AutoMed - An Automated Mediator for Multi-Issue Bilateral Negotiations*

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Abstract

In this paper, we present AutoMed, an automated mediator for multi-issue bilateral negotiation under time constraints. AutoMed elicits the negotiators preferences and analyzes them. It monitors the negotiations and proposes possible solutions for resolving the conflict.

We conducted experiments in a simulated environment. The results show that negotiations mediated by AutoMed are concluded significantly faster than non-mediated ones and without any of the negotiators opting out. Furthermore, the subjects in the mediated negotiations are more satisfied with the resolutions than the subjects in the non-mediated negotiations.

1 Introduction

Engaging in negotiations is an everyday activity. Some negotiations cannot be concluded in a manner satisfying both sides without the involvement of someone other than the negotiators themselves. In such cases, the intervention of a non-biased, competent authority such as a court of justice is required in order to finalize the debate. Another possible third party intervention can be that of a mediator. In mediation scenarios, the objective is to help the negotiators reach a mutually beneficial agreement. Namely, one that provides the best possible solution considering the various preferences of each negotiator [22, 11].

Several types of mediators are described in the literature. A *manipulative* mediator [40] uses his position to manipulate the parties into agreement, while

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the *formulating* mediator [46] proposes new solutions and assists the negotiators when an impasse in the negotiation is reached.

Aside from reaching an agreement, there are two additional options to concluding a negotiation. First, each negotiator can opt out of the negotiations, forcing continuation of the present situation of status quo on both sides. Second, the negotiation might reach a deadline, if such exists, thereby maintaining the status quo on issues not yet agreed upon. Concluding the negotiations with the status quo most probably will not resolve the dispute but worsen it by intensifying a strike or declaring the beginning of battles, etc.

Sometimes approaching a human mediator is undesirable due to either high financial costs or because the parties are unable to agree on a mutual mediator. One option is to use Online Dispute Resolution (ODR) [3] tools which usually act as support systems for dispute resolutions, such as negotiation, mediation, and arbitration provided online. In many cases, a completely automated mediator can present an alternative. It can be completely confidential, non-biased and can offer neutral ground. There have been a number of attempts to create automated mediators. Some act as support systems (i.e., SmartSettle [37]), while others are topic embedded, such as Family_Winner [1] and the PERSUADER [36], which acts as a manipulative mediator. The HERMES system [16] is a collaborative decision support system which uses ZENO [13, 17] as its argumentation framework.

Our research focuses on developing an automated formulating mediator, termed AutoMed, which is not topic embedded. This type of mediator can also be used as a standardized mediator for studies in psychology and political science [12].

Most negotiating systems use a quantitative model in order to represent the negotiators, mainly comprising utility functions [24]. Utility functions are ideal for representing and reasoning with user preferences in quantitative models. Unfortunately, people find it difficult to express their preferences using a utility function. Moreover, many real-world situations are not suitable for the application of utility functions, especially delicate situations which might include possible loss of lives, imprisonment or serious injuries. In such cases, the association of exact numerical values to solution possibilities is a highly difficult task, so that using utility functions is equally difficult.

An alternative preference representation approach is models that allow the user to represent preferences without assigning accurate numerical values. Instead they only require the user to rank attributes and their possible values. Such approaches include, for example, Quantitative Belief Functions [43], preferences on goals [42], 3-point intervals [31], CP networks [4, 5, 6]. However, the mediator must compare possible agreements and rank them. For this, AutoMed takes the loose order given by the negotiators, assigns a numerical value to each agreement and uses it as an estimation for ordering the agreements for each negotiator. Finally, it uses these ordered lists to make proposals to the negotiators.

We make the following assumptions concerning the negotiations with which we deal:

- Each negotiator knows her own preferences regarding the possible solutions but has no accurate knowledge of the other negotiator's preferences. Thus we are concerned with *incomplete information* environments.

- There is at least one agreement that is preferred by both negotiators over the options of opting out of the negotiations or reaching the deadline with no resolution.

These assumptions are valid in several dispute domains, such as e-commerce, settlement of labor disputes through labor contracts, etc. In such environments the duration of the negotiation might have a great effect on its outcome, since the dispute may incur high costs - financial or other - for both or at least one of the parties or costs might even rise as time goes by. There might also be some deadline whereby an agreement must be reached before negotiations become irrelevant (e.g. approaching a court date, outbreak of battles, intensification of a strike, etc.).

This research focuses on the development of a new mediation tool and presents AutoMed, an automated mediator for bilateral negotiations under time constraints. The situations we consider are bilateral negotiations, in which, for simplicity reasons, each side is represented by a single negotiator.

A number of innovative approaches were used while developing AutoMed:

- Most negotiating tools existing today use utility functions as the preferred user representation model. Since utility functions might be very difficult to define in situations like the ones described, AutoMed allows the negotiators to represent their preferences without assigning accurate numerical values.

