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A mathematical model with flexible negotiation strategies for agent based negotiations in dynamic e-commerce environments

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Abstract In this paper, a mathematical model with flexible negotiation strategies for agent based negotiations is developed which can be applied suitably in bilateral/multilateral multi-issue negotiation environments. Unlike the existing approaches for offer value computation for the negotiation issues, this model considers not only the reservation values but also the offer values proposed in the preceding negotiation round. This approach for offer value computation enables the traders to reach consensus much quicker than the existing approaches. This model considers the compelling urge of the trader in buying/selling a product based on which the reservation values are adjusted automatically at the end of the negotiation process in order to reach consensus in a deal which is otherwise not possible. The formula devised in this model to determine the concession speed of each negotiation issue handles the dynamicity of the negotiation environment and reflects the importance of each negotiation issue from the traders' perspective. The effectiveness of the proposed strategies is evaluated using various hypothetical cases representing the real-world negotiation scenarios in an e-commerce environment. The test results show that the proposed negotiation strategies are able to optimize the utility process and also improve the rate of reaching consensus in the negotiation process.

1. Introduction

In the current scenario, business transactions have become unthinkable without Internet services, thanks to its cheaper cost and wide bandwidth availability. It becomes inevitable for any business to embrace e-services to exploit the advantages of internet technologies in order to survive in the competitive market. The development of e-shopping portals transformed the traditional way of buying and selling goods into a more convenient, cost and time saving benefits for both

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buyers and sellers. e-Commerce encompasses a broad range of issues including security, trust, reputation, law, payment mechanisms, advertising, ontologies, on-line catalogues, and back-office management. Agent technologies can be applied to any of these areas where a personalized, continuously running, semi-autonomous behaviour is desirable (Guttman et al., 1998). A software agent is a computational entity which perceives, acts upon its environment and is autonomous in its behaviour (Weiss, 1999). Negotiation in e-commerce domain is an emerging topic of research. There are a considerable number of research works being carried out in designing automated negotiators capable of making autonomous decisions depending upon the prevailing e-market situations. Design of automated negotiators involves three major operations such as identifying the negotiation objects, defining the negotiation protocols, and devising the agent's decision making models (Jennings et al., 2001). The negotiating agents are capable of exchanging proposals, evaluating proposals, and also accepting or rejecting proposals to reach mutual deals (Chen and Huang, 2009). Faratin et al. (1998) named the sequence of offers and counter-offers in a two-party negotiation as a *negotiation thread* and also proposed to implement multi-party, many issues negotiations as multiple concurrent threads.

Sim and Wang (2004) designed negotiation agents that employ fuzzy rules to provide flexibility in making concessions to reflect the changing market conditions. He and Jennings (2004) proposed the design of intelligent bidding agent that uses fuzzy techniques to make bidding decisions in the face of uncertainty, to make predictions about the likely outcomes of auctions, and to alter the agent's bidding strategy in response to the prevailing market conditions. Matos et al. (1998) adopted an evolutionary approach by mapping the strategies and tactics to the genetic material in a genetic algorithm and showed the relative success of different strategies against different types of opponents in different environments. Lau et al. (2008) proposed a negotiation knowledge discovery method based upon non-parametric approach that supports multi-party many-issue negotiation situations in dynamic negotiation environment and a probabilistic negotiation decision making mechanism to improve the performance of negotiation agents.

Narayanan and Jennings (2005) developed a negotiation model that can adapt the agent's strategy in response to resources availability and variation in negotiation parameters. Kwon (2009) proposed a two-step approach for bilateral multi-attribute consensus formation by developing an algorithm based on collaborative learning theory at step one to recognize the negotiation feasible space and then reducing the time taken for optimization at step two. Ren et al. (2009) extended Market-Driven Agents (MDA) negotiation models by designing agent negotiation strategies that are capable of making adjustable rates of concession in an open and dynamic negotiation environment.

Wang and Wong (2013) proposed a three-staged adaptive negotiation behaviour configuration mechanism to tackle the negotiation dynamics and provided a computational model to organize agent-based e-commerce negotiations with adaptive negotiation behaviours. Ren and Zhang (2014) proposed a negotiation model to dynamically modify agents' negotiation behaviours based upon the changes in the number of participants in the e-market and the agents' motivation on accomplishment of a negotiation.

Liang et al. (2012) have developed a methodology to appraise the performance of intelligent agents and demonstrate the use in the B2C e-commerce negotiation process. Baarslag et al. (2011) summarized the result of ANAC 2011 competition which aims to advance the state-of-the-art in the area of practical bilateral multi-issue negotiations, and to encourage the design of agents that are able to operate effectively across a variety of negotiation scenarios. Chen and Weiss (2015) proposed a negotiation approach called OMAC*, the decision making component of which adaptively adjusts its utility expectations and negotiation moves by enabling the agents to efficiently model opponents in real-time through discrete wavelet transformation and non-linear regression with the Gaussian processes. OMAC* outperformed the top agents from ANAC 2012, 2011 and 2010 in a broad range of negotiation scenarios. Patrikar et al. (2015) proposed a multilateral automated negotiation system based upon linear programming and pattern matching techniques that outperforms negotiation systems based upon fuzzy inference logic, multithreading, linear programming and genetic algorithm.

Deployment of automated negotiators in e-commerce transactions greatly reduces the human efforts and time consumed. The design of automated negotiators involve the consideration of various issues including the number of parties – bilateral or multilateral (one buyer/one seller, one buyer/many sellers, many buyers/one seller, many buyers/many sellers) involved in the negotiation process, the number of negotiation issues (price, date of delivery, warranty, etc) on which mutual agreements are to be achieved, the number of negotiation rounds – fixed/variable and partial/complete/no knowledge on opponents negotiation strategies and priorities. As the real e-market is dynamic in nature, an automated negotiator embedded with fixed negotiation scheme cannot outperform well compared to the ones that are capable of adopting flexible negotiation schemes depending upon the current e-market situation in order to emerge as the ultimate winner.

In this paper, a mathematical model with the flexible negotiation strategies is being devised which can be applied to generate proposals/counter proposals basically in bilateral (one buyer – one seller) single-issue/multi-issue negotiation environments. In case of multilateral negotiation environments where there could be one-to-many, many-to-one, many-to-many buyer/seller combinations, the same model can be applied to generate required number of proposals/counter proposals simultaneously on a one-to-one basis. Flexibility in the proposed negotiation strategy is also achieved by making it suitable for the negotiation environments that are based on either a specific time limit or a number of negotiation rounds. The remaining content of the paper is organized as follows: Section 2 introduces the mathematical model for the agent based negotiation strategies. Section 3 illustrates the effectiveness of the proposed strategies with hypothetical cases representing real world trading environment. Section 4 concludes the paper by identifying the future direction of further research.

2. Mathematical model with flexible negotiation strategies

Bilateral negotiations in an e-commerce environment involve two parties: a buyer and a seller. The negotiation begins when either the buyer/seller makes a proposal for the product to buy/sell. The given proposal will be evaluated by the opponent and it will be either accepted or the opponent will generate a counter proposal. This process will continue until both the parties reach consensus or the time elapses.

