Benchmarking: An International Journal

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Article information:

To cite this document:
Prashant M. Ambad Makarand S. Kulkarni , (2015),"A warranty based bilateral multi-issue negotiation approach", Benchmarking: An International Journal, Vol. 22 Iss 7 pp. 1247 - 1280
Permanent link to this document:
http://dx.doi.org/10.1108/BIJ-11-2013-0103

A warranty based bilateral multi-issue negotiation approach

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Received 7 November 2013
Revised 18 July 2014
Accepted 20 July 2014

Abstract

Purpose – The purpose of this paper is to propose a warranty-based bilateral automated multi-issue negotiation approach.
Design/methodology/approach – A methodology for bilateral automated negotiation process is developed considering the targets such as warranty attractiveness, warranty cost, mean time between failures, spare parts cost to the end user over the useful life of the life. The negotiation methodology is explained using different cases of negotiation. The optimization for each negotiation step is carried out using genetic algorithm with elitism strategy.
Findings – The result after optimization indicates that the desired target values are achieved and manufacturer obtained desired profit margin.
Practical implications – Application of automated negotiation model is illustrated using a real life case of an automobile engine manufacturer. The proposed approach helps the manufacturer of any product to develop a methodology for carrying out the negotiation process. The approach also results into taking warranty-related decisions at the design stage.
Originality/value – This paper contributes in proposing a generalized methodology for warranty-based negotiation in which the negotiation is carried out between the manufacturer and the customer.
Keywords Genetic algorithm, Automated negotiation, MTBF, Multi-issue negotiation, Warranty attractiveness index, Warranty cost
Paper type Research paper

1. Introduction

With increasing competition, number of products are entering in the market. For the product to be competitive, manufacturers need to make their product more attractive. Warranty is one of the tools which can be used by a manufacturer to attract the customers but this needs to be achieved along with a competitive selling price. In a number of cases, the product is a sub assembly and it is supplied to the Original Equipment Manufacturer (OEM) who is the customer. In such cases the decision regarding selling price is influenced heavily by the customer. The manufacturer of the product faces the following challenges:

- To get an edge over the competitors, warranty provided by the manufacturer should be more attractive than that of the competitors.
- Warranty-related decisions are critical and these need to be taken at the design stage. These decisions can be taken using warranty-based optimization.
- As the selling price is dictated by the customer, it may so happen that the solution obtained after optimization may not lead to a desired profit margin for the manufacturer.
- However, instead of cancelling the deal, there may be a possibility of negotiation between the manufacturer and the customer. Modelling such a negotiation mechanism is a challenge as it will involve re-optimizing all the decision variables under varying degree of relaxation of target values by the customer.

Benchmarking: An International Journal
Vol. 22 No. 7, 2015
pp. 1247-1280

1463-5771
DOI 10.1108/BIJ-11-2013-0103

The above set of challenging problems is the motivation behind the development of the warranty-based negotiation approach in this paper. Negotiation for deciding the selling price considering a number of warranty decision variables and at the same time, satisfying a number of constraints is a complex problem which can be addressed using automated negotiation.

The manufacturer under study is an engine manufacturer who supplies engines to an OEM who manufactures commercial vehicles. Manufacturer has number of competitors in the market for the same set of engines. Also the engines are supplied to number of OEMs. Each OEM has different requirements according to their priority. So the target goals also set accordingly, whereas manufacturer also has set some targets, also he/she wants selling price should be such that he/she should obtained the minimum set profit margin. All these constraints can be solved by using multi-objective optimization problem. Goal programming is a convenient way to solve these types of problems. A negotiation between the manufacturer and OEM is also difficult with number of warranty-related issues are involved. In the present paper, a warranty-based bilateral automated multi-issue negotiation model is developed in which the negotiation is carried out between the manufacturer and the OEM.

The negotiation process is carried out in two iterations. In the first iteration, there are two stages. The first stage is related to the OEM side activities in which the OEM sets the targets to be achieved. The target values set are related to the warranty attractiveness, spare parts cost to the customer, mean time between failures (MTBF) and buying price of the product. The second stage is related to the supplier side activities in which the manufacturer sets the targets related to the expected warranty cost as well as selling price and tries to optimize the values of the decision variables to achieve the targeted values and the required profit. The decision variables considered are component alternatives, warranty duration, warranty policy and support level. In case a solution satisfying the customer and manufacturer targets is not obtained, the second iteration is initiated.

In the second iteration, the manufacturer and the OEM will negotiate by relaxing the warranty attractiveness target, spare parts cost target, or agreeing for a higher buying price or order quantity.

In the present case of negotiation, the manufacturer makes an appropriate offer to the OEM which maximizes its utility function. The OEM accepts the offer in case if it satisfies its utility function. If the utility function of the OEM is not satisfied to the expected level, the OEM gives counter offer by providing relaxation preferences in the target values and the manufacturer makes second offer by considering those preferences. This process continues until they reach an agreement. The utility function defines the level to which the objective function is satisfied.

The negotiation approach suggested in the present paper has following advantages as compared to other feasible techniques:

- A methodology for bilateral automated negotiation between supplier and manufacturer is developed.
- Parties involved have choice to change their priorities, this makes the methodology flexible.
- The technique gives quick results after satisfying all the constraints imposed on it. Use of genetic algorithm speeds up the process of obtaining the solution.
- Manufacturer as well as customer will get benefitted.

- With automated negotiation, human efforts involved in manual negotiation will be reduced considerably.
- Once all preferences are provided, rest of the care will be taken by the automated negotiation and no manual interference needed.
- Customer will get the product at the targeted buying price as well as manufacturer will able to sell it at the selling price such that the desired profit margin will be achieved.
- Manufacturer will get edge over the competitor by offering a competitive warranty terms to the customer.
- The decisions are taken at the design stage offers more satisfaction to the customer and will help to improve the warranty parameters at the starts as against post-warranty analysis done in the present scenario.

The rest of the paper is divided into following sections. Section 2 reviews the literature related to negotiation and warranty. Section 3 presents a warranty attractiveness index (WAI). In Section 4, warranty-based negotiation model is formulated and the warranty-based automated negotiation process is discussed. In Section 5 warranty optimization problem is formulated and warranty-based optimization model using goal programming approach is presented. In Section 6, negotiation methodology is explained using a real life example of an automobile engine manufacturer. Paper ends with conclusion in Section 7.

2. Literature review

Negotiation is the act of reaching an agreement on number of parameters between the buyer and the supplier. The negotiation process is carried out in an iterative manner until the parties involved will reach to an outcome on different issues. Negotiation is either carried out between two parties or multi parties. The way in which issues are negotiated is specified by agenda. In negotiation, the issues are either negotiated all at one time or discussed sequentially. In the first case, it is called as exogenous agenda and in other it is called as endogenous agenda (Fatima *et al.*, 2003). For effective negotiation, it is necessary that each party should concede in order to reduce difference between them and to converge to an agreement with objective to maximize the payoffs of parties involved in it (Choi *et al.*, 2001).

The existing literature on negotiation is mainly divided into types: single issue negotiation and multi-issue negotiation. While the single issue negotiation is extensively studied in the literature, the research on multi-issue negotiation is at an early stage (Lai and Sycara, 2009). In multi-issue negotiation, agents with different preferences can cooperate with each other to reach an agreement that is beneficial for both the agents. A negotiation outcome is efficient if it is Pareto optimal. A Pareto-optimal solution is one, where the utility of one agent cannot be improved without decreasing other agent's utility (Saha, 2006). Negotiation is common where large and complex business transactions are involved. Negotiation on various terms of deal offers the potential to yield the involved parties the best payoff. It allows terms of deal to be set according to market demand and supply. However, human negotiations could be costly and non-optimal. Therefore automated negotiations are useful due to its relatively low cost (Choi *et al.*, 2001). Automated negotiation is an ultimate choice where multi-issues are involved and relatively complex nature of situation occurs.

In the literature, different models for the negotiation are studied by the researchers. The negotiation problems are solved by using game theory and a variety of artificial intelligence approaches like Bayesian learning, genetic algorithm, fuzzy constraints, etc.

Lai *et al.* (2004) carried out an extensive literature review of the multi-attribute negotiations in the fields of economics and artificial intelligence. They discussed the motivation for multi-attribute negotiations and difficulties faced in implementation. They also reviewed the literature related to the multi criteria decision making in relation to multi-attribute negotiation problems. Jennings *et al.* (2001) developed a generic framework for classifying and viewing automated negotiations. This framework is used to discuss and analyze the three main approaches that have been adopted for automated negotiation; namely, game theoretic, heuristic and argumentation-based approaches. Aknine *et al.* (2004) presented an extended multi-agent protocol that is efficient in time and tolerates crash failures in multi-agent systems through managing the several negotiation processes in parallel, optimizing the length of a negotiation processes, etc. Li *et al.* (2013b) described a generic framework for automated negotiation, which captures descriptively the social dynamics of the negotiation process. Zheng *et al.* (2013) investigated offer generation methods for automated negotiation on multiple issues with no information about the opponent's utility function. Baarslag *et al.* (2014) proposed effective acceptance conditions in real automated negotiations and demonstrated that they outperform the other conditions.

Bac and Raff (1996) and Talluri (2002) studied the negotiation using game theory where two players are involved and decision regarding partition of pie and bid selection are taken using the game theory approach.

Some of the papers have used Bayesian learning to update an agent's belief (Zeng and Sycara, 1997) and estimate the opponent's reserve price (Gwak and Sim, 2011) to support the negotiation with incomplete information. Bayesian learning is also used in a bilateral multi-issue negotiation model which can help the negotiators to achieve win-win agreements without disclosing their preferences (Li *et al.*, 2013a).

Multi-issue negotiation problems involve complex and large search space with a number of conflicting issues (Lai *et al.*, 2006; Chen and Weiss, 2013). Genetic algorithm is suitable for such tasks due to its efficient searching in such complex problems (Goldberg, 1989; Zitzler *et al.*, 2000; Rubenstein-Montano, 2002; Kattan *et al.*, 2013; Lang and Fink, 2014). Genetically learned rules, when used in real negotiations, yield results that may prove to be better than the results obtained by humans in the same negotiation situation (Matwin *et al.*, 1991).

