation where it is not advantageous for either player to move to another state unilaterally because it will produce a worse payoff or at least one which is not better than the current one. Equilibrium DD represents the case where both prisoners will defect. Because Nash fails to predict state CC as an equilibrium, Howard [27] refers to this situation as a “breakdown of rationality”. Howard, therefore, derived the solution concepts of GMR and SMR, which realistically predict state CC as well as
DD as equilibria. The SEQ solution concept developed by Fraser and Hipel [22] also forecasts CC, along with DD as equilibria. An attractive feature of SEQ stability is that only credible sanctioning is permitted by the sanctioning player. As an example of how to calculate SEQ stability, consider state CC from player 1’s viewpoint. As shown in Table 1, if the game were at state CC, player 1 can unilaterally improve from state CC to state DC by changing his strategy from cooperate to defect (notice that the ordinal payoff for player 1 is 4 in state DC versus 3 at state CC). However, player 2 has a unilateral improvement from state DC to DD since by changing his or her strategy from cooperate to defect his or her ordinal payoff goes from 1 to 2. Because player 1 prefers state DD less than state CC, the possible unilateral improvement by player 1 from state CC to DC is credibly sanctioned by player 2 and, therefore, state CC is SEQ stable for player 1, as indicated in the bottom portion of Table 5. In a similar fashion, it can be demonstrated that state CC is also SEQ stable for player 2. Hence, overall state CC constitutes an equilibrium according to the SEQ solution concept.

If one considers that in some real life situations a move may be irreversible and cannot be taken back once it is invoked, a state may no longer be stable according to a particular solution concept. In fact, the graph model for conflict resolution can directly account for irreversible moves [18]. For example, once a prisoner confesses to the police one may wish to assume that the prisoner cannot reverse this decision and thereby deny his or her confession. Since each has an incentive to defect when the other confesses (set free), in the absence of trust, each will fear that the other will betray him or her. In this case, each will behave in a rational manner and defect. The outcome in this case is that both will be sent to jail for 6 years. The absence of trust weakens the coalition between the two prisoners though it is clear that it is better for both of them if they cooperate.

On the other hand, if trust is present, it eliminates any fears of betrayal even if they do not know each other preferences. It acts like a binding agreement that strengthens and supports the coalition between the two players. The stronger the trust, the stronger is the coalition. Each will sacrifice a chance for a short term benefit (set free) for a guaranteed long term benefit for both. Though they both will spend 2 years in prison, neither of them will abuse the trust invested in him or her. This is important in explaining the case of repeated encounters like repeated Prisoner’s Dilemma. Any short term benefits gained from betraying the other will result in a long term loss in any future interaction. In such repeated encounters, building a good reputation is crucial for future long lasting benefits. Likewise, it can justify why state CC could be stable in a single encounter.

7. Elmira conflict

About 15 km north of the twin cities of Kitchener and Waterloo, lays the town of Elmira situated in rich agricultural land in Southern Ontario, Canada. It is a prosperous town that is famous for its annual maple syrup festival.
which is the largest in the world. The 7500 residences of this small town depend mainly on an underground aquifer for their water supplies. In 1989, the Ministry of Environment (MoE), noticed that the water supplies were contaminated with N-nitroso demethylamine (NDMA). Having a pesticide and rubber plant in the town combined with a bad environmental record, Uniroyal Chemical Ltd. (UR) was the first suspect. The MoE issued a Control Order requesting UR to implement a long term collection and treatment system. The cooperation from the UR side was important in determining the cause as well as the best way to cleanse the contaminated aquifer and to carry out the necessary cleaning actions under MoE supervision. In favor of cancelling this Control Order or at least modifying it, UR immediately exercised its right to appeal. The Regional Municipality of Waterloo and the Township of Woolwich (referred to as Local Government or LG) were encouraged by their citizens to take a strong position in the dispute. The MoE wants to carry out its responsibilities in an effective and efficient way. The UR would like the Control Order to be lifted or modified. The local government wants to protect its citizens and industrial base [25,28].