2.1. Significant features of the proposed model

The proposed model has the following significant features:

- It enables the traders to simultaneously involve in the negotiation process of buying/selling a collection of distinct products.
- It enables the traders to negotiate on a number of issues such as price, delivery time, warranty, etc. of the product to buy/sell.
- It enables the traders to assign weights for each negotiation issue under consideration representing their relative importance during the negotiation process.
- It enables the traders to choose a range of acceptable values for each of the negotiation issue under consideration which are termed as 'reservation values'.
- It also takes into account the compelling urge of the trader in buying/selling a product which is used in adjusting the offer values in order to complete the deal.
- It generates proposals/counter proposals which contain offer values for each negotiation issue.
- It identifies a suitable offer value for each issue from among the reservation values for making a proposal/counter proposal depending upon the negotiation environment.
- It exclusively defines a parameter to determine the concession speed of each negotiation issue. This parameter handles the dynamicity of the negotiation environment (demand/supply ratio of a particular product) and reflects the importance of each negotiation issue from the traders' perspective.
- It proposes negotiation strategies that are suitable for negotiation environments based upon a specific time limit or a number of negotiation rounds.
- It determines the benefit of the proposed offer/counter offer value of each negotiation issue by computing a numerical score for it.
- It evaluates a proposal/counter proposal by computing a numerical score for it.
- It distinguishes between cost type and benefit type issues as the objective of the buyer is to minimize the cost and maximize the benefit and vice versa for the seller. According to the type of issue, the scores are computed in order to optimize the utility of the trader.
- Depending upon the compelling urge of the trader to buy/sell the product, the model adjusts the maximum acceptable value for cost type issues and minimum acceptable value for benefit type issues of the buyer and vice versa for the seller.
- The modified reservation values are applied only at the end of the negotiation process in order to verify the possibility of reaching consensus.

2.2. Notations used in the proposed model

i. $\{P_i\}_{i=1}^{n}$ – The list of n products $\{P_1, P_2, P_3, \ldots\}$ to buy/sell.

ii. $\{P_i^j\}_{j=1}^{m}$ – The list of m issues of product P_i such as $\{P_1^{Price}, P_1^{Warranty}, P_1^{leadtime}, \ldots\}$ on which negotiation is to be carried out.

iii. $\{W_i^j\}_{j=1}^{m}$ – The list of weights assigned to m negotiation issues of product P_i indicating their relative importance. It is assumed that the sum of all weights is equal to1.

$$\sum_{j=1}^{m} W_i^j = 1$$

iv. $\{min(P_i^j), max(P_i^j)\}_{j=1}^{m}$ – The list of reservation values (range of acceptable values) preferred for the m negotiation issues of product P_i.

v. $\{pap_i^j\}_{j=1}^{m}$ – The compelling urge of the trader to buy/sell the product P_i is indicated by a percentage termed as Preference Adjustment Percentage (pap) which can be used to modify the reservation values of each negotiation issue j in order to reach an agreement.

vi. c_i^j – A positive real number, the value of which determines the concession speed of issue j of product P_i. When $c_i^j \ll 1$, the concession rate is very high initially and then gradually reduces and when $c_i^j \gg 1$, the concession rate is very low initially and then gradually increases.

$$\left.\begin{aligned} c_i^j &= \left(\frac{\textit{No. of Sellers}}{\textit{No. of Buyers}}\right) + W_i^j, \quad \textit{at Buyer end} \\ c_i^j &= \left(\frac{\textit{No. of Buyers}}{\textit{No. of Sellers}}\right) + W_i^j, \quad \textit{at Seller end} \end{aligned}\right\} \tag{1}$$

This formula is devised to handle the dynamicity of the negotiation environment and to reflect the importance of each negotiation issue from the trader's perspective.

vii. $N_t^{B\to S}(P_i)$ – Negotiation of the Buyer Agent (B) with the Seller Agent (S) for the product P_i at time/negotiation round t which contains offer values for a list of m issues under consideration.

viii. $CN_t^{S\to B}(P_i)$ – Counter Negotiation of S to B for the one submitted at time/negotiation round t.

ix. $x_t^{B\to S}(P_i^j)$ – An offer value computed by B for the issue j of product P_i from the range of its acceptable values for submission to S at t.

x. $x_t^{S\to B}(P_i^j)$ – Counter offer value computed by S for submission to B for issue j of product P_i at t.

xi. $NS(x_t^{B\to S}(P_i^j))$ – Numerical Score of the offer value $x_t^{B\to S}(P_i^j)$.

xii. $NS(x_t^{S\to B}(P_i^j))$ – Numerical Score of the counter offer value $x_t^{S\to B}(P_i^j)$.

xiii. $NSP_t^{B\to S}$ – Numerical Score of the proposal $N_t^{B\to S}(P_i)$.

xiv. $NSP_t^{S\to B}$ – Numerical Score of the counter proposal $CN_t^{S\to B}(P_i)$

2.3. Formulating and evaluating proposals/counter proposals of both buyer and seller

2.3.1. Buyer's initial proposal

As the objective of the buyer is to minimize the cost and maximize the benefit during the negotiation process, the offer values for the various negotiation issues are computed depending upon their type in order to optimize the utility of the buyer.

$$N^{B\to S}(P_i^t) = \{x_t^{B\to S}(P_i^j)\}_{j=1}^{m} \quad (2)$$

where

$$x_t^{B\to S}(P_i^j) = min(P_i^j) + K_t(max(P_i^j) - min(P_i^j)) \quad \text{(For cost type issues)} \quad (3)$$

$$x_t^{B\to S}(P_i^j) = max(P_i^j) - K_t(max(P_i^j) - min(P_i^j)) \quad \text{(For benefit type issues)} \quad (4)$$

where $K_t = (t/r)^{c_i^j}$ if the negotiation environment is based upon a number of negotiation rounds.

t – Current negotiation round; r – Total No. of negotiation rounds;

Otherwise $K_t = \left(\frac{t_{end}-t}{t_{tot}}\right)^{c_i^j}$ if the negotiation environment is based upon a specific time limit.

t_{end} – Closing time of the negotiation process.
t_{tot} – Total time duration of the negotiation process.
t – Current time in the negotiation process.

2.3.2. Buyer's subsequent proposal

$$x_t^{B\to S}(P_i^j) = x_{t-1}^{B\to S}(P_i^j) + K_t(max(P_i^j) - x_{t-1}^{B\to S}(P_i^j)) \quad \text{(For cost type issues)} \quad (5)$$

$$x_t^{B\to S}(P_i^j) = x_{t-1}^{B\to S}(P_i^j) - K_t(x_{t-1}^{B\to S}(P_i^j) - min(P_i^j)) \quad \text{(For benefit type issues)} \quad (6)$$

2.3.3. Computation of numerical score of Buyer's proposal

$$NSP_t^{B\to S} = \sum_{j=1}^{m} NS(x_t^{B\to S}(P_i^j))W_i^j \quad (7)$$

where

$$NS(x_t^{B\to S}(P_i^j)) = \frac{\max(P_i^j) - x_t^{B\to S}(P_i^j)}{\max(P_i^j) - \min(P_i^j)} \quad \text{(For cost type issues)} \quad (8)$$

$$NS(x_t^{B\to S}(P_i^j)) = \frac{x_t^{B\to S}(P_i^j) - \min(P_i^j)}{\max(P_i^j) - \min(P_i^j)} \quad \text{(For benefit type issues)} \quad (9)$$

2.3.4. Computation of $NSP_{t_{end}}^{B\to S}$

Depending upon the compelling urge of the trader to buy a product, the maximum acceptable value is increased for cost type issues and minimum acceptable value is decreased for benefit type issues by a percentage (pap_i^j – preference adjustment percentage for each issue j of product P_i) indicated by the trader. This adjustment is done only at the end of the negotiation process in order to check the possibility of accepting the offer instead of rejecting it.