The issues usually considered in negotiations are price, quantity, processing days and features, rebate, payment time, delivery method, delivery time, payment method, gift and quality, transportation, service after sales, etc. (Choi *et al.*, 2001; Lau, 2005; Niu and Wang, 2008; Li *et al.*, 2008; Wu *et al.*, 2009a, b; Chen and Li, 2010; Gao and Chen, 2010; Gao *et al.*, 2010; Song and Zhang, 2010).

Simulated annealing approach has also been used in automated negotiation of complex contracts (Klein *et al.*, 2003; Fei and Chen, 2007).

A number of papers have also focused on the use of fuzzy methods to develop bilateral multi-attribute negotiation models (Chen and Huang, 2007; Wu *et al.*, 2007; Meng and Fu, 2004; Lopez-Carmona and Velasco, 2006; Wang and Ling, 2008).

The literature on warranty is vast and there are number of papers which focus on single or multiple objective optimization of warranty-related parameters like, warranty cost, reliability, warranty type and duration, price, warranty reserves, etc. from different perspectives (Mitra and Patankar, 1988, 1993; Manna *et al.*, 2006; Murthy *et al.*, 2007; Matis *et al.*, 2008; Kim and Park, 2008; Zhou *et al.*, 2009; Shafiee *et al.*, 2011, 2013; Aggrawal *et al.*, 2014).

In the literature, there are number of papers on warranty optimization considering warranty-related parameters. From the literature reviewed on automated negotiation, it can be seen that number of papers focused on multi-issue negotiation are using number of different solution approaches. Lot of papers used GA as a solution approach for carrying out automated negotiation process. Some papers consider the warranty as one of the issue in negotiation.

From the literature, following research gaps are identified:

- Approaches that consider the effect of decision variables on attractiveness of a warranty policy in a quantitative manner have received relatively less attention.
- Models which help the designers in decision making regarding warranty at the design stage have received less attention.
- In order to optimize warranty-related parameters, it is necessary to consider multi-objective optimization with achievement of multiple goals like customer satisfaction and warranty attractiveness. Such approaches are scarce in the literature.
- Approaches that can help in taking warranty-related decision based on negotiation between two parties are not found in the literature.

This paper contributes in proposing an approach for warranty-based negotiation in which the negotiation is carried out between the manufacturer and the customer. The negotiation methodology involved re-optimization of warranty decision variables under varying degree of relaxation.

In warranty optimization, one of the targets is the warranty attractiveness, which is a quantitative measure of customer's attractiveness towards the product warranty. In the following section, details about the WAI are presented.

3. WAI

During the design stage, manufacturer has to take the warranty-related decisions. In order to achieve customer's satisfaction, manufacturer needs to make the warranty more attractive than competitors. The attractiveness of the warranty depends on the parameters like cost of the component, type of warranty policy and duration for which it is given and support given in the event of failure of the items. To make the warranty more attractive than competitors, manufacturer needs to capture the attractiveness in quantitative terms. Ambad and Kulkarni (2015) proposed a WAI in order to capture the attractiveness of warranty in quantitative manner.

To capture the above parameters WAI is formulated using three indices namely, cost criticality index (CCI), policy attractiveness index (PAI) and support attractiveness index (SAI). The parameter like cost of component is captured through CCI, the policy type and duration of warranty is captured by PAI and support level provided is captured by SAI.

The multiplication of these three indices will provide the WAI for the component and is given as follows:

$$WAI = CCI \times PAI \times SAI \tag{1}$$

WAI is calculated at the component level, to calculate it at product level an overall attractiveness index (OAI) is proposed (Ambad and Kulkarni, 2015) and for a product with n components it can be determined as follows:

$$OAI = \sum_{i=1}^{n} WAI_i \tag{2}$$

The Equation (2) can be used to calculate OAI for product under study as well for the competitor. The comparison between OAI of product under study and the competitor is given by an Attractiveness Advantage Ratio (AAR) (Ambad and Kulkarni, 2015). The AAR can be calculated as follows:

$$\text{Attractiveness Advantage (AAR)} = \frac{\text{OAI}_{\text{Mfg}}}{\text{OAI}_{\text{Comp}}} \tag{3}$$

where, OAI_{Mfg} is the overall attractiveness index for the product under study (manufacturer), OAI_{Comp} the overall attractiveness index for the competitor's product.

In the present paper, the OAI is used in order to capture the attractiveness of the warranty for the product under study as well as for the competitor and AAR is used to compare OAI for the both the products. Estimation of the OAI for the competitor can be easily done as all the parameters required for calculation are easily accessible.

In the next section, the details of an automated negotiation model formulation and the process for warranty-based automated negotiation are discussed.

4. Automated negotiation model

An automated negotiation model is formulated considering the negotiation protocol and negotiation strategy. The warranty-based automated negotiation process is carried out in two iterations. The details about which are summarized in the following sub-sections.

4.1 Negotiation protocol

In Rubinstein's alternating-offer game (Rubinstein, 1982), a protocol is used in which each player make offer to the opponent, who either accepts the offer or makes a counter offer or rejects it. In the case of acceptance or rejection of the offer, the negotiation ends. The opponent may also make a counter offer and the negotiation continues until they reach a mutually agreeable condition or the deadline is reached. The model presented in this paper is different from this in the sense that one of the players in the negotiation, who is the buyer (OEM) communicates target values for a set of performance measures to the other player who is the supplier (engine manufacturer). The manufacturer on the other hand also has his/her own target values for warranty cost, selling price and profit margin, and attempts to optimize a joint optimization function with given decision variables. If target values are not achieved, an automated negotiation between the engine manufacturer and the OEM is carried out. The OEM provides the relaxation preferences and also the magnitude of the maximum allowable relaxation for each of the parameters. For each relaxation, the manufacturer re-optimizes to achieve the required solution. The relaxation is given in steps until the target values are achieved. However, the constraint on the maximum allowable relaxation is not violated. If the solution is achieved with the given preferences and inputs, the negotiation ends successfully. If the solution cannot be achieved with the given relaxation preferences and magnitude of relaxation, the manufacturer tries to achieve the solution by relaxing more than one target values at a time with different combinations and proportions until the solution is achieved.

During negotiation process, manufacturer and customer negotiates based on the negotiation strategy. The details of which are explained in the following section.

4.2 Negotiation strategy

The negotiation strategy is basically divided into three components: conceding, responding and proposing.

Conceding strategy determines how to concede in negotiation and it is determined based on the minimum utility desired by the player in each stage of the negotiation. Responding strategy determines whether a player should accept or reject the offer proposed by the opponent. The proposing strategy determines which strategy to be offered to the opponent.

In the present paper, a conceding strategy is used in which at each offer, the manufacturer finds out the selling price achieved after optimization process carried out by relaxing one or more of the target values. The relaxation priorities are decided between the manufacturer and the OEM through discussion. The selling price for the manufacturer is calculated as follows:

$$SP_{Mfg} = Engine\ Cost_{Mfg} + WC + Profit_{Mfg} \tag{4}$$

where, $SP_{Mfg}$is the minimum selling price affordable to the manufacturer, WC the warranty cost, $Engine\ Cost_{Mfg}$ the engine cost for the manufacturer, $Profit_{Mfg}$ the profit for the manufacturer.

Each time, the manufacturer compares the selling price (SP_{Mfg}) with the buying price acceptable to the OEM (BP_{OEM}).

In responding strategy, after each optimization, the target buying price is compared with the estimated selling price. If $BP_{OEM} \geqslant SP_{Mfg}$, the OEM accepts the offer and negotiation ends successfully. If $BP_{OEM} < SP_{Mfg}$, the manufacturer proceeds with the next offer. In short, the logic is as follows:

$$SP_{Mfg} = \begin{cases} \text{accept}, & \text{if } BP_{OEM} \geqslant SP_{Mfg} \\ \text{next offer}, & \text{if OEM agree} \\ \text{reject}, & \text{otheriwse} \end{cases} \tag{5}$$

In proposing strategy, the manufacturer proposes the offer considering the given relaxation. The type of relaxation depends upon the mutually agreed priority by the manufacturer and the OEM. Once the priority is defined, the next step is to start with the first target value. For each target value, the relaxation is given in incremental steps and optimization is carried out for each increment until the condition $BP_{OEM} \geqslant SP_{Mfg}$ is achieved along with the other target values. The process can continue till the maximum allowable relaxation limit is reached. The manufacturer proposes this solution to the OEM.

If the target values are not achieved for the given relaxation, the above process is repeated for the next target value for which relaxation is given. The manufacturer again proposes the obtained solution to the OEM. The algorithm designed for the present study can also consider two or more target values at a time.

In this way, the negotiation will proceed until the required solution is achieved or the OEM rejects all the offers and quits the negotiation process. As an option, the manufacturer may also compromise by accepting a lower profit margin of profit leading to successful negotiation.

Based on the negotiation strategy discussed, negotiation process is carried out. For this negotiation model is formulated. The process is carried out in two iterations. Next section explains about the negotiation process.

4.3 Warranty-based automated negotiation process

The proposed automated warranty-based negotiation model is formulated by considering the warranty decision variables such as warranty policy, component alternatives, warranty duration and support level. The details of iterative process are presented in the following sub-sections.

4.3.1 Iteration 1. 4.3.1.1 Stage 1: OEM side activities. The OEM sets the target value for the AAR by comparing the current OAI for the manufacturer and the competitor.

The OEM is also interested in achieving target values for mean time between the failures (MTBF) and spare parts cost over the useful life of the product (SPCL). In the case of MTBF, the manufacturer may not have information about the competitor's failure data. For setting the target value for MTBF, five-year MTBF for the components is calculated and a higher MTBF than the current one is set as the target value for the MTBF. The other parameter, SPCL, is related to the spares cost which is incurred by the customer till the end of the service life of the component. In case of pro-rata warranty, additional cost is incurred by the customer even during warranty period, which is the difference between component cost and the partial rebate provided by the manufacturer. The manufacturer has information about the expected number of spare parts required over the useful life of the product. Based on this information, the OEM sets the target value for the SPCL. The OEM also sets the buying price (BP_{OEM}) which is equal to the target cost that has been pre-decided for the engine.