The main decision makers and their options are shown in Table 6. The MoE already issued the Control Order but it can still modify it to make it more acceptable to UR. For its part, UR can exercise its right to appeal and gain more time, accept the original Control Order as is, or just simply abandon its operations in Elmira. The LG motivated by protecting its citizens and its industrial base, would insist on the application of the original Control Order.

Out of 32 possible states, only 9 are feasible. For example, UR cannot abandon its operations in Elmira and at the same time accept the Control Order or appeal. The set of feasible states are shown in Table 7. For simplicity, the feasible states have been numbered as 1–9. A “Y” besides an option for a particular player means that the player chooses that option. On the other hand, an “N” besides an option for a particular player means that the player decides not to choose that option. When having a “–” besides an option, it means either a “Y” or a “N”, because it actually does not make a difference whether it is a “Y” or an “N”. For example, if UR decided to abandon its operations in Elmira, it does not make a difference what other options are selected by any player. State 8 in Table 7 represents the state where MoE decides to modify the Control Order to make it more acceptable to UR (indicated by a “Y” beside that option), UR accepts the Control Order (a “Y” beside the “Accept” option and an “N” beside each of the remaining two), and the LG insists on the application of the original Control Order (a “Y” opposite the option “Insist”).

The preferences of all the decision makers over all the possible states are shown in Table 8. The states are ranked from the most preferred on the left to the least preferred on the right. MoE’s most preferred state is number 7 representing

<table>
<thead>
<tr>
<th>DM</th>
<th>Options</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td>MoE</td>
<td>Modify</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>–</td>
</tr>
<tr>
<td>UR</td>
<td>Delay</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>Accept</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>Abandon</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td>LG</td>
<td>Insist</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>–</td>
</tr>
</tbody>
</table>
Table 8
Preferences for each decision maker

<table>
<thead>
<tr>
<th></th>
<th>MoE</th>
<th>UR</th>
<th>LG</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>3</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>4</td>
<td>8</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td>8</td>
<td>5</td>
<td>3</td>
<td>7</td>
</tr>
<tr>
<td>5</td>
<td>9</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>6</td>
<td>9</td>
</tr>
<tr>
<td>2</td>
<td>6</td>
<td>4</td>
<td>2</td>
</tr>
</tbody>
</table>

the situation where under the pressure of LG, it does not modify the original Control Order and UR will accept it as is. For UR, the most preferred state is number 1 where it exercises its right of appeal with no action taken by both MoE and LG. For LG, the most preferred state is state number 7 which is actually the most preferred one for MoE. On the other hand, the least preferred state for both MoE and LG is state number 9 where UR will simply abandon its operations in Elmira. Likewise, the least preferred state for UR is state number 6 where LG will pressure MoE to apply the original Control Order while UR will exercise its right to appeal and MoE will accept to modify the original Control Order. In reality, it is difficult to satisfy the preferences of all the decision makers involved in a dispute and one needs to make a compromise to reach a stable state for all the players but not necessarily the most preferred by all of them.

Fig. 4 summarizes the entire Elmira Conflict in what is called an integrated graph model defined within the paradigm of the Graph Model for Conflict Resolution [18]. It shows all the decision makers (labels on the arrows), the feasible states (circled numbers), and the allowable moves by each decision maker between the different feasible states (directed arrows). For example, entries in Table 8 reveal that state 7 is the most preferred by both MoE and LG while for UR, state 7 is the third least preferred state. From this state, MoE can only move in one direction towards state 8 (irreversible move represented by a one-sided arrow). Likewise, UR can move from state 7 in an irreversible fashion to state 9. All of the moves in this diagram are irreversible with the exception of the moves by LG as all its moves are reversible.