$$\max(P_i^j)_{t_{end}} = (1 + pap_i^j)\max(P_i^j) \quad \text{(For cost type issues)} \quad (10)$$

$$\min(P_i^j)_{t_{end}} = (1 - pap_i^j)\min(P_i^j) \quad \text{(For benefit type issues)} \quad (11)$$

$$x_{t_{end}}^{B\to S}(P_i^j) = x_{t_{end}-1}^{B\to S}(P_i^j) + K_{t_{end}}(\max(P_i^j)_{t_{end}} - x_{t_{end}-1}^{B\to S}(P_i^j)) \quad \text{(For cost type issues)} \quad (12)$$

$$x_{t_{end}}^{B\to S}(P_i^j) = x_{t_{end}-1}^{B\to S}(P_i^j) - K_{t_{end}}(x_{t_{end}-1}^{B\to S}(P_i^j) - min(P_i^j)t_{end}) \quad \text{(For benefit type issues)} \quad (13)$$

$$NS(x_{t_{end}}^{B\to S}(P_i^j)) = \frac{\max(P_i^j)_{t_{end}} - x_{t_{end}}^{B\to S}(P_i^j)}{\max(P_i^j)_{t_{end}} - \min(P_i^j)} \quad \text{(For cost type issues)} \quad (14)$$

$$NS(x_{t_{end}}^{B\to S}(P_i^j)) = \frac{x_{t_{end}}^{B\to S}(P_i^j) - \min(P_i^j)_{t_{end}}}{\max(P_i^j) - \min(P_i^j)_{t_{end}}} \quad \text{(For benefit type issues)} \quad (15)$$

$$NSP_{t_{end}}^{B\to S} = \sum_{j=1}^{m} NS(x_{t_{end}}^{B\to S}(P_i^j))W_i^j \quad (16)$$

2.3.5. Seller's initial proposal

As the objective of the seller is to maximize the cost and minimize the benefit during the negotiation process, the issue values for the various negotiation issues are computed depending upon their type in order to optimize the utility of the seller.

$$N_t^{S\to B}(P_i) = \{x_t^{S\to B}(P_i^j)\}_{j=1}^{m} \quad (17)$$

where

$$x_t^{S\to B}(P_i^j) = max(P_i^j) - K_t(max(P_i^j) - min(P_i^j)) \quad \text{(For cost type issues)} \quad (18)$$

$$x_t^{S\to B}(P_i^j) = min(P_i^j) + K_t(max(P_i^j) - min(P_i^j)) \quad \text{(For benefit type issues)} \quad (19)$$

2.3.6. Seller's subsequent proposal

$$x_t^{S\to B}(P_i^j) = x_{t-1}^{S\to B}(P_i^j) - K_t(x_{t-1}^{S\to B}(P_i^j) - min(P_i^j)) \quad \text{(For cost type issues)} \quad (20)$$

$$x_t^{S\to B}(P_i^j) = x_{t-1}^{S\to B}(P_i^j) + K_t(max(P_i^j) - x_{t-1}^{S\to B}(P_i^j)) \quad \text{(For benefit type issues)} \quad (21)$$

2.3.7. Computation of numerical score of Seller's proposal

$$NSP_t^{S\to B} = \sum_{j=1}^{m} NS(x_t^{S\to B}(P_i^j))W_i^j \quad (22)$$

Table 1 Preferences of the Buyer/Seller over the negotiation issues Price and Warranty.

	Buyer's preferences					Seller's preferences				
Issue	min	max	weight	pap	c	min	max	weight	pap	c
Price	200	300	0.8	0.2	1.8	250	400	0.7	0.3	1.7
Warranty	30	48	0.2	0.2	1.2	24	36	0.3	0.2	1.3

Table 2 Description of the Negotiation algorithm with the hypothetical data.

	Algorithm Steps at Compile Time	**Algorithm Steps at Run Time**
INITIALIZATION	Buyer Agent B reads the required input from the buyer: $\{P_i\}_{i=1}^{n}, \{P_i^j\}_{j=1}^{m},$, $\{max(P_1^{warranty}), min(P_1^{warranty})\}$, $\{w_1^{price}, w_1^{warranty}\}$, $\{pap_1^{price}, pap_1^{warranty}\}$	$\{P_i\}_{i=1}^{n} = \{\boldsymbol{P_1}\}$, $\{P_i^j\}_{j=1}^{m} = \{\boldsymbol{price}, \boldsymbol{warranty}\}$, $\{max(P_1^{price}), min(P_1^{price})\} = \{\mathbf{200}, \mathbf{300}\}$, $\{max(P_1^{warranty}), min(P_1^{warranty})\} = \{\mathbf{36}, \mathbf{48}\}$, $\{w_1^{price}, w_1^{warranty}\} = \{\mathbf{0.8}, \mathbf{0.2}\}$ $\{pap_1^{price}, pap_1^{warranty}\} = \{\mathbf{0.2}, \mathbf{0.2}\}$
	B computes values for $\{c_1^{price}, c_1^{warranty}\}$ using **Eq-1**. It also identifies the value of t_{tot} or r.	$\{c_1^{price}, c_1^{warranty}\} = \{\mathbf{1.8}, \mathbf{1.2}\};$ $r = \mathbf{10};\ t = \mathbf{1};$
	B generates initial negotiation, $N_1^{B\to S}(P_1) = \Big\{min(P_1^{price}) + \left(\frac{t}{r}\right)^c \left(max(P_1^{price}) - min(P_1^{price})\right),\ max(P_1^{warranty}) - \left(\frac{t}{r}\right)^c \left(max(P_1^{warranty}) - min(P_1^{warranty})\right)\Big\}$	$N_1^{B\to S}(P_1) = \begin{Bmatrix} 200 + \left(\frac{1}{10}\right)^{1.8} * (300 - 200), \\ 48 - \left(\frac{1}{10}\right)^{1.2} * (48 - 30) \end{Bmatrix}$ $= \{\mathbf{201.58}, \mathbf{46.86}\}$
t = 1	B receives counter negotiation from S: $CN_1^{S\to B}(P_1)$	$CN_1^{S\to B}(P_1) = \{\mathbf{397.01}, \mathbf{24.60}\}$
	B computes the numerical score of S's counter proposal: $NSP_1^{S\to B} = \sum_{i=1}^{n} NS\left(x_t^{S\to B}(P_i^j)\right) W_i^j = NS\left(x_t^{S\to B}(P_1^{price})\right) * W_1^{price} + NS\left(x_t^{S\to B}(P_1^{warranty})\right) * W_1^{warranty}$	$\boldsymbol{NS\left(x_1^{S\to B}(P_1^{price})\right)} = \frac{\max(P_1^{price}) - x_t^{S\to B}(P_1^{price})}{\max(P_1^{price}) - \min(P_1^{price})} = (300 - 397.01)/(300 - 200) = \mathbf{-0.97}$ $\boldsymbol{NS\left(x_1^{S\to B}(P_1^{warranty})\right)} = \frac{x_1^{S\to B}(P_1^{warranty}) - \min(P_1^{warranty})}{\max(P_1^{warranty}) - \min(P_1^{warranty})} = (24.60 - 30)/(48 - 30) = \mathbf{-0.3}$ $\boldsymbol{NSP_1^{S\to B}} = -0.97 * 0.8 + -0.3 * 0.2 = \mathbf{-0.84}$

Table 2 (*continued*)