Once the target values are set for the AAR, MTBF, SPCL and buying price, the OEM communicates these values to the engine manufacturer along with the production quantity.

4.3.1.1 Stage 2: manufacturer side activities. The manufacturer identifies different component alternatives with higher reliability which will improve the MTBF. In case of warranty policy, there is a variety of policies offered for different products by the manufacturers (Blischke and Murthy, 1994, 1996; Chattopadhyay and Rahman, 2008; Murthy and Blischke, 2006). The manufacturer also identifies different types of warranty policies that can be offered. In this paper, four types of warranty policies are considered namely, non-renewing free replacement (FRW-NR), non-renewing pro-rata (PRW-NR), renewing free replacement (FRW-R) and renewing pro rata (PRW-R). The warranty duration considered varies from 12 months to 120 months. The maximum duration is considered by assuming service life of the engine as 120 months. The manufacturer considers three types support levels i.e., Level 1-Level 3 (Ambad and Kulkarni, 2015).

The manufacturer sets the target value for the warranty cost by restricting it to some proportion of the revenue i.e., selling price of the engine. The manufacturer also sets the target for the profit to be achieved. The summation of cost of all components decides the engine cost. The product cost for the engine is decided by adding warranty cost and engine cost. The manufacturer also decides the minimum selling price (SP_{Mfg}) that can be offered to the OEM.

The targets to be achieved may be stated as follows:

$$\begin{aligned} & AAR \geqslant AAR_{Target} \\ & SPCL \leqslant SPCL_{Target} \\ & MTBF \geqslant MTBF_{Target} \\ & WC \leqslant WC_{Target} \\ & \left(SP_{Mfg} - Product\ Cost\right) \geqslant Profit_{Target} \end{aligned} \tag{6}$$

where, AAR_{Target}, $SPCL_{Target}$ and $MTBF_{Target}$ are the targeted values of the AAR, SPCL and MTBF specified by the OEM.

WC_{Target} and $Profit_{Target}$ are the maximum acceptable warranty cost and minimum required profit values set by the manufacturer:

$$Product\ cost = Engine\ Cost_{\mathrm{Mfg}} + WC$$

The decision variables considered are component alternatives, warranty duration, warranty policy and support level.

If $BP_{OEM} \geqslant SP_{Mfg}$ and if the above set of target values are achieved then the solution has been achieved and there is no need of negotiation. Else, Iteration 2 begins in which negotiations are carried out between the manufacturer and the OEM through relaxing the target values.

4.3.2 Iteration 2. The manufacturer and the OEM will negotiate on the basis of either relaxing the OAI, SPCL requirements or agreeing for a higher buying price or higher order quantity in which manufacturer could take advantage of economy of scale and may be able to minimize product costs to the extent that $BP_{OEM} \geqslant SP_{Mfg}$.

The inputs to the automated negotiation are provided by the manufacturer and the OEM. Inputs given are related to the priority of relaxation, steps for each relaxation in each optimization run, maximum relaxation allowed for given target value and the relaxation limit allowed by the OEM. With the given inputs, the entire optimization will be run again at this stage.

A number of cases for the negotiation are generated using combination of the relaxation of one or more of the target values of AAR, SPCL or buying price (BP_{OEM}) and order quantity. Again the magnitude of relaxation is decided by the manufacturer in consultation with the OEM. Table I shows different combinations of cases that can be generated by relaxing one or more target values. The manufacturer takes decision on priorities in which the relaxation is carried out in case if he/she wants to relax more than one target values. The priority for relaxation is given as mutually agreed by the manufacturer and the OEM.

Once the negotiation process is defined in two iterations, problem is formulated. The details about problem formulation are explained in the next section.

Combination	AAR	SPCL	Buying price	Order quantity
1.	NR	NR	NR	NR
2.	R	NR	NR	NR
3.	NR	R	NR	NR
4.	NR	NR	R	NR
5.	NR	NR	NR	R
6.	R	R	NR	NR
7.	NR	R	R	NR
8.	NR	NR	R	R
9.	NR	R	NR	R
10.	R	NR	R	NR
11.	R	NR	NR	R
12.	R	R	R	NR
13.	R	R	NR	R
14.	R	NR	R	R
15.	NR	R	R	R
16.	R	R	R	R

Note: NR, no relaxation; R, relaxation

Table I. Different combination for relaxation in negotiation process

5. Problem formulation

The negotiation process is started with Iteration 1 in which the problem is formulated following Stage 1 and 2 as discussed in the previous section. In this case, the OEM decides the target OAI. First of all, the OEM calculates current OAI based on inputs from the manufacturer. These have been calculated for 29 critical components. These components were selected based on their contribution to warranty costs and failure rate of the engine under study.

As the warranty offered by the manufacturer is FRW-NR with warranty duration of 12 months the OAI_{Mfg} obtained by the OEM using Equation (2) in this case is 93, while the competitor offers the similar warranty policy with 18 months duration. The OAI_{Comp} obtained for the competitor is 275. Current AAR is obtained using Equation (3) as 0.34. As this is very low, the OEM sets the target for AAR as 1.10. The MTBF and SPCL is calculated considering the expected number of failures over a period of five years for MTBF and ten years for SPCL, which is determined through failure simulation using the time to failure distribution of the component. The failure distribution is assumed to follows Weibull distribution. The current value for MTBF is calculated as 390 hr. The target for the MTBF is set at 10 per cent higher than the current one. In case of SPCL, the current value is obtained as Rs 59,000. The OEM wants to reduce this value in order to improve customer satisfaction. The OEM sets the target value for SPCL as 90 per cent of the current value. The OEM also sets the current buying price as Rs 35,000 per engine based the information available with him.

The OEM communicates these target values to the manufacturer. The manufacturer will act accordingly and identify the component alternatives, warranty type, warranty duration, support level and component costs for different alternatives. The manufacturer sets the target for the warranty cost as 2 per cent of the selling price. Warranty cost is calculated using the warranty cost models for the warranty policies considered in the present paper and the simulation-based approach. The manufacturer also decides the minimum affordable selling price and the acceptable profit. In the present case, manufacturer decides the target for the profit as 20 per cent of the total product cost of the engine. Once all parameters are identified, optimization is carried out. Targets to be achieved may be stated as:

$$\begin{aligned} &OAI_{Mfg} \geqslant 1.10 \times OAI_{Comp} \\ &SPCL_{\text{Target}} \leqslant 0.90 \times SPCL_{Current} \\ &MTBF_{\text{Target}} \geqslant 1.10 \times MTBF_{Current} \\ &WC_{\text{Target}} \leqslant 0.02 \times SP_{Mfg} \\ &Profit_{\text{Target}} \geqslant 0.20 \times Product\ Cost \end{aligned} \tag{7}$$

After optimization, if the $BP_{OEM} \geqslant SP_{Mfg}$ and also all the other constraints are satisfied, then there is no need for negotiation. Otherwise, next iteration can be considered for optimization.

In the second iteration as stated earlier, the automated negotiation is carried out. The manufacturer negotiates by relaxing one or more of the parameters to obtain the required solution. The relaxation in the target values is provided by the manufacturer in a number of increments in agreement with the OEM. The AAR is set at 10 per cent higher than the competitor's OAI while the SPCL is set at 10 per cent less than the current value. The maximum relaxation will be given based on the negotiation with the OEM. In the case of order quantity, relaxation is in terms of a higher quantity than initially committed by the OEM. Due to such a relaxation, the manufacturer can take the benefit of economy of scale. This is due to the fact that the suppliers supplying parts to the manufacturer offer a quantity-based discount. This helps the manufacturer to reduce the overall engine cost. The manufacturer does not achieve this benefit if the order quantity is upto 5,000 units. Above 5,000 units, the manufacturer obtains an average reduction of 0.5 per cent per thousand units in the component cost till 25,000 units. For order quantities above 25,000 units, no further benefits are achieved. For the buying price, the relaxation is provided by the OEM in terms of a higher than initially decided buying price. Based on the relaxations provided, the targets for the optimization can be stated as:

$$\begin{aligned} &OAI_{Mfg} \geqslant (A - relx_{AAR}) \times OAI_{Comp} \\ &SPCL_{Target} \leqslant (S + relx_{SPCL}) \times SPCL_{Current} \\ &MTBF_{Target} \geqslant 1.10 \times MTBF_{Current} \\ &WC_{Target} \leqslant 0.02 \times SP_{Mfg} \\ &Profit_{Target} \geqslant 0.20 \times Product\ Cost \end{aligned} \tag{8}$$

where, A and S are the target proportions set for AAR and SPCL, respectively; $relx_{AAR}$ and $relx_{SPCL}$ are the relaxation proportion provided to AAR and SPCL.

The details of warranty-based optimization using goal programming approach are discussed in the next sub-section.

5.1 Warranty-based optimization model using goal programming approach

In this paper, a weighted goal programming approach is used. The objective function is formulated as the sum of the weighted deviations of each of the objectives from its target and is given as follows:

$$Objective\ function\ \ F = \sum D_i \tag{9}$$

where, $D_i = w_i \times d_i$, d_i is the deviation function and w_i theweight of the objective.

The objective is to find a set of decision variable values which minimizes this total weighted sum of deviations and also satisfies all the targeted values. The manufacturer and the OEM have decided the weights for the target values to be achieved. The target values have been assigned following weights, $w_{OAI} = 0.10$, $w_{MTBF} = 0.10$, $w_{WC} = 0.20$, $w_{SPCL} = 0.10$, $w_{Profit} = 0.50$. The deviation function is formulated using quadratic loss function and the details of which are discussed in the next sub-section.

5.1.1 Loss functions for objectives. Quadratic loss functions have been used to quantify the deviation of objective values from the ideal values. Larger the loss function value, larger is the deviation from the ideal values. A quadratic loss function (Taguchi *et al.*, 1989; Ross, 2005) is as follows:

$$L(y) = k(y - T)^2 \tag{10}$$

where, y is the objective value and T is the target.

In the present paper, the loss coefficient "k" is assigned a value such that at the maximum or the minimum allowable limit of each objective, the loss value becomes 1.