Doing the analysis manually or using the Graph Model for Conflict Resolution software called GMCR II (see Refs. [19,20] for more details), the strongest equilibrium points are states 5, 8, and 9. States 5 and 8 are more preferred by all players to state 9. State 8 is more preferred by both MoE and UR to state 5. As depicted in Fig. 4, it is not possible for any of them to move from 5 to 8 on an individual basis. In order to do so, UR needs to move first to state 7, which is less preferred by UR, and, subsequently, MoE can move from state 7 to state 8. In case MoE does not move to state 8, UR will end up in a less preferred situation and might need to abandon its entire operations in Elmira.

Table 9 shows the evolution of the Elmira conflict from the status quo, to a transitional non-cooperative equilibrium and ultimately to a final cooperative coalition equilibrium. The status quo is state number 1 which is the most preferred state for UR but less preferred by both MoE and LG. As indicated by the arrow connecting states 1 and 5 in Table 9,
LG can unilaterally cause the conflict to move from states 1 to 5 by changing its strategy from not insisting that the original Control Order be adopted to insisting that it be applied. In fact, because LG prefers state 5 to 1 (see the third row in Table 8), this change in state constitutes a unilateral improvement for LG. Though state number 5 is not the most preferred for both MoE and LG, it is still more preferred than state number 1. From state number 5, it is not possible for any player to improve unilaterally. In order to move from state 5 to state 8, two players, MoE and UR, need to move together. This requires moving to an intermediate state: either 6 or 7. If MoE initiates the move, then the intermediate state is 6. Since state 6 is less preferred by UR compared to state 8, it is natural that UR wants to move jointly with MoE to directly reach state 8. If UR initiates the move from state 5, then the intermediate state is state 7 which is the most preferred state for MoE. Accordingly, for the coalition consisting of MoE and UR to jointly improve from states 5 to 8, the decision makers must trust one another.

As explained above, if UR moves from state 5 without the participation of MoE, the less preferred state 7 will be formed, which happens to be MoE’s most preferred state. Hence, MoE has an incentive to remain at state 7 if it fools UR into trustingly moving to state 7. If it does not wish to abuse the trust required of UR, it will remain in the coalition and select its strategy such that state 8 is reached. Of course, both MoE and UR prefer state 8 to state 5 and this joint gain helps solidify trust and vice versa.

In the foregoing situation, both MoE and UR have an incentive not to carry out their obligation and move the coalition from the intermediate state 5 to the final state 8. Only if there is a minimum level of trust, will each execute its obligation and sacrifice individual benefits for a more preferred one by both (but might be less preferred for one when compared to the intermediate state). UR needs to calculate the trust index for both MoE and LG to ascertain if it is worth forming a coalition with any of them. To calculate the trust index between UR and MoE, using the information in Table 10 and employing Eq. (5), one obtains the fuzzy values for the main criteria as follows:

- trust = (0.371, 0.568, 0.845, 1.240),
- circumstances = (0.460, 0.650, 0.862, 1.130),
- judgment = (0.560, 0.800, 1.125, 1.428).

Computing the fuzzy attractiveness value using Eq. (5), one obtains: FAR = (0.325, 0.598, 1.062, 1.810).

By using Eq. (6), the Euclidean distance from FAR to each member in set LT at $\alpha$-cut = 0 is calculated to be:

- $D(FAR, L) = 1.837$,
- $D(FAR, FL) = 1.503$,
- $D(FAR, M) = 1.209$,
- $D(FAR, FH) = 0.992$,
- $D(FAR, H) = 0.988$. 