	B does the following assessments: i. If $t = t_{end}\ or\ t = r$ then compute $NSP^{B\to S}_{t_{end}}$. a) If $NSP^{S\to B}_{t} \geq NSP^{B\to S}_{t_{end}}$, then accept the offer. b) Else reject the offer. ii. Else, generate $N^{B\to S}_{2}(P_1)$. a) If $NSP^{S\to B}_{1} \geq NSP^{B\to S}_{2}$, then accept the offer. b) Else, submit $N^{B\to S}_{t+1}(P_i)$, t=t+1;	i. $t \neq r$ ii. $\boldsymbol{N^{B\to S}_{2}(P_1)} = \{x^{B\to S}_1(P^{price}_1) + K_2\left(max(P^{price}_1) - x^{B\to S}_1(P^{price}_1)\right), x^{B\to S}_1(P^{warranty}_1) - K_2\left(x^{B\to S}_1(P^{warranty}_1) - min(P^{warranty}_1)\right)\}$ $= \begin{Bmatrix} 201.58 + \left(\frac{2}{10}\right)^{1.8} * (300 - 201.58), \\ 46.86 - \left(\frac{2}{10}\right)^{1.2} * (46.86 - 30) \end{Bmatrix}$ $\boldsymbol{N^{B\to S}_{2}(P_1)} = \{\mathbf{207.02, 44.42}\}$ $\boldsymbol{NSP^{B\to S}_{2}} = \left(\frac{300-207.02}{300-200}\right) * 0.8 + \left(\frac{44.42-30}{48-30}\right) * 0.2$ $= 0.74 + 0.16 = \mathbf{0.9}$ If $NSP^{S\to B}_{1} \geq NSP^{B\to S}_{2}$(condition false) $\therefore Submit\ \ N^{B\to S}_{2}(P_1)$, t = t+1 = 2;
t = 2	B receives counter negotiation from S: $CN^{S\to B}_{2}(P_1)$	$CN^{S\to B}_{2}(P_1) = \{\mathbf{387.48, 26.01}\}$
	B generates $N^{B\to S}_{3}(P_1)$ and computes $NSP^{B\to S}_{3}$ and $NSP^{S\to B}_{2}$	$N^{B\to S}_{3}(P_1) = \{\mathbf{217.66, 41.02}\}$ $NSP^{B\to S}_{3} = \mathbf{0.78}$ $NSP^{S\to B}_{2} = \mathbf{-0.7}$ If $NSP^{S\to B}_{2} \geq NSP^{B\to S}_{3}$(condition false) $\therefore Submit\ \ N^{B\to S}_{3}(P_1)$, t = t+1 = 3;
t = 3	B receives counter negotiation from S: $CN^{S\to B}_{3}(P_1)$	$CN^{S\to B}_{3}(P_1) = \{\mathbf{369.72, 28.1}\}$
	B generates $N^{B\to S}_{4}(P_1)$ and computes $NSP^{B\to S}_{4}$ and $NSP^{S\to B}_{3}$	$N^{B\to S}_{4}(P_1) = \{\mathbf{233.49, 37.35}\}$ $NSP^{B\to S}_{4} = \mathbf{0.61}$ $NSP^{S\to B}_{3} = \mathbf{-0.58}$ If $NSP^{S\to B}_{3} \geq NSP^{B\to S}_{4}$(condition false)

Table 2 (*continued*)

		$\therefore Submit\ N_4^{B\to S}(P_1)$, t = t+1 = 4;
t = 4	B receives counter negotiation from S: $CN_4^{S\to B}(P_1)$	$CN_4^{S\to B}(P_1) = \{\mathbf{344.51, 30.5}\}$
	B generates $N_5^{B\to S}(P_1)$ and computes $NSP_5^{B\to S}$ and $NSP_4^{S\to B}$	$N_5^{B\to S}(P_1) = \{\mathbf{252.59, 34.15}\}$ $NSP_5^{B\to S} = \mathbf{0.43}$ $NSP_4^{S\to B} = \mathbf{-0.35}$ If $NSP_4^{S\to B} \geq NSP_5^{B\to S}$(condition false) $\therefore Submit\ N_5^{B\to S}(P_1)$, t = t+1 = 5;
t = 5	B receives counter negotiation from S: $CN_5^{S\to B}(P_1)$	$CN_5^{S\to B}(P_1) = \{\mathbf{315.42, 32.73}\}$
	B generates $N_6^{B\to S}(P_1)$ and computes $NSP_6^{B\to S}$ and $NSP_5^{S\to B}$	$N_6^{B\to S}(P_1) = \{\mathbf{271.49, 31.9}\}$ $NSP_6^{B\to S} = \mathbf{0.25}$ $NSP_5^{S\to B} = \mathbf{-0.09}$ If $NSP_5^{S\to B} \geq NSP_6^{B\to S}$(condition false) $\therefore Submit\ N_5^{B\to S}(P_1)$, t = t+1 = 6;
t = 6	B receives counter negotiation from S: $CN_6^{S\to B}(P_1)$	$CN_6^{S\to B}(P_1) = \{\mathbf{287.97, 34.41}\}$
	B generates $N_7^{B\to S}(P_1)$ and computes $NSP_7^{B\to S}$ and $NSP_6^{S\to B}$	$N_7^{B\to S}(P_1) = \{\mathbf{286.49, 30.66}\}$ $NSP_7^{B\to S} = \mathbf{0.12}$ $NSP_6^{S\to B} = \mathbf{0.15}$ If $NSP_6^{S\to B} \geq NSP_7^{B\to S}$(condition true) $\therefore \boldsymbol{Buyer\ accepts\ the\ offer\ CN_6^{S\to B}(P_1)}$ $= \{\mathbf{287.97, 34.41}\}$

where

$$NS(x_t^{S\to B}(P_i^j)) = \frac{x_t^{S\to B}(P_i^j) - \min(P_i^j)}{\max(P_i^j) - \min(P_i^j)} \quad \text{(For cost type issues)} \tag{23}$$

$$NS(x_t^{S\to B}(P_i^j)) = \frac{\max(P_i^j) - x_t^{S\to B}(P_i^j)}{\max(P_i^j) - \min(P_i^j)} \quad \text{(For benefit type issues)} \tag{24}$$

2.3.8. Computation of $\boldsymbol{NSP_{t_{end}}^{S\to B}}$

$$\min(P_i^j)_{t_{end}} = (1 - pap_i^j)\min(P_i^j) \quad \text{(For cost type issues)} \tag{25}$$

$$\max(P_i^j)_{t_{end}} = (1 + pap_i^j)\max(P_i^j) \quad \text{(For benefit type issues)} \tag{26}$$

$$x_{t_{end}}^{S\to B}(P_i^j) = x_{t_{end}-1}^{S\to B}(P_i^j) - K_{t_{end}}(x_{t-1}^{S\to B}(P_i^j) - min(P_i^j)t_{end}) \quad \text{(For cost type issues)} \tag{27}$$

$$x_{t_{end}}^{S\to B}(P_i^j) = x_{t_{end}-1}^{S\to B}(P_i^j) + K_{t_{end}}(max(P_i^j)t_{end} - x_{t-1}^{S\to B}(P_i^j)) \quad \text{(For benefit type issues)} \tag{28}$$

$$NS(x_{t_{end}}^{S\to B}(P_i^j)) = \frac{x_{t_{end}}^{S\to B}(P_i^j) - \min(P_i^j)_{t_{end}}}{\max(P_i^j) - \min(P_i^j)_{t_{end}}} \quad \text{(For cost type issues)} \tag{29}$$

$$NS(x_{t_{end}}^{S\to B}(P_i^j)) = \frac{\max(P_i^j)_{t_{end}} - x_{t_{end}}^{S\to B}(P_i^j)}{\max(P_i^j)_{t_{end}} - \min(P_i^j)} \quad \text{(For benefit type issues)} \tag{30}$$

$$NSP_{t_{end}}^{S\to B} = \sum_{j=1}^{m} NS(x_{t_{end}}^{S\to B}(P_i^j))W_i^j \tag{31}$$