To generalize, the loss coefficient k can be calculated as:

$$k = \left[\frac{1}{(T - y_{Min})^2}\right] \quad \text{for } y_i < T \tag{11}$$

$$k = \left[\frac{1}{(y_{Max} - T)^2}\right] \quad \text{for } y_i > T \tag{12}$$

where, y_{Max} is the maximum allowable value; y_{Min} is the minimum allowable value of the objective.

However, if it is the case of symmetric form then, $(y_{Max} - T)^2 = (y_{Min} - T)^2$. For the smaller the better (STB) and larger the better (LTB) cases, the loss coefficient will be $\left[1/(y_{Max})^2\right]$ and $(y_{Min})^2$, respectively. This will keep the allowable values for each loss function between 0 and 1.

Therefore, loss for the NTB type response, can be calculated as:

$$L(y) = \left[\frac{(y_i - T)^2}{(T - y_{Min})^2}\right] \quad \text{for } y_i < T \tag{13}$$

$$L(y) = \left[\frac{(y_i - T)^2}{(y_{Max} - T)^2}\right] \quad \text{for } y_i > T \tag{14}$$

$$L(y) = 1 \quad \text{for } y_i > y_{Max} \text{ and } y_i < y_{Max} \tag{15}$$

For the LTB case, the loss function will take the form:

$$L(y) = \left[\frac{y_{Min}}{y_i}\right]^2 \tag{16}$$

$$L(y) = 1 \quad \text{for } y_i < y_{Min} \tag{17}$$

and for the STB case, the loss function will take the form:

$$L(y) = \left[\frac{y_i}{y_{Max}}\right]^2 \tag{18}$$

$$L(y) = 1 \quad \text{for } y_i > y_{Max} \tag{19}$$

Here, y_i is the value of the objective, y_{Max} the maximum allowable value and y_{Min} the minimum allowable value of the objective.

Since, in the case of OAI, MTBF and profit, higher values are more desirable, LTB type of loss functions are used as shown below:

$$L_{OAI} = k_{OAI}\left(\frac{1}{OAI}\right)^2 \tag{20}$$

where, L_{OAI} is the loss function for the OAI; k_{OAI} is the deviation co-efficient $[(1.10 - relx_{AAR}) \times QAI_{Comp}]^2$:

$$L_{MTBF} = k_{MTBF}\left(\frac{1}{MTBF}\right)^2 \tag{21}$$

where, L_{MTBF} is the loss function for the MTBF; k_{MTBF} is the deviation co-efficient $= [1.10 \times MTBF_{Current}]^2$:

$$L_{Profit} = k_{Profit} \times \left(\frac{1}{SP_{Mfg} - Product\ Cost}\right)^2 \tag{22}$$

where, L_{Profit} is the loss function for the manufacturer's profit; k_{Profit} is the deviation co-efficient $= [0.20 \times Product\ Cost]^2$.

For warranty cost and spare parts cost over the useful life of the engine, smaller vales are desirable the loss function is of STB type. Here, the intention is to reduce the warranty cost incurred by the manufacturer and the spare parts cost incurred by the end user over the useful life of the engine. The loss functions for warranty cost and spare parts cost is as follows:

$$L_{WC} = k_{WC}(WC)^2 \tag{23}$$

where, L_{WC} is the loss function for the warranty cost; k_{WC} is the deviation co-efficient $= \left[1/0.02 \times Engine\ \ Price\right]^2$.

$$L_{SPCL} = k_{SPCL}(SPCL)^2 \tag{24}$$

where, L_{SPCL} is the loss function for the SPCL; K_{SPCL} is the deviation co-efficient $= \left[1/(S + relx_{SPCL}) \times SPCL_{Current}\right]^2$

5.1.2 Deviation functions. The deviation function is defined as the deviation of the loss value from its maximum allowable value. The maximum allowable value for the loss function is 1. The deviation functions are as follows:

$$d_{OAI}^{+} = \begin{cases} (L_{OAI}-1) & \text{for } L_{OAI} > 1 \\ 0 & \text{for } L_{OAI} \leqslant 1 \end{cases} \tag{25}$$

$$d_{OAI}^{-} = \begin{cases} (L_{OAI}-1) & \text{for } L_{OAI} < 1 \\ 0 & \text{for } L_{OAI} \geqslant 1 \end{cases} \tag{26}$$

$$d_{MTBF}^{+} = \begin{cases} (L_{MTBF}-1) & \text{for } L_{MTBF} > 1 \\ 0 & \text{for } L_{MTBF} \leqslant 1 \end{cases} \tag{27}$$

$$d_{MTBF}^{-} = \begin{cases} (L_{MTBF}-1) & \text{for } L_{MTBF} < 1 \\ 0 & \text{for } L_{MTBF} \geqslant 1 \end{cases} \tag{28}$$

$$d_{Profit}^{+} = \begin{cases} (L_{Profit}-1) & \text{for } L_{Profit} > 1 \\ 0 & \text{for } L_{Profit} \leqslant 1 \end{cases} \tag{29}$$

$$d_{Profit}^{-} = \begin{cases} (L_{Profit}-1) & \text{for } L_{Profit} < 1 \\ 0 & \text{for } L_{Profit} \geqslant 1 \end{cases} \tag{30}$$

$$d_{WC}^{+} = \begin{cases} (L_{WC}-1) & \text{for } L_{WC} > 1 \\ 0 & \text{for } L_{WC} \leqslant 1 \end{cases} \tag{31}$$

$$d_{WC}^{-} = \begin{cases} (L_{WC}-1) & \text{for } L_{WC} < 1 \\ 0 & \text{for } L_{WC} \geqslant 1 \end{cases} \tag{32}$$

$$d_{SPCL}^{+} = \begin{cases} (L_{SPCL}-1) & \text{for } L_{SPCL} > 1 \\ 0 & \text{for } L_{SPCL} \leqslant 1 \end{cases} \tag{33}$$

$$d_{SPCL}^{-} = \begin{cases} (L_{SPCL}-1) & \text{for } L_{SPCL} < 1 \\ 0 & \text{for } L_{SPCL} \geqslant 1 \end{cases} \tag{34}$$

5.1.3 Objective function. The objective function is the sum of weighted deviations of each of the loss function derived in the previous sub-section and can be stated as follows.

Objective function:

$$\text{Minimize } 0.10d^-_{OAI} + 0.10d^-_{MTBF} + 0.50d^-_{Profit} + 0.20d^-_{WC} + 0.10d^-_{SPCL} \quad (35)$$

Subject to:

$$L_{OAI} - d^+_{OAI} + d^-_{OAI} = 1$$

$$L_{MTBF} - d^+_{MTBF} + d^-_{MTBF} = 1$$

$$L_{Profit} - d^+_{Profit} + d^-_{Profit} = 1$$

$$L_{WC} - d^+_{WC} + d^-_{WC} = 1$$

$$L_{SPCL} - d^+_{SPCL} + d^-_{SPCL} = 1$$

As the objective function incorporates only the negative deviations, minimization would mean bringing the loss values closer to zero. This approach to problem formulation ensures uniformity in the scale and values of the components of the objective function. In this case the deviation function can take values only between −1 and 0. Hence the objective function values also range between −1 and 0. The decision variables to be considered are the warranty type, warranty duration, component alternatives and support level.

The optimization problem is solved using genetic algorithm with elitism strategy. The various input parameters used for genetic algorithm are population size of 200, number of iterations of 200 with cross-over probability of 0.9 and mutation rate of 0.01 (Bakirtzis *et al.*, 2002; Cus and Balic, 2003).

The various critical component alternatives along with their failure distribution parameters, manufacturing cost and spares parts cost are as shown in Table II. The cost of non-critical components is taken as Rs 11,000 and do not have any alternatives for them.

In the next section, the negotiation methodology is explained using a real case example of an automobile manufacturer.

6. Negotiation methodology

The negotiation process is carried out in two iterations as explained in the previous section. In the first iteration, once the OEM provides the requirements in terms of the target values for the objectives to the manufacturer, the basic solution considering the target values is obtained. The results of the optimization are shown in Table III. The result shows that the target selling price (SP_{Mfg}) obtained by the manufacturer is more than the target buying price (BP_{OEM}) by Rs 2,575.35, as well as the target profit

Table II. Critical component alternatives and their details

Sl. no.	Component	β	η	Alternative-1 Mfr cost (Rs)	OEM selling price (Rs)	β	η	Alternative-2 Mfr cost (Rs)	OEM selling price (Rs)
1	Crank case	3.88	13,496.37	2,559.81	3,378.96	3.88	16,149.1	2,816.11	3,717.28
2	Starter motor	2.83	8,747.26	2,309.13	3,048.05	2.83	10,410.8	2,670.18	3,524.63
3	Fuel pump assy	3.62	8,199.72	1,835.32	2,422.62	3.62	9,811.42	2,054.33	2,711.71
4	Crank shaft	2.18	9,932.81	1,488.09	1,964.28	2.18	10,907.1	1,757.25	2,319.57
5	Nozzle	3.45	9,634.98	1,350.53	1,782.70	3.45	11,536.4	1,564.59	2,065.26
6	Cyl. head	2.42	9,331.37	1,184.33	1,563.32	2.42	11,139.1	1,359.60	1,794.67
7	FMA	3.88	13,496.37	1,100.00	1,452.00	3.88	14,758.3	1,248.53	1,648.06
8	BP kit	1.98	8,333.48	1,089.61	1,438.28	1.98	9,951.9	1,296.19	1,710.97
9	Regulator	4.40	10,602.86	681.34	899.37	4.40	12,722.9	805.54	1,063.31
10	Ex. muffler	3.62	8,199.72	662.42	874.39	3.62	9,760.83	778.12	1,027.11
11	Delivery valve	2.83	4,373.63	587.38	775.35	2.83	5,214.75	656.35	866.38
12	CAM shaft	1.79	28,851.96	491.84	649.23	1.79	31,696.5	583.28	769.92
13	Feed pump	1.39	47,555.60	333.33	440.00	1.39	52,173.5	390.35	515.26
14	Crank shaft support	2.01	38,249.60	284.43	375.44	2.01	45,657.8	327.48	432.27
15	Connecting rod assy	2.43	4,665.68	274.88	362.85	2.43	5,566.89	310.73	410.16
16	Lub oil pump	1.90	18,083.35	238.09	314.28	1.9	19,713.6	262.26	346.18
17	CAM and follower set	1.61	29,065.05	235.68	311.10	1.61	31,707.5	261.41	345.06
18	Governor gear	3.36	5,554.26	181.57	239.67	3.36	6,663.39	228.72	301.91
19	Governor support assy	4.40	5,301.43	201.26	265.66	4.40	6,356.82	224.35	296.14
20	Valve set	2.07	10,146.41	154.01	203.29	2.07	12,167.2	171.97	227.00
21	Roller tappet	4.40	5,301.43	126.44	166.90	4.4	6,355.22	151.58	200.09
22	Set of rocker lever	2.29	6,420.42	122.13	161.21	2.29	7,649.58	139.78	184.51
23	Diaphragm	2.83	2,915.75	80.85	106.72	2.83	3,471.4	89.90	118.67
24	High pressure pipe	3.36	11,108.52	74.86	98.81	3.36	13,240.7	82.38	108.74
25	LE bearing	1.79	12,767.51	48.24	63.68	1.79	13,917.7	53.11	70.10
26	Set of bushes	1.70	49,520.84	61.60	81.31	1.7	54,164.9	70.09	92.52
27	Bush STD	1.70	49,520.84	49.44	65.26	1.7	54,164.9	57.02	75.26
28	Bush F.W.E. side	1.70	49,520.84	45.07	59.49	1.7	54,164.9	52.15	68.84
29	Set of valve guides	2.79	14,013.15	37.16	49.04	2.79	15,348.8	43.11	56.90