<table>
<thead>
<tr>
<th>Table 9</th>
<th>Evolution of Elmira conflict</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Status Quo</td>
</tr>
<tr>
<td><strong>MoE</strong>: 1. Modify</td>
<td>N</td>
</tr>
<tr>
<td><strong>UR</strong>: 2. Delay</td>
<td>Y</td>
</tr>
<tr>
<td>3. Accept</td>
<td>N</td>
</tr>
<tr>
<td>4. Abandon</td>
<td>N</td>
</tr>
<tr>
<td><strong>LG</strong>: 5. Insist</td>
<td>N</td>
</tr>
<tr>
<td>State Number</td>
<td>1</td>
</tr>
</tbody>
</table>
Table 10
Trust index for UR with MoE

<table>
<thead>
<tr>
<th>Sub-criteria</th>
<th>Fuzzy values</th>
<th>Fuzzy weights</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trust</td>
<td>(0.9, 1.0, 1.0, 1.0; 1.0)</td>
<td>(0.7, 0.8, 0.9, 1.0; 1.0)</td>
</tr>
<tr>
<td>Risk</td>
<td>(0.6, 0.7, 0.8, 0.9; 1.0)</td>
<td>(0.7, 0.8, 0.9, 1.0; 1.0)</td>
</tr>
<tr>
<td>Uncertainty</td>
<td>(0.6, 0.7, 0.8, 0.9; 1.0)</td>
<td>(0.7, 0.8, 0.9, 1.0; 1.0)</td>
</tr>
<tr>
<td>Common goals</td>
<td>(0.4, 0.5, 0.6, 0.7; 1.0)</td>
<td>(0.5, 0.6, 0.7, 0.8; 1.0)</td>
</tr>
<tr>
<td>Shared values</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Circumstances</td>
<td>(0.7, 0.8, 0.9, 1.0; 1.0)</td>
<td>(0.7, 0.8, 0.9, 1.0; 1.0)</td>
</tr>
<tr>
<td>Importance</td>
<td>(0.6, 0.7, 0.8, 0.9; 1.0)</td>
<td>(0.9, 1.0, 1.0, 1.0; 1.0)</td>
</tr>
<tr>
<td>Value</td>
<td>(0.4, 0.5, 0.6, 0.7; 1.0)</td>
<td>(0.7, 0.8, 0.9, 1.0; 1.0)</td>
</tr>
<tr>
<td>Alternatives</td>
<td>(0.8, 0.9, 1.0, 1.0; 1.0)</td>
<td>(0.7, 0.8, 0.9, 1.0; 1.0)</td>
</tr>
<tr>
<td>Judgment</td>
<td>(0.5, 0.6, 0.7, 0.8; 1.0)</td>
<td>(0.7, 0.8, 0.9, 1.0; 1.0)</td>
</tr>
<tr>
<td>Attractiveness</td>
<td>(0.8, 0.9, 1.0, 1.0; 1.0)</td>
<td>(0.7, 0.8, 0.9, 1.0; 1.0)</td>
</tr>
<tr>
<td>Feelings and Emotions</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

From these calculations, one concludes that the trust index between UR and MoE is high.

To calculate the trust index between UR and LG, using the information in Table 11 employing Eq. (5), one obtains the fuzzy values for main criteria as follows:

- trust = (0.307, 0.488, 0.745, 1.120),
- circumstances = (0.260, 0.407, 0.577, 0.826),
- judgment = (0.140, 0.267, 0.450, 0.714).

Computing the fuzzy attractiveness value using Eq. (5), one obtains: FAR = (0.165, 0.344, 0.665, 1.265).

By using Eq. (6), the Euclidean distance from FAR to each member in set LT at $\alpha$-cut = 0 is calculated to be:

- $D$(FAR, L) = 1.110,
- $D$(FAR, FL) = 0.811,
- $D$(FAR, M) = 0.634,
- $D$(FAR, FH) = 0.684,
- $D$(FAR, H) = 0.945.

From these calculations, one concludes that the trust index between UR and LG is medium.