2.4. Algorithm for negotiation process (Buyer's Perspective)

1. Buyer Agent B reads values for $\{P_i\}_{i=1}^{n}, \{P_i^j\}_{j=1}^{m}, \{W_i^j\}_{j=1}^{m}$, $\{\langle min(P_i^j), max(P_i^j)\rangle\}_{j=1}^{m}$ and $\{pap_i^j\}_{j=1}^{m}$.
2. B computes the value of c_i^j and identifies the value of t_{tot} or r depending upon the negotiation environment.
3. B generates initial proposal $N_t^{B\to S}(P_i)$ and submits to the Seller Agent S.
4. B receives the counter proposal $CN_t^{S\to B}(P_i)$ from S and evaluates it by computing the numerical score $NSP_t^{B\to S}$ of Seller's counter proposal.
5. Buyer does the following assessments:
   i. If $t = t_{end} or t = r$ then compute $NSP_{t_{end}}^{B\to S}$.
      a) If $NSP_t^{S\to B} \geqslant NSP_{t_{end}}^{B\to S}$, then accept the offer.
      b) Else reject the offer.

   ii. Else, generate $N_{t+1}^{B\to S}(P_i)$.
      a) If $NSP_t^{S\to B} \geqslant NSP_{t+1}^{B\to S}$, then accept the offer.
      b) Else, submit $N_{t+1}^{B\to S}(P_i)$, t = t + 1; go to step 4.

2.5. Description of the negotiation algorithm with the hypothetical data

Here we consider a bilateral negotiation environment with a Buyer Agent B and a Seller Agent S. B is interested in buying a product P_1 by negotiating on the issues {Price, Warranty} with S. The preferences of the buyer and seller on the negotiation issues under consideration are given in Table 1. Table 2 demonstrates the step-by-step instruction in the negotiation algorithm using the hypothetical data given in Table 1.

3. Results & findings

In the conventional models, computation of offer values for each negotiation issue while generating proposals/counter proposals involve only the consideration of reservation values. But in the proposed model, the offer values for each negotiation issue in the subsequent proposals are computed by taking into consideration the offer values quoted in the preceding proposal. The offer values computed based upon our model and the conventional model for the negotiation issues 'Price' and 'Warranty' during a negotiation process with a maximum of 10 concession steps, i.e. r = 10, are shown in Table 3 and Table 4 respectively and the same data are projected in Figs. 1 and 2. From the empirical results, it is clear that our model helps the traders to reach consensus in the negotiation process much earlier than the conventional model and it also increases the utility of the traders.

Figs. 3 and 4 show the comparison between our model and conventional models in computation of offer values for the issues 'Price' and 'Warranty' respectively in a negotiation scenario with a maximum of 200 concession steps i.e. r = 200. From the results, it is clear that even with the increased no. of negotiation rounds, our model outperforms well when compared with the conventional models.

Figs. 5 and 6 show the comparison between our model and conventional models in computation of offer values for the issues 'Price' and 'Warranty' respectively when maintaining a fixed concession speed i.e. $c_i^j = 0.5$ for all the negotiation issues at both buyer and seller end. The experimental results prove that our model not only improves the utility of the traders but also helps them in reaching consensus much quicker than the conventional models.

The mathematical model proposed in this paper also uses a parameter called '*Preference Adjustment Percentage – pap*' to adjust the reservation values depending upon the compelling urge of the trader to buy/sell a product. This adjustment is done only at the end of the negotiation process to check the possibility of reaching consensus. Consider the reservation values of seller for the issues 'Price' and 'Warranty' as $\{350, 500\}$ and $\{18, 24\}$ respectively. In this case, the traders will not be able to reach consensus as per the conventional model. But the proposed model will adjust the reservation values as per the given '*pap*' during the final round and completes the deal. The offer values for the issues 'Price' and 'Warranty' are computed using Eqs. (12) and (13) in the final negotiation round and it is shown in Tables 5 and 6 respectively. It has been

Table 3 Offer value of Negotiation Issue – 'Price' – Our Model Vs Conventional Model.

Concession Steps	1	2	3	4	5	6	7	8	9	10
Negotiation Issue 'Price' – Our Model (Consensus reached at step 7)										
Buyer	201.58	207.02	217.66	233.49	252.59	271.49	**286.49**	295.53	299.23	300.00
Seller	397.01	387.48	369.72	344.51	315.42	287.97	267.26	255.45	250.89	250.00
Negotiation Issue 'Price' – Conventional Model (Consensus reached at step 9)										
Buyer	201.58	205.52	211.45	219.22	228.72	239.87	252.62	266.92	**282.72**	300.00
Seller	397.01	390.28	380.63	368.41	353.83	337.06	318.20	297.35	274.60	250.00

Table 4 Offer value of Negotiation Issue 'Warranty' – Our Model Vs Conventional Model.

Concession Steps	1	2	3	4	5	6	7	8	9	10
Negotiation Issue – Warranty – Our Model (Consensus reached at Step 5)										
Buyer	46.86	44.42	41.02	37.35	34.15	31.90	30.66	30.16	30.02	30.00
Seller	24.60	26.01	28.10	30.50	**32.73**	34.41	35.41	35.85	35.98	36.00
Negotiation Issue – Warranty – Conventional Model (Consensus reached at Step 8)										
Buyer	46.86	45.39	43.76	42.01	40.17	38.25	36.27	34.23	32.14	30.00
Seller	24.60	25.48	26.51	27.65	28.87	30.18	31.55	**32.98**	34.46	36.00

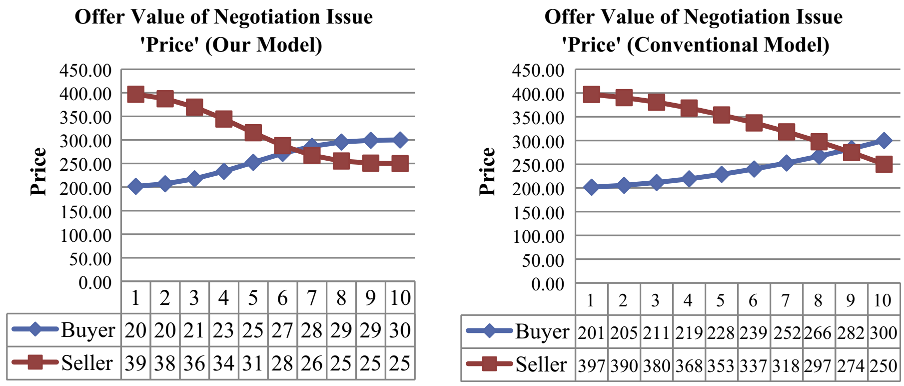

Figure 1 Offer value of Negotiation Issue 'Price' – Our Model Vs Conventional Model.