achieved by the manufacturer is Rs 3,687.19 which is 11.78 per cent and is less than the actual target of 20 per cent.

Results of the Iteration 1 shows that the values obtained are not as per the expectations. However, instead of cancelling the deal, there may be a possibility of negotiation between the manufacturer and the OEM. Modelling such negotiation mechanism is a challenge as it will involve re-optimizing all the decision variables under varying degree of relaxation of target values by the OEM.

As the solution is not achieved in the first iteration, the automated negotiation process start with the second iteration in which relaxation is given in one or more of the target values like AAR, SPCL or buying price (OEM) and order quantity. Some of the cases of automated negotiation are discussed in the following section. The preferences used for relaxation in the following cases are only illustrative examples to demonstrate the utility of the negotiation model. In other case, the relaxation priority may vary and it can be decided as per the mutual agreement between manufacturer and OEM.

The increments and the priority in which the relaxation can be carried out are given as an input based on the agreement between the manufacturer and the OEM. For example, the relaxation for buying price is given in steps of 5 per cent each with maximum of 10 per cent. In the automated negotiation at the decision point, with given relaxation steps, the manufacturer carries out optimization until the condition of $BP_{OEM} \geqslant SP_{Mfg}$ is satisfied. Once this is achieved, the manufacturer compares it with the maximum allowed relaxation input given by the OEM. If the maximum allowed relaxation is less than the relaxation with which the solution of the optimization is achieved. Then the maximum allowed relaxation is carried forward and the manufacturer offers relaxation in the next priority target value and same steps are followed as like previous relaxation given. If still the solution is not achieved, the manufacturer tries to achieve the solution with relaxation in combination of two or more target values at the same time.

6.1 Case 1

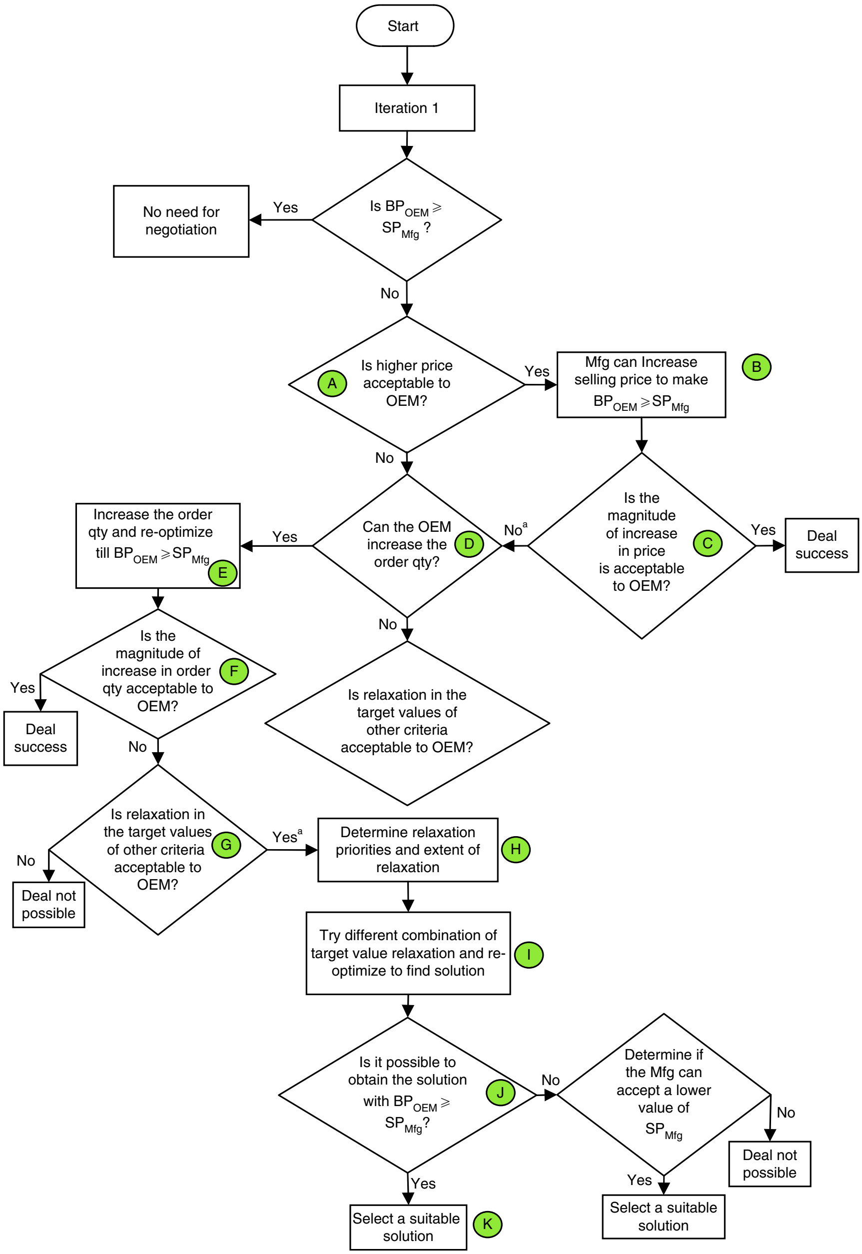
The flow of steps followed is represented using flowchart as shown in Figure 1.

The manufacturer and the OEM have decided the priority for the relaxation in the sequence of buying price (OEM), order quantity, SPCL and AAR. This is given as an input for the automated negotiation.

The maximum relaxation in the buying price and the order size is decided by the OEM and based on that, the input is given for the negotiation stages. For example, in the present case, the OEM has communicated the initial order quantity as 5,000 units. The maximum relaxation allowed for the order quantity is decided by the OEM at the appropriate negotiation stage.

	Warranty cost (Rs)	AAR/ OAI	MTBF (hr)	SPCL (Rs)	Product cost (Rs)	Profit (Rs)	Buying price of engine (Rs)
Ratio							
Target	–	1.1000	1.1000	0.9000	–	0.2000	1.0000
Achieved	–	1.1294	1.1529	0.9254	–	0.1178	1.0736
Values							
Target	700.00	302.50	429.00	53,100.00	–	6,262.56	35,000.00
Achieved	699.44	310.58	449.65	54,600.01	31,312.79	3,687.21	37,575.35

Table III. Basic solution obtained using targeted values



Note: [a]Use max. allowable increase

Figure 1.
Flowchart representing case "A" to "K" of negotiation

This case shows that the solution is achieved with relaxation of target values in different proportions, demonstrating a successful negotiation. The results of the case are discussed in greater detail in the following steps.

Step "A": after carrying out optimization in the first iteration, the manufacturer compares the selling price (SP_{Mfg}) of the engine with the buying price (BP_{OEM}) set by the OEM. If the SP_{Mfg} is higher than the BP_{OEM}, the manufacturer obtains the OEM inputs with regards to allowable relaxation in the buying price. For the present case, it is assumed that the OEM has agreed for increasing the buying price (BP_{OEM}) and hence the manufacturer proceeds to the next step.

Step "B": the manufacturer increases the allowable buying price and relooks for a solution such that $BP_{OEM} \geqslant SP_{Mfg}$. The manufacturer carries out re-optimization by setting the increase in the buying price as 5 per cent in each step.

Table IV shows the optimization results for a 5 per cent increase in the BP_{OEM}. The result shows, the selling price (SP_{Mfg}) is higher than buying price (BP_{OEM}) by Rs 1,383.18 and also the profit obtained is Rs 4,972.34 which is 15.65 per cent which is still less than targeted 20 per cent.

The manufacturer again resets the allowable increase in the BP_{OEM} as 10 per cent, leading to a BP_{OEM} of Rs 38,500, and re-optimizes. The result indicated in Table V shows that the manufacturer now able to offer a selling of Rs 38,359.21, which is less than the new target buying price for the OEM. The manufacturer has also succeeded in achieving a profit of Rs 6,533.99 which is 20.44 per cent of the product cost.

Step "C": based on these results, the manufacturer check with the input given by the OEM. The manufacturer checks whether this much increase in buying price is acceptable to the OEM? If the OEM agrees then the deal is successful and negotiation ends here.