Table 11
Trust index for UR with LG

<table>
<thead>
<tr>
<th>Sub-criteria</th>
<th>Fuzzy values</th>
<th>Fuzzy weights</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trust</td>
<td>(0.9, 1.0, 1.0, 1.0; 1.0)</td>
<td>(0.7, 0.8, 0.9, 1.0; 1.0)</td>
</tr>
<tr>
<td>Risk</td>
<td>(0.4, 0.5, 0.6, 0.7; 1.0)</td>
<td>(0.7, 0.8, 0.9, 1.0; 1.0)</td>
</tr>
<tr>
<td>Uncertainty</td>
<td>(0.4, 0.5, 0.6, 0.7; 1.0)</td>
<td>(0.7, 0.8, 0.9, 1.0; 1.0)</td>
</tr>
<tr>
<td>Common goals</td>
<td>(0.6, 0.7, 0.8, 0.9; 1.0)</td>
<td>(0.5, 0.6, 0.7, 0.8; 1.0)</td>
</tr>
<tr>
<td>Shared values</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Circumstances</td>
<td>(0.7, 0.8, 0.9, 1.0; 1.0)</td>
<td>(0.7, 0.8, 0.9, 1.0; 1.0)</td>
</tr>
<tr>
<td>Importance</td>
<td>(0.4, 0.5, 0.6, 0.7; 1.0)</td>
<td>(0.9, 1.0, 1.0, 1.0; 1.0)</td>
</tr>
<tr>
<td>Value</td>
<td>(0.4, 0.5, 0.6, 0.7; 1.0)</td>
<td>(0.7, 0.8, 0.9, 1.0; 1.0)</td>
</tr>
<tr>
<td>Alternatives</td>
<td>(0.2, 0.3, 0.4, 0.5; 1.0)</td>
<td>(0.7, 0.8, 0.9, 1.0; 1.0)</td>
</tr>
<tr>
<td>Judgment</td>
<td>(0.5, 0.6, 0.7, 0.8; 1.0)</td>
<td>(0.7, 0.8, 0.9, 1.0; 1.0)</td>
</tr>
<tr>
<td>Attractiveness</td>
<td>(0.2, 0.3, 0.4, 0.5; 1.0)</td>
<td>(0.7, 0.8, 0.9, 1.0; 1.0)</td>
</tr>
<tr>
<td>Feelings and Emotions</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Given the preferences for each decision maker and by comparing the two trust indices, one can envision UR trusting MoE and, hence, forming a coalition with MoE is more promising than forming one with the LG.

In reality, UR formed a coalition with MoE and accepted the Control Order and at the same time the MoE modified it to be more favorable to UR though such an action is not accepted by LG. This coalition between MoE and UR caused the game to move from state 5 to state 8 [28].

8. Conclusions

The foregoing analysis for Prisoners’ Dilemma shows the effectiveness of the fuzzy approach in modeling trust characteristics of players that other approaches fail to accomplish on their own. More specifically, the fuzzy approach to trust complements and strengthens the arguments that stability results may suggest as to when it is in players’ interests to form coalitions in order to benefit coalition members. For example, even though all coalition members may fare better within a coalition, one or more coalition members may still be tempted to act independently because they think they may gain even more if they behave selfishly. The famous game of Prisoner’s Dilemma and the real-world environmental conflict are employed to illustrate and explain how trust can provide useful insights about human behavior under conflict.

The fuzzy approach to trust adds a more realistic dimension to the study of conflict by capturing how the players would think and behave in a situation in which a decision to cooperate is to be made. It also shows the strong relationship between trust and cooperative actions and how one’s strategy choices change realizing the fact that one is being trusted or trusting the other party. Generally speaking, one could say that the presence of complete distrust will eliminate any chance for cooperation. In the Elmira conflict, the idea of coalition analysis gives a partial answer to the question of whether to cooperate or not. While the coalition analysis highlights the possible improvements by forming a coalition, it does not give a full answer on how and why the coalition will form nor which coalitions will take place. Through the use of the fuzzy approach and the introduction of the concept of trust among coalition members, this research provides an answer to these questions.

References


[34] M. Mares, Fuzzy Cooperative Games, Physica-Verlag, Germany, 2001.