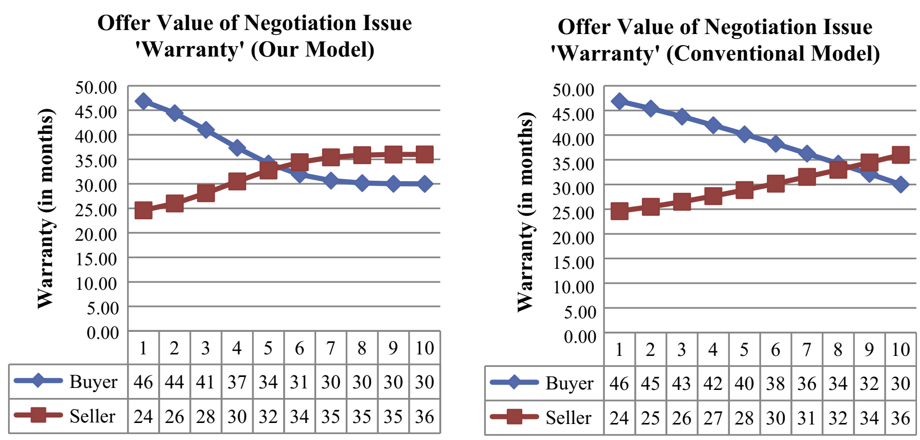

Figure 2 Offer value of Negotiation Issue 'Warranty' – Our Model Vs Conventional Model.

Figure 3 Offer value of Negotiation Issue 'Price' – Our Model Vs Conventional Model with r = 200.

proved that when applying the parameter 'pap', the traders are able to reach consensus which is otherwise not possible as shown in Figs. 7 and 8.

The buyer agent accepts or rejects a proposal by computing the numerical score of the seller's proposal and comparing it with the numerical score of its subsequent counter proposal. The numerical score of a proposal/counter proposal at the buyer end is computed using Eq. (7). If the numerical score of the seller's proposal is greater than or equal to that of the buyer's counter proposal then the proposal is accepted.

Figure 4 Offer value of Negotiation Issue 'Warranty' – Our Model Vs Conventional Model with r = 200.

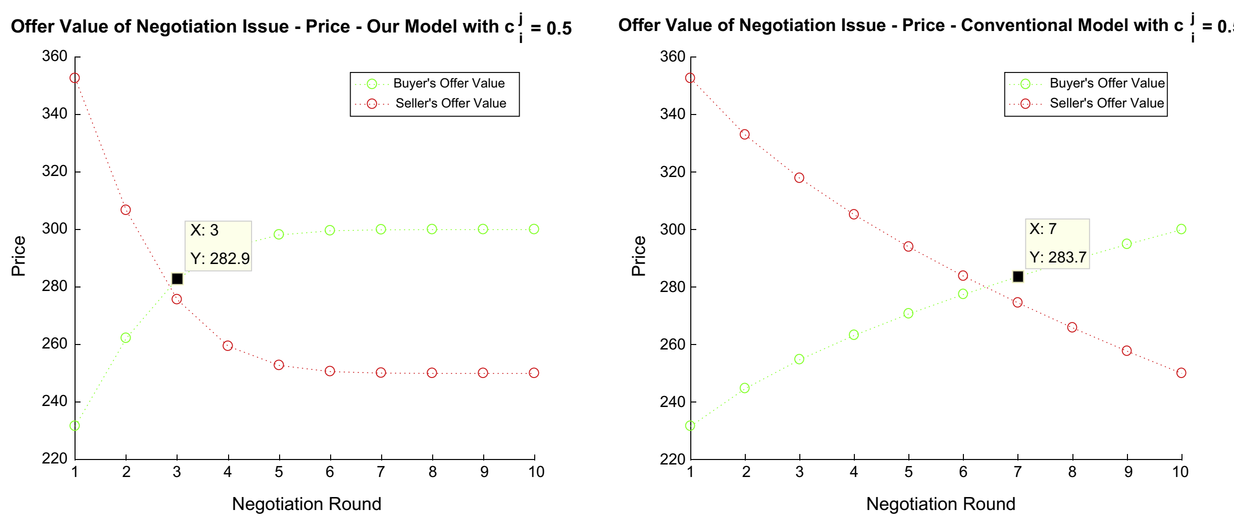

Figure 5 Offer value of Negotiation Issue 'Price' – Our Model Vs Conventional Model with $c_i^j = 0.5$.

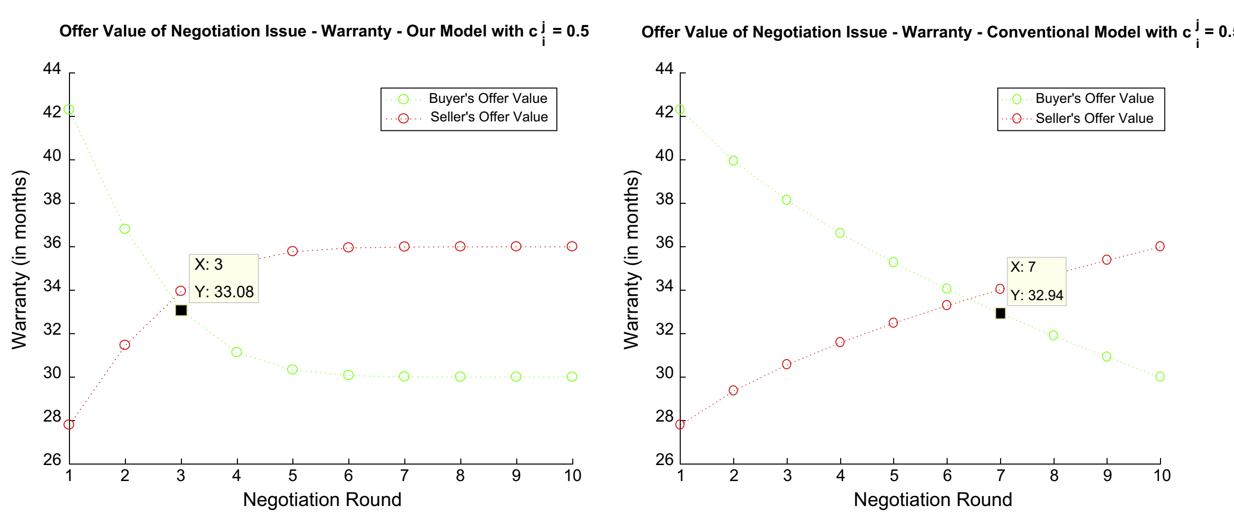

Figure 6 Offer value of Negotiation Issue 'Warranty' – Our Model Vs Conventional Model with $c_i^j = 0.5$.

Table 5 Computation of offer value for the issue 'Price' – Without 'pap' Vs With 'pap'.

Concession Steps	1	2	3	4	5	6	7	8	9	10
Negotiation Issue 'Price' – Without 'pap'										
Buyer	201.58	207.02	217.66	233.49	252.59	271.49	286.49	295.53	299.23	300.00
Seller	497.01	487.48	469.72	444.51	415.42	387.97	367.26	355.45	350.89	350.00
Negotiation Issue 'Price' – With 'pap'										
Buyer	201.58	207.02	217.66	233.49	252.59	271.49	286.49	295.53	299.23	360.00
Seller	497.01	487.48	469.72	444.51	415.42	387.97	367.26	355.45	350.89	350.00

Table 6 Computation of offer value for the issue 'Warranty' – Without 'pap' Vs With 'pap'.