	Warranty cost (Rs)	AAR/ OAI	MTBF (hrs)	SPCL (Rs)	Product cost (Rs)	Profit (Rs)	Buying price of engine (Rs)
Ratio							
Target	–	1.1000	1.1000	0.9000	–	0.2000	1.0500
Achieved	–	1.1495	1.1853	0.9140	–	0.1565	1.0895
Values							
Target	735.00	302.50	429.00	53,100.00	–	6,355.53	36,750.00
Achieved	668.38	316.12	462.27	53,924.98	31,777.65	4,972.35	38,133.18

Table IV. Solution obtained using 5 per cent relaxation in BP_{OEM}

	Warranty cost (Rs)	AAR/ OAI	MTBF (hrs)	SPCL (Rs)	Product cost (Rs)	Profit (Rs)	Buying price of engine (Rs)
Ratio							
Target	–	1.1000	1.1000	0.9000	–	0.2000	1.1000
Achieved	–	1.1102	1.2280	0.9184	–	0.2044	1.0960
Values							
Target	770.00	302.50	429.00	53,100.00	–	6,393.20	38,500.00
Achieved	710.75	305.30	478.93	54,188.04	31,966.01	6,533.99	38,359.21

Table V. Solution obtained using 10 per cent relaxation in BP_{OEM}

Since in the present case, the OEM agrees only for 5 per cent relaxation, the negotiation process moves to Step D.

From Table IV, it can be seen that with 5 per cent increase in the buying price, the solution cannot be obtained.

Step "D": the manufacturer checks for the next priority for relaxation and decides to consider a relaxation in the order quantity as agreed by the OEM.

Note: it may be noted that the negotiation process first tries one target relaxation at a time, i.e., while it considers relaxation in the order quantity, it does not consider the relaxation in the BP_{OEM}.

Step "E": the manufacturer re-optimizes with a relaxation in the order quantity until the condition $BP_{OEM} \geqslant SP_{Mfg}$. In the first step, the manufacturer considers a higher order quantity of 15,000 units for which the manufacturer will get benefit of 5 per cent reduction in the component costs. Table VI shows the optimization results for an order quantity of 15,000 units. The solution shows that the value obtained for the selling price (SP_{Mfg}) is more than the target buying price (BP_{OEM}) by Rs 1,106.57 and the profit obtained is 16.32 per cent which is less than the target profit of 20 per cent.

The manufacturer goes to the next step where the OEM needs to order a minimum of 25,000 units for which the manufacturer gets a reduction of 10 per cent in the component cost.

With an order quantity of 25,000 units, the optimization is carried out by the manufacturer, the results of which are shown in Table VII. With this relaxation, the manufacturer has now obtained a solution such that $BP_{OEM} \geqslant SP_{Mfg}$ and profit margin = 21.45 per cent.

Step "F": based on these results, the manufacturer checks whether this much increase in the order quantity is acceptable to the OEM? If the OEM agrees then the

Table VI. Result obtained for an order quantity of 15,000 units

	Warranty cost (Rs)	AAR/ OAI	MTBF (hrs)	SPCL (Rs)	Product cost (Rs)	Profit (Rs)	Buying price of engine (Rs)
Ratio							
Target	–	1.1000	1.1000	0.9000	–	0.2000	1.0000
Achieved	–	1.1473	1.1758	0.9153	–	0.1632	1.0316
Values							
Target	700.00	302.50	429.00	53,100.00	–	6,017.76	35,000.00
Achieved	716.49	315.50	458.55	54,003.04	30,088.81	4,911.19	36,106.57

Table VII. Result obtained for an order quantity of 25000 units

	Warranty cost (Rs)	AAR/ OAI	MTBF (hrs)	SPCL (Rs)	Product cost (Rs)	Profit (Rs)	Buying price of engine (Rs)
Ratio							
Target	–	1.1000	1.1000	0.9000	–	0.2000	1.0000
Achieved	–	1.1465	1.2238	0.9119	–	0.2145	0.9880
Values							
Target	700.00	302.50	429.00	53,100.00	–	5,763.51	35,000.00
Achieved	700.16	315.29	477.27	53,802.08	28,817.53	6,182.47	34,581.04

deal is successful and the negotiation ends here. In the present case it is assumed that the OEM is ready to increase the order to 9,000 units where manufacturer will get a 2 per cent reduction in components cost. But results in Table VI shows, even with order quantity of 15,000 units, the solution cannot be achieved.

Till this point, only one target relaxation was considered at a time. Since a solution could not be obtained, the negotiation process proceeds by simultaneously considering multiple relaxations. This is however done by considering only the allowable values of relaxation.

The manufacturer decides to check whether the solution can be obtained with combination of relaxation in buying price of 5 per cent and order quantity of 9,000 units which is the maximum relaxation allowed by the OEM. The manufacturer again carries out the optimization with this combination, the results of which are shown in Table VIII. It shows that required target values cannot be achieved as the SP_{Mfg} is higher than BP_{OEM} by Rs 497.23 and the profit achieved is 18.40 per cent.

Step "G": since the solution is not achieved, the negotiation will proceed further only is the OEM agrees to relax the other targets which are related to the SPCL and AAR. These were not provided till now as they are directly related to customer's perception and satisfaction. For this illustrative case, it is assumed that the OEM has agreed for some relaxation in these targets.

Step "H": based on the inputs given, first priority for relaxation is given to SPCL and then to AAR. Considering these priorities, optimization is carried out in the next step with different combinations of target value relaxations to find out the solution.

Step "I": it may be noted that the maximum allowable relaxation in BP_{OEM} and order quantity is carry forward for all optimizations. The combinations considered are:

(1) relaxation of 5 per cent in BP_{OEM}, 9,000 units as order quantity and 5 per cent in SPCL;

(2) relaxation of 5 per cent in BP_{OEM}, 9,000 units as order quantity and 5 per cent in AAR; and

(3) relaxation of 5 per cent in BP_{OEM}, 9,000 units as order quantity, 5 per cent in SPCL and 5 per cent in AAR.

The results of optimization for the above three combinations are given in Tables IX-XI.

Step "J": the results obtained in Tables IX-Table XI are compared. It shows that, lowest the lowest SP_{Mfg} of Rs 35,682.97 and highest profit margin of 23.59 per cent is obtained in Table XI but it violates the SPCL constraint. However, the solution in Table IX satisfies all the constraints and hence should be considered as the final solution.

	Warranty cost (Rs)	AAR/OAI	MTBF (hrs)	SPCL (Rs)	Product cost (Rs)	Profit (Rs)	Price of engine (Rs)
Ratio							
Target	–	1.1000	1.1000	0.9000	–	0.2000	1.0000
Achieved	–	1.1473	1.1749	0.9143	–	0.1840	1.0642
Values							
Target	735.00	302.50	429.00	53,100.00	–	6,207.87	36,750.00
Achieved	742.90	315.50	458.22	53,942.17	31,039.36	5,710.64	37,247.23

Table VIII. Result obtained for 5 per cent relaxation in BP_{OEM} and an order quantity of 9000 units

Step "K": hence, the manufacturer decided to offer the solution with relaxation of 5 per cent in BP_{OEM}, 9,000 units as order quantity and 5 per cent relaxation in SPCL to the OEM. The deal is successful and the negotiation ends here.

6.2 Case 2

The Case 2 is represented using flowchart in Figure 2. The flow of process is indicated by "a" to "f".

In this case, the OEM is not agreed to increase the buying price but ready to increase the order quantity. The manufacturer carries out relaxation with steps of 5 per cent each and checks for the solution. The OEM is not agree to increase the order quantity beyond certain limit, i.e., above 15,000 units in which maximum of 5 per cent relaxation in order quantity is possible. If the solution is not achieved with this, the OEM is also not ready to compromise on other target values. With the given constraints, the

Table IX. Solution obtained for relaxation of 5 per cent in BP_{OEM}, SPCL and an order quantity of 9,000 units

	Warranty cost (Rs)	AAR/OAI	MTBF (hrs)	SPCL (Rs)	Product cost (Rs)	Profit (Rs)	Buying price of engine (Rs)
Ratio							
Target	–	1.1000	1.1000	0.9500	–	0.2000	1.0500
Achieved	–	1.1283	1.1047	0.9481	–	0.2319	1.0228
Values							
Target	735.00	302.50	429.00	56,050.00	–	5,966.36	36,750.00
Achieved	688.75	310.28	430.82	55,940.31	29,831.79	6,918.21	35,798.15

Table X. Result obtained for relaxation of 5 per cent in BP_{OEM}, AAR and an order quantity of 9,000 units

	Warranty Cost (Rs)	AAR/OAI	MTBF (hrs)	SPCL (Rs)	Product Cost (Rs)	Profit (Rs)	Buying Price of Engine (Rs)
Ratio							
Target	–	1.0500	1.1000	0.9000	–	0.2000	1.0500
Achieved	–	1.1268	1.1883	0.9142	–	0.1813	1.0667
Values							
Target	735.00	288.75	429.00	53,100.00	–	6,222.18	36,750.00
Achieved	722.88	309.86	463.43	53,939.55	31,110.91	5,639.09	37,333.09

Table XI. Result obtained for relaxation of 5 per cent in BP_{OEM}, SPCL, AAR and an order quantity of 9,000 units

	Warranty cost (Rs)	AAR/OAI	MTBF (hrs)	SPCL (Rs)	Product cost (Rs)	Profit (Rs)	Buying price of engine (Rs)
Ratio							
Target	–	1.0500	1.1000	0.9500	–	0.2000	1.0500
Achieved	–	1.0884	1.1151	0.9542	–	0.2359	1.0195
Values							
Target	735.00	288.75	429.00	56,050.00	–	5,947.16	36,750.00
Achieved	683.43	299.32	434.90	56,296.59	29,735.81	7,014.19	35,682.97

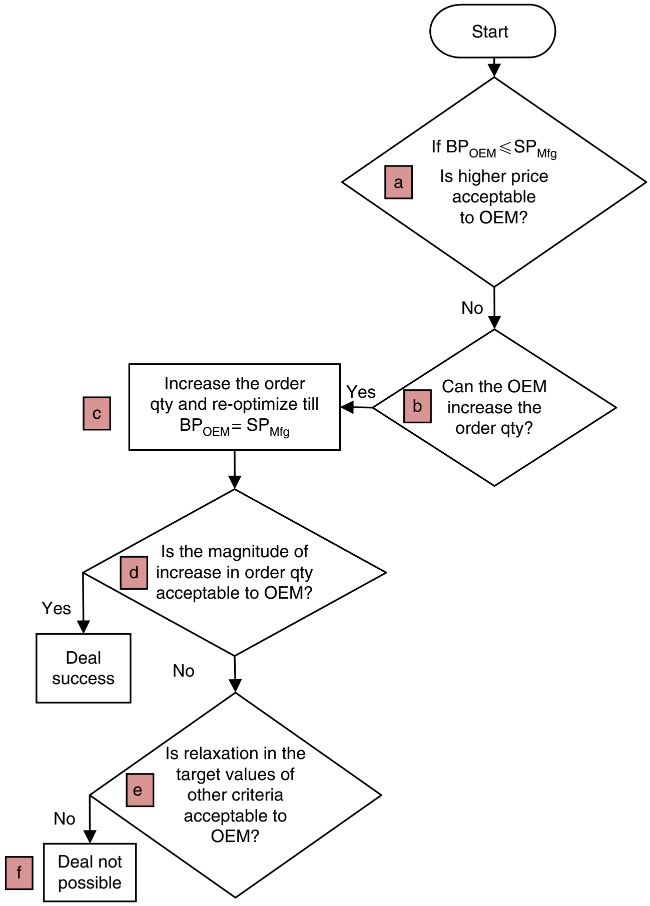


Figure 2.
Flowchart representing case "a" to "f" of negotiation

solution is not achieved and this results into case of unsuccessful negotiation. With the given inputs, the working of automated negotiation is explained in detail in the following steps:

Step "a": if the condition in shown flowchart after Iteration 1 is not satisfied, the manufacturer offers to increase the selling price to satisfy the condition.

Step "b": if the OEM rejects it, the manufacturer checks for relaxation in order quantity. If the OEM is agreed, the manufacturer moves to the next step.

Step "c": the manufacturer internally carried out optimization to achieve the required target values for selling price. Results in Table XII shows that, with an order quantity of 15,000, the targeted values are not obtained with selling price is higher by Rs 1,106.57 as compared to target value and profit of 16.32 per cent against set target of 20 per cent.

The manufacturer again carry out re-optimization with an order quantity 25,000. He/she obtained the solution as shown in Table XIII, with selling price as Rs 34,571.04 and profit of 21.45 per cent. The manufacturer asks the OEM, whether 10 per cent increase in order quantity is acceptable with order size of at least 25,000 units.

Step "d": the OEM is not agree to increase the order quantity as per the inputs given. The manufacturer checks for the magnitude of relaxation acceptable to the OEM in the order quantity and carried it forward.

Step "e": the manufacturer checks for relaxation in other parameters. The OEM is not ready to relax other parameters, therefore he/she rejects the offer. The feasible solution is not obtained.

Step "f": the manufacturer and the OEM decide to quit the negotiation process. The deal is not successful in this case.

6.3 Case 3

The case is represented by using flowchart as shown in Figure 3. It flow of steps is shown by "1" to "8". In this case, the OEM is not ready to compromise on buying price and order quantity. The manufacturer carries out optimization with relaxation in SPCL first with steps of 5 per cent and then with 10 per cent. If the solution is not achieved then again he/she checks with AAR for relaxation. This is followed by trying with different combination of target value relaxation for SPCL and AAR. It is observed that the solution is not achieved as per the condition given for buying price of the OEM should be at least equal to selling price of the manufacturer. Based on the internal decisions, the manufacturer compromised on the solution with lower values of selling price and profit in order to make a successful deal with the OEM. This finally results into successful negotiation. The detail of the case is explained in the following paragraphs.

Step "1": in this step as per the input given by the OEM, he/she is not agreed to increase the buying price to make it equal to selling price which the manufacturer has obtained in Iteration 1.

Table XII. Solution obtained for an order quantity of 15,000 units

	Warranty cost (Rs)	AAR/ OAI	MTBF (hrs)	SPCL (Rs)	Product cost (Rs)	Profit (Rs)	Buying price of engine (Rs)
Ratio							
Target	–	1.1000	1.1000	0.9000	–	0.2000	1.0000
Achieved	–	1.1473	1.1758	0.9153	–	0.1632	1.0316
Values							
Target	700.00	302.50	429.00	53,100.00	–	6,017.76	35,000.00
Achieved	716.49	315.50	458.55	54,003.04	30,088.81	4,911.19	36,106.57

Table XIII. Solution obtained for an order quantity of 25000 units

	Warranty cost (Rs)	AAR/ OAI	MTBF (hrs)	SPCL (Rs)	Product cost (Rs)	Profit (Rs)	Buying price of engine (Rs)
Ratio							
Target	–	1.1000	1.1000	0.9000	–	0.2000	1.0000
Achieved	–	1.1465	1.2238	0.9119	–	0.2145	0.9880
Values							
Target	700.00	302.50	429.00	53,100.00	–	5,763.51	35,000.00
Achieved	700.16	315.29	477.27	53,802.08	28,817.53	6,182.47	34,581.04

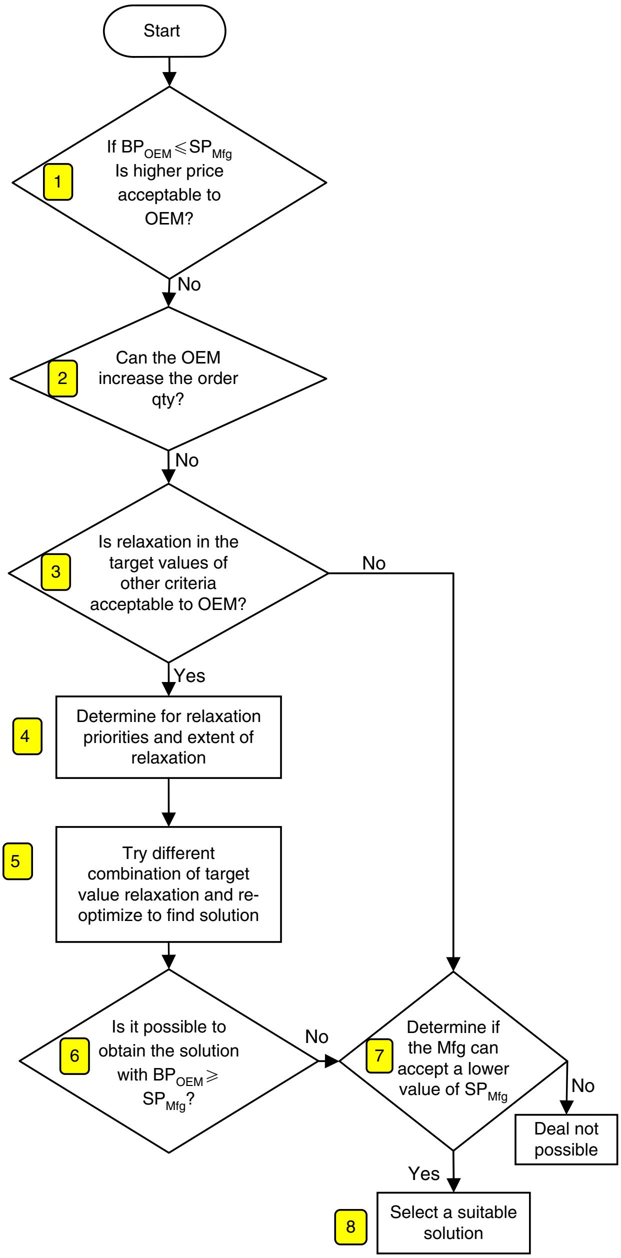


Figure 3.
Flowchart representing case "1" to "8" of negotiation

Step "2": when the manufacturer offers to increase the selling price, the OEM is not agreed for it. Therefore, the manufacturer check for whether a higher order quantity where cost benefits can be obtained based on the inputs given by the OEM.

Step "3": if the OEM is not agreed, the manufacturer checks for relaxation in other parameters like SPCL and AAR.

Step "4": the first priority for relaxation is given to SPCL followed by next is given to AAR as decided by the manufacturer and the OEM. The extent of relaxation is decided by the OEM with maximum of 10 per cent each for SPCL and AAR.

Step "5": the manufacturer carries out the optimization with relaxation in SPCL. The manufacturer does it upto maximum of 10 per cent in steps until the given condition is satisfied. In this case, as discussed before the steps of 5 per cent each are taken for the illustrative purpose. If he/she achieves solution in the first step he/she stops there, otherwise proceed to the next step. The achieved solution is offered to the OEM for the approval. With relaxation of 5 per cent in SPCL, the solution obtained is shown in Table XIV. It can be seen that the required solution is not obtained for selling price and profit as targeted by the manufacturer. The value of the selling price is higher than Rs 969.02 as compared to target buying price and profit is 16.77 per cent of the product cost as compared to the target value of 20 per cent.

The manufacturer carries out the re-optimization with 10 per cent relaxation in SPCL. He/she obtained further improvement in the solution with selling price as Rs 828.77 which is more than the target buying price set by the OEM and the profit of 17.22 per cent as shown in Table XV. But it can be seen that the required solution is not obtained.

Manufacturer decides to relax the AAR requirements again in steps of 5 per cent and carry out optimization. The results with relaxation of 5 per cent in AAR are shown in Table XVI. It shows the selling price of the engine (SP_{Mfg}) obtained is very high with value of Rs 37,778.74 and also profit margin is very less with achieved value of 11.17 per cent.

The manufacturer again carries out relaxation of 10 per cent in AAR, the results obtained in Table XVII shows there is not much improvement in the values of the

Table XIV.
Solution obtained with 5 per cent relaxation in SPCL

	Warranty cost (Rs)	AAR/OAI	MTBF (hrs)	SPCL (Rs)	Product cost (Rs)	Profit (Rs)	Buying price of engine (Rs)
Ratio							
Target	–	1.1000	1.1000	0.9500	–		1.0000
Achieved	–	1.1708	1.0619	0.9501	–	0.1677	1.0277
Values							
Target	700.00	302.50	429.00	56,050.00	–	5,994.84	35,000.00
Achieved	715.02	321.96	414.15	56,053.85	29,974.18	5,025.82	35,969.02

Table XV.
Solution obtained with 10 per cent relaxation in SPCL

	Warranty cost (Rs)	AAR/OAI	MTBF (hrs)	SPCL (Rs)	Product cost (Rs)	Profit (Rs)	Buying price of engine (Rs)
Ratio							
Target	–	1.1000	1.1000	1.0000	–	0.2000	1.0000
Achieved	–	1.1008	0.9863	0.9844	–	0.1722	1.0237
Values							
Target	700.00	302.50	429.00	59,000.00	–	5,971.46	35,000.00
Achieved	699.31	302.73	384.65	58,081.72	29,857.31	5,142.69	35,828.77

results. Selling price obtained is somewhat better with Rs 37,637.29 and profit of 11.59 per cent. The values are still less than the target.