Concession Steps	1	2	3	4	5	6	7	8	9	10
Negotiation Issue 'Warranty' – Without 'pap'										
Buyer	46.86	44.42	41.02	37.35	34.15	31.90	30.66	30.16	30.02	30.00
Seller	18.30	19.00	20.05	21.25	22.37	23.21	23.71	23.93	23.99	24.00
Negotiation Issue 'Warranty' – With 'pap'										
Buyer	46.86	44.42	41.02	37.35	34.15	31.90	30.66	30.16	30.02	24.00
Seller	18.30	19.00	20.05	21.25	22.37	23.21	23.71	23.93	23.99	24.00

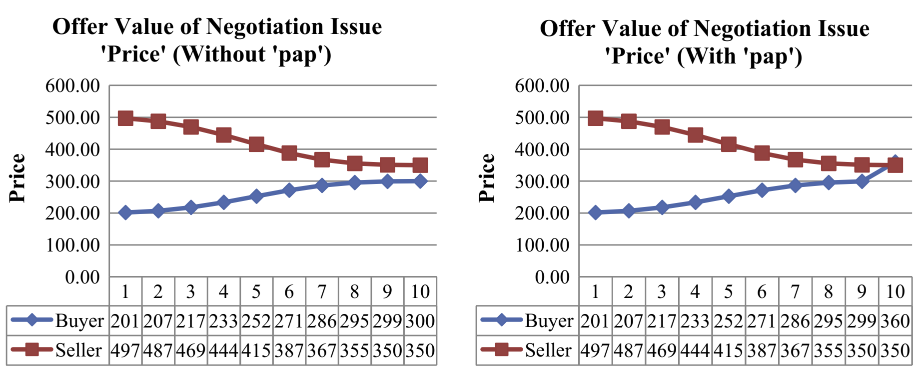

Figure 7 Negotiation Issue 'Price' – Without 'pap' Vs With 'pap'.

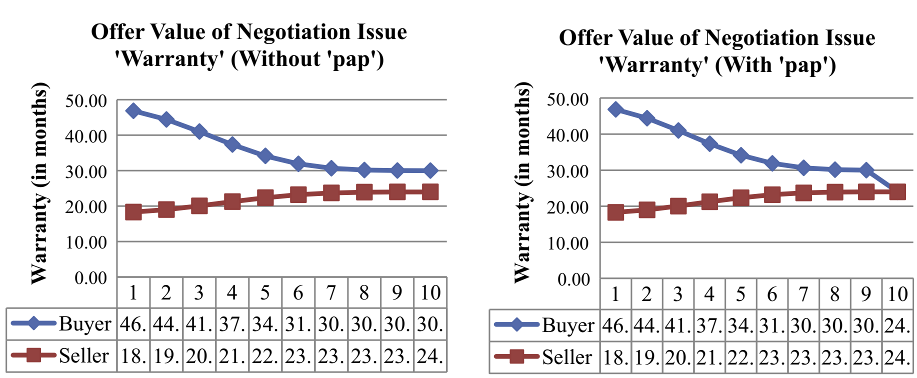

Figure 8 Negotiation Issue 'Warranty' – Without 'pap' Vs With 'pap'.

Otherwise, the buyer agent either generates the counter proposal or exits from the negotiation process depending upon the negotiation deadline. Fig. 9 displays the MATLAB code for computing the numerical score of the buyer's and seller's proposals/counter proposals at the buyer end (offer value computation based upon our model and conventional model) and to plot the graph against these two values. Figs. 10–12 depict the graphs comparing our model and the conventional models

BNSPVsSNSP.m

```matlab
BPri(1)= BPriMin + ((1 / R) ^ BPriC)* (BPriMax - BPriMin);
BWar(1)= BWarMax - ((1 / R) ^ BWarC)* (BWarMax - BWarMin);
SPri(1)= SPriMax - ((1 / R) ^ SPriC)* (SPriMax - SPriMin);
SWar(1)= SWarMin + ((1 / R) ^ SWarC)* (SWarMax - SWarMin);
for i=2:R
  BPri(i)= BPri(i-1) + ((i / R) ^ BPriC)* (BPriMax - BPri(i-1));
  BWar(i)= BWar(i-1) - ((i / R) ^ BWarC)* (BWar(i-1)- BWarMin);
  SPri(i)= SPri(i-1) - ((i / R) ^ SPriC)* (SPri(i-1) - SPriMin);
  SWar(i)= SWar(i-1) + ((i / R) ^ SWarC)* (SWarMax - SWar(i-1));
end
for i = 1:R
  BPriNS(i) = (BPriMax - BPri(i))/(BPriMax - BPriMin);
  BWarNS(i) = (BWar(i) - BWarMin)/(BWarMax - BWarMin);
  BNSP(i) = BPriNS(i)*BPriWt + BWarNS(i)*BWarWt;
  SPriNS(i) = (BPriMax - SPri(i))/(BPriMax - BPriMin);
  SWarNS(i) = (SWar(i) - BWarMin)/(BWarMax - BWarMin);
  SNSP(i) = SPriNS(i)*BPriWt + SWarNS(i)*BWarWt;
end
figure(1)
hold on
plot(BNSP,'--go')
plot(SNSP,':r*')
title('Numerical Score of the Proposals (Buyer''s Perspective)- Our Model')
xlabel('Negotiation Round')
ylabel('Numerical Score of the Proposals')
legend('Score of Buyer''s Proposal','Score of Seller''s Proposal')
```

BNSPVsSNSPCon.m

```matlab
for i=1:R
    BPri(i)= BPriMin + ((i / R) ^ BPriC)* (BPriMax - BPriMin);
    BWar(i)= BWarMax - ((i / R) ^ BWarC)* (BWarMax - BWarMin);
    SPri(i)= SPriMax - ((i / R) ^ SPriC)* (SPriMax - SPriMin);
    SWar(i)= SWarMin + ((i / R) ^ SWarC)* (SWarMax - SWarMin);
end
for i = 1:R
  BPriNS(i) = (BPriMax - BPri(i))/(BPriMax - BPriMin);
  BWarNS(i) = (BWar(i) - BWarMin)/(BWarMax - BWarMin);
  BNSP(i) = BPriNS(i)*BPriWt + BWarNS(i)*BWarWt;
  SPriNS(i) = (BPriMax - SPri(i))/(BPriMax - BPriMin);
  SWarNS(i) = (SWar(i) - BWarMin)/(BWarMax - BWarMin);
  SNSP(i) = SPriNS(i)*BPriWt + SWarNS(i)*BWarWt;
end
figure(1)
hold on
plot(BNSP,'--go')
plot(SNSP,':r*')
title('Numerical Score of the Proposals (Buyer''s Perspective)- Conventional Model')
xlabel('Negotiation Round')
ylabel('Numerical Score of the Proposals')
legend('Score of Buyer''s Proposal','Score of Seller''s Proposal')
```

Figure 9 MATLAB code for computing the numerical score of the proposals (Our Model/Conventional Model).

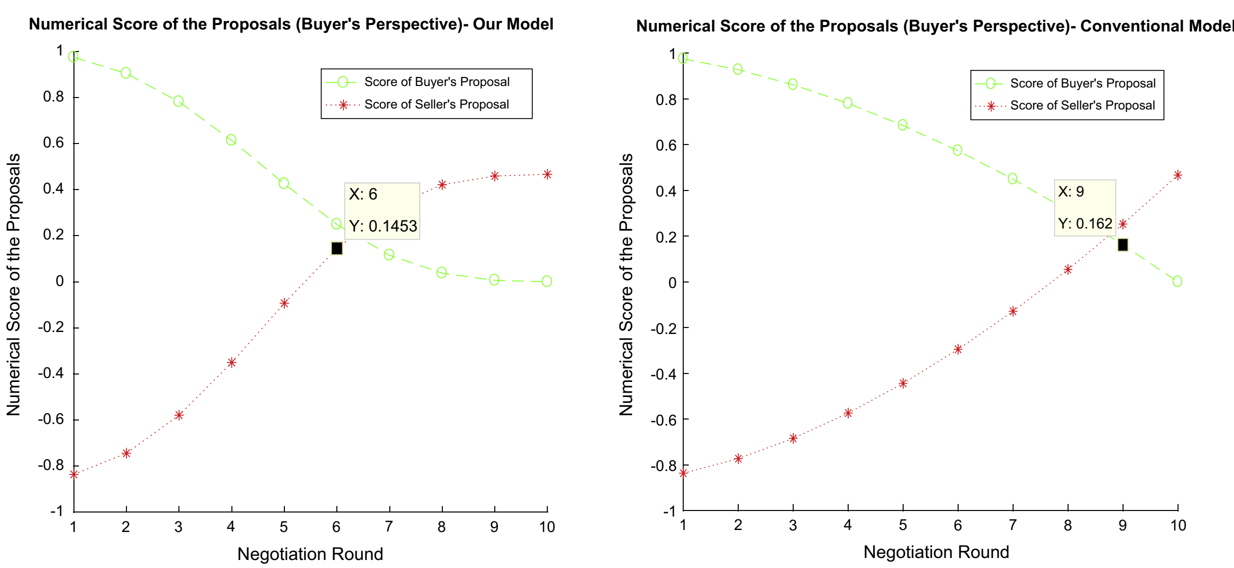

Figure 10 Numerical Score of the Buyer's Proposal Vs Seller's Proposal when r = 10.

for the numerical score of both the buyer's and seller's proposals in different negotiation scenarios with r = 10, r = 200 and $c_i^j = 0.5$ respectively.

4. Conclusion and future work

In this paper, a mathematical model with flexible negotiation strategies is developed which can be applied suitably in multi-lateral, multi-issue e-commerce negotiation environments that are based upon either a number of negotiation rounds or a specific time limit. This model is novel in its approach in computation of offer values for the negotiation issues. The advantage of our approach is evaluated in different negotiation scenarios with hypothetical data and the experimental results prove that our model enables the traders to reach consensus much quicker than the existing approaches

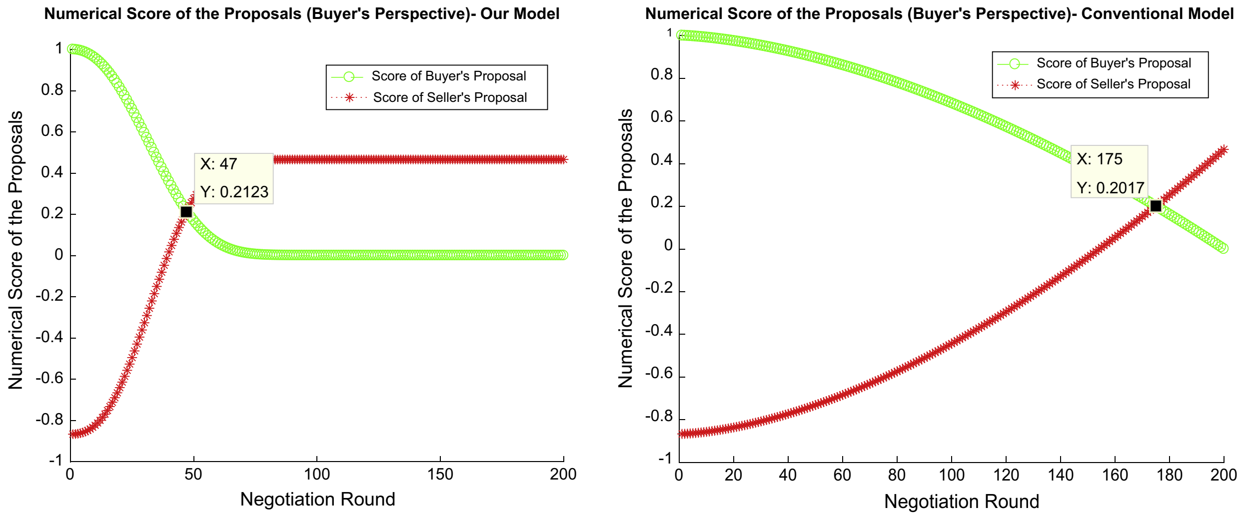

Figure 11 Numerical Score of the Buyer's Proposal Vs Seller's Proposal when r = 200.

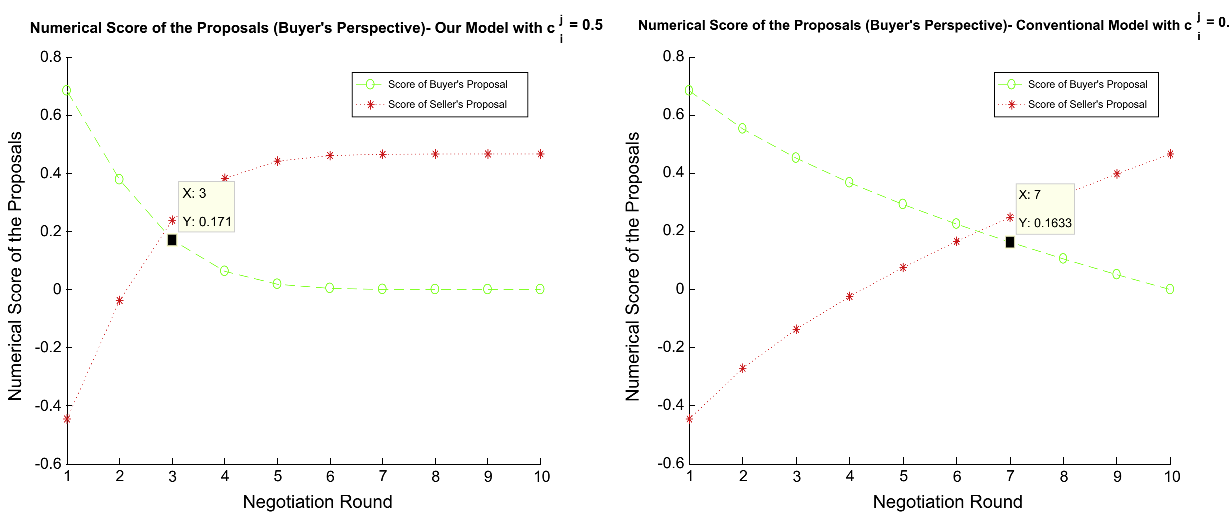

Figure 12 Numerical Score of the Buyer's Proposal Vs Seller's Proposal when r = 10 and $c_i^j = 0.5$.

and it also improves the utility of the traders. The proposed model is also advantageous in its approach in considering the compelling urge of the trader in buying/selling a product. This feature of our model helps the traders in completing a deal which is otherwise not possible. On the whole, the empirical study proves that the proposed model when compared with the existing strategies improves the rate of reaching consensus and also increases the utility of both buyer and seller.

However, this model has currently considered only the negotiation issues that are quantitative and in the future it will also include the representation of qualitative issues that take linguistic values. The negotiation procedures and tactics in auction based e-commerce environments are different from typical bargaining scenarios. The negotiation strategies proposed in this model are applicable in bilateral/multilateral bargaining scenarios which cannot be applied as such in auction based e-commerce environments. Thus, this model will be extended in the future to define negotiation strategies that are suitable for online auction houses. In this paper, the performance of the proposed model is evaluated in a bilateral negotiation scenario with the hypothetical data. In the future, the proposed negotiation strategies will be embedded in JADE agents and their performance in both bilateral and multilateral negotiation scenarios involving two or more participants will be evaluated and compared.

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