By looking into results obtained with relaxation in SPCL and AAR in different proportion, the required solution is not obtained. Hence, the manufacturer decides to optimize the SPCL and AAR in combination with different proportion of relaxation. Table XVIII shows the results obtained with different proportion of combinations of AAR and SPCL.

Step "6": it is observed from the values obtained in Table XVIII that no solution is achieved in terms of targeted values for selling price (SP_{Mfg}) and profit margin. With relaxation of 10 per cent each in SPCL and AAR, to the OEM, the minimum value of SP_{Mfg} with Rs 35,479.02 and the maximum profit of 18.38 per cent is achieved as compared with other solutions obtained.

Step "7": the manufacturer decides internally about lowering the selling price to make it equal to target buying price, i.e., Rs 35,000. With this decision he/she has settle with lower selling price. The profit margin is also reduced to 16.76 per cent. It is seen that other target values for AAR, warranty cost and SPCL are also obtained. Only in case of MTBF, the value obtained is lower than the target value but this can be acceptable.

Step "8": the manufacturer conveys the offer with relaxation of 10 per cent each in SPCL and AAR, to the OEM and once the OEM accepts this offer, the negotiation ends here successfully.

Different cases of negotiation are discussed in the present section. In the first case, negotiation is successful when relaxation provided by 5 per cent each in buying price, SPCL and AAR and 2 per cent in order quantity. In the second case, negotiation is not successful as OEM is not agreed for relaxation in any of the target values. In the third

	Warranty cost (Rs)	AAR/ OAI	MTBF (hrs)	SPCL (Rs)	Product cost (Rs)	Profit (Rs)	Buying price of engine (Rs)
Ratio							
Target	–	1.0500	1.1000	0.9000	–	0.2000	1.0000
Achieved	–	1.0655	1.1837	0.9204	–	0.1117	1.0794
Values							
Target	700.00	288.75	429.00	53,100.00	–	6,296.46	35,000.00
Achieved	688.49	293.02	461.64	54,305.70	31,482.28	3,517.72	37,778.74

Table XVI. Solution obtained with 5 per cent relaxation in AAR

	Warranty cost (Rs)	AAR/ OAI	MTBF (hrs)	SPCL (Rs)	Product cost (Rs)	Profit (Rs)	Buying price of engine (Rs)
Ratio							
Target	–	1.0000	1.1000	0.9000	–		1.0000
Achieved	–	1.0300	1.1635	0.9218	–	0.1159	1.0754
Values							
Target	700.00	275.00	429.00	53,100.00	–	6,272.88	35,000.00
Achieved	704.20	283.26	453.76	54,388.96	31,364.41	3,635.59	37,637.29

Table XVII. Solution obtained with 10 per cent relaxation in AAR

Table XVIII. Solution obtained with relaxation in SPCL and in AAR in different proportions

	Warranty cost (Rs)	AAR/OAI	MTBF (hrs)	SPCL (Rs)	Product cost (Rs)	Profit (Rs)	Buying price of engine (Rs)
5% relaxation in SPCL and 5% in AAR							
Ratio							
Target	–	1.0500	1.1000	0.9500	–	0.2000	1.0000
Achieved	–	1.0885	1.0523	0.9518	–	0.1628	1.0314
Values							
Target	700.00	288.75	429.00	56,050.00	–	5,901.14	35,000.00
Achieved	691.22	299.34	410.39	56,159.05	29,505.70	4,803.07	36,098.06
5% relaxation in SPCL and 10% in AAR							
Ratio							
Target	–	1.0000	1.1000	0.9500	–	0.2000	1.0000
Achieved	–	1.0483	1.0336	0.9607	–	0.1668	1.0284
Values							
Target	700.00	275.00	429.00	56,050.00	–	5,999.12	35,000.00
Achieved	705.06	288.29	403.11	56,681.22	29,995.60	5,004.40	35,994.72
10% relaxation in SPCL and 5% in AAR							
Ratio							
Target	–	1.0500	1.1000	1.0000	–	0.2000	1.0000
Achieved	–	1.0726	0.9863	0.9868	–	0.1719	1.0240
Values							
Target	700.00	288.75	429.00	59,000.00	–	5,973.06	35,000.00
Achieved	700.21	294.97	384.64	58,220.82	29,865.29	5,134.71	35,838.35
10% relaxation in SPCL and AAR							
Ratio							
Target	–	1.0000	1.1000	1.0000	–	0.2000	1.0000
Achieved	–	1.0052	0.9828	0.9799	–	0.1838	1.0137
Values							
Target	700.00	275.00	429.00	59,000.00	–	5,913.17	35,000.00
Achieved	677.01	276.43	393.30	57,812.44	29,565.85	5,434.15	35,479.02

case, negotiation is successful with relaxation of 10 per cent each in SPCL and AAR, but manufacturer has to settle with lower selling price and lower profit margin.

6.4 Results

From the different cases discussed in the previous section for negotiation, in two of the cases negotiation is successful and it is unsuccessful for the other case. The values for the decision variables for two of the successful negotiation cases are shown in Tables XIX and XX.

The results show that better warranty parameters are achieved after optimization and also results into achievement of other target goals set by the manufacturer as well as customer.

7. Conclusion and future scope

In this paper a bilateral automated warranty-based negotiation model is developed. The model is illustrated using a real life example of an automobile engine manufacturer. Negotiation methodology is demonstrated using different cases for negotiation. The proposed negotiation methodology explained in this paper will help the manufacturer in optimizing the decision variables while achieving the targeted profit. The manufacturer and customer may change their target goals and give the preferences as per their priorities. The approach is really useful at the design stage

Sl. no.	Component	Warranty duration (months)	Component alternatives	Warranty policy	Support level
1	Crank case	25	1	PRW-NR	2
2	Starter motor	21	1	PRW-NR	1
3	Fuel pump assy	17	2	PRW-NR	3
4	Crank shaft	17	1	PRW-NR	2
5	Nozzle	19	1	PRW-NR	2
6	Cylinder head	16	1	PRW-NR	3
7	FMA	22	1	PRW-NR	1
8	BP Kit	26	2	PRW-NR	3
9	Regulator	19	2	PRW-NR	1
10	Ex. muffler	20	2	PRW-NR	3
11	Delivery valve	18	2	PRW-NR	1
12	CAM shaft	16	1	PRW-NR	1
13	Feed pump	23	2	PRW-NR	2
14	Crank shaft support	16	1	PRW-R	1
15	Connecting rod assy	17	1	PRW-NR	3
16	Lub oil pump	23	1	PRW-NR	3
17	CAM and follower set	16	1	PRW-NR	3
18	Governor gear	20	2	PRW-NR	1
19	Governor support assy	21	2	PRW-NR	1
20	Valve set	17	2	PRW-NR	1
21	Roller tappet	20	2	FRW-NR	1
22	Set of rocker lever	21	1	PRW-NR	3
23	Diaphragm	17	2	PRW-NR	3
24	High pressure pipe	16	2	PRW-NR	1
25	LE bearing	16	2	FRW-NR	3
26	Set of bushes	29	1	PRW-NR	3
27	Bush STD	16	2	PRW-NR	1
28	Bush F.W.E. side	23	2	PRW-NR	1
29	Set of valve guides	18	2	PRW-NR	3

Table XIX. Decision variables for Case "A" to "K"

where decision regarding the warranty-related parameters is a critical task for the designer. As the approach also considers competitor's warranty strategy, the results obtained using this approach are also helpful to decide the competitive strategy while achieving the targeted goals set by the manufacturer.

The present study has following limitations:

- only two parties are considered in the negotiation; and
- warranty policies considered are one dimensional warranty policies.

The present work can be extended for future research by considering the following aspects:

- the influence of maintenance policy on warranty parameters like SPCL, warranty cost, MTBF, etc can be considered;
- the negotiation problem can be solved by considering two dimensional warranty policy;
- the multi-lateral negotiation of complex systems can be considered for negotiation; and
- the problem can be extended to multi-party negotiation.

Sl. no.	Component	Warranty duration (months)	Component alternatives	Warranty policy	Support level
1	Crank case	16	1	PRW-R	3
2	Starter motor	21	1	PRW-NR	3
3	Fuel pump assy	21	1	PRW-NR	3
4	Crank shaft	16	1	PRW-NR	3
5	Nozzle	20	1	PRW-R	3
6	Cylinder head	20	2	PRW-NR	2
7	FMA	21	2	PRW-NR	1
8	BP kit	16	1	PRW-R	3
9	Regulator	16	1	PRW-NR	3
10	Ex. muffler	17	1	PRW-NR	3
11	Delivery valve	16	1	PRW-NR	1
12	CAM shaft	17	1	FRW-NR	3
13	Feed pump	17	1	PRW-NR	3
14	Crank shaft support	22	1	PRW-NR	3
15	Connecting rod assy	17	1	PRW-NR	3
16	Lub oil pump	20	1	PRW-NR	3
17	CAM and follower set	18	1	PRW-NR	3
18	Governor gear	17	1	PRW-NR	3
19	Governor support assy	19	2	PRW-NR	3
20	Valve set	20	1	PRW-R	1
21	Roller tappet	21	1	PRW-NR	3
22	Set of rocker lever	16	1	PRW-NR	1
23	Diaphragm	20	1	FRW-NR	3
24	High pressure pipe	18	1	PRW-NR	3
25	LE bearing	21	1	PRW-NR	3
26	Set of bushes	21	1	PRW-NR	3
27	Bush STD	29	1	PRW-NR	1
28	Bush F.W.E. side	20	1	PRW-NR	1
29	Set of valve guides	21	1	PRW-NR	3

Table XX.
Decision variables for Case "1" to "8"

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