- The disputes AutoMed mediates can consist of a finite number of multiple issues and a finite number of possible multiple values for each issue, while the negotiators need to agree on a single value for each issue. Since there is no one agreement which is the *best* for both negotiators, AutoMed must find a middle ground which the negotiators might agree upon. Looking for tradeoffs makes the negotiation - and the mediation - more complex than most of the human-computer negotiations which have been dealt with to date.

- AutoMed is a fully automatic mediator which is not topic embedded and can be used for any bilateral dispute that meets our assumptions. AutoMed can be presented with a predefined set of issues and values to be discussed in the current scenario. Alternatively, it can supply an environment for defining it.

- AutoMed acts as a formulating mediator, rather than a manipulative one. It tries to propose solutions and helps the negotiators reach a mutually agreed outcome.

Two separate experiments were conducted. In the first, 48 participants took part. This experiment was conducted in order to decide which preference representation method to use - utility function or the issues and values ranking method (IVR). The experiment clearly shows that the IVR model is easier to use and significantly less time consuming than the utility functions model.

In the second experiment, 82 participants took part, and the results show that negotiations mediated by AutoMed are concluded significantly faster than non-mediated ones. They also show that all the negotiations mediated by

AutoMed conclude with agreements accepted by both parties, while in non-mediated negotiations, some end when the time limit is reached or when one side opts out. The satisfaction level of the results reached is also higher among the mediated negotiation participants.

The rest of this paper is organized as follows. First, related work is reviewed in section 2. The negotiation environment we use is detailed in section 3. AutoMed's design and developed algorithms are introduced in section 4. Proof that AutoMed suggestions are, in fact, Nash bargaining solutions is given in section 4.3 and the experiments are presented in section 5. We conclude and propose directions for future work in section 6.

2 Related Work

2.1 Mediation tools

Online Dispute Resolutions (ODR) [3] are methods for resolving disputes, the majority of which are provided online. Most ODR services are alternatives to litigation and to state justice. In this sense, they are the online transposition of the methods developed as Alternative Dispute Resolutions (ADR) [32]. One of the main forms of ODR systems is on-line mediation. Many online mediation service providers are available. For example, eBay designed a mediation room mainly in order to help resolve buyer-seller conflicts [10].

These Dispute Resolution services supply a neutral and virtual negotiation forum and discussion rules. Almost all ODR services use a human mediator to help resolve the disputes.

In recent years, a new term was introduced by Katsh & Rifken [19] in the research and development of ODR tools. While the human mediator is considered a "third party" to the dispute resolution process, the assisting "fourth party" is the technology itself. The concept of the "fourth party" suggests that ODR should not strive to create online models that simply copy offline approaches, as suggested earlier [32], but provide capabilities that were not available before and that were not employed in face to face meetings [18, 20]. These capabilities are available today due to the globalization of business, information and culture over the Internet [21], and might affect ODR as we know it today in many new ways [15]. Extensive future research is expected in this field [41].

A number of negotiation support systems are described in the literature. Family_Winner [1] is a Negotiation Support System in Australian Family Law. SmartSettle [37] is another negotiation support system that networks multiple parties located anywhere in the world and manages their confidential information with a neutral Internet site [37]. Unlike the Family_Winner and SmartSettle, AutoMed is a fully automated mediator.

The HERMES system [16] is a collaborative decision support system which was developed as part of the GeoMed (Geographical Mediation) project. HERMES acts as an assistant and advisor by facilitating communication and recommending solutions to members of a decision makers group aiming at reaching a decision. It uses an argumentation framework which is an extension of ZENO [13, 17] that provides an issue-based discussion forum [14] whereby users can propose and discuss alternative solutions by sending electronic messages to a GeoMed server. While receiving these messages, the system builds a discussion forum on the Web by classifying the inputs according to their context. Users are able to use hyperlinks to access a structured protocol of the discussion. Unlike HERMES, AutoMed is not intended for collaborative environments but rather for dispute resolutions. Whereas HERMES searches for possible solutions between user defined alternatives, AutoMed looks for alternatives not yet discussed by negotiators. Both HERMES and AutoMed use the issue-based discussion approach.

PERSUADER [36] is a computer program that acts as an automated labor mediator in hypothetical negotiations relying on Case-Based Reasoning (CBR) methods. It is a manipulative mediation system (as defined in the introduction) - unlike our development of a formulation mediation tool. Another fundamental issue is that since PERSUADER relies mainly on CBR, it might find it difficult to resolve disputes of a completely new nature not described in its database. In contrast, AutoMed relies exclusively on the definitions of the dispute at hand and the negotiators preferences over these definitions rather than on a database. Where experimentation is concerned, PERSUADER was not simulated with people, while AutoMed was.

e-Alliance [7] is a facilitator mediator that offers support for multi-issue, multi-participant (different partners can be involved) and multiple-cycle (cycles of proposals and counter proposals over the same set of attributes) negotiations. These characteristics make the facility flexible enough for use in different domains. It focuses mainly on automated agent negotiations while we consider human negotiations and focus on formulator mediators.

Oliva et al. [29, 28] formalize the functionalities an automatic mediator should be able to activate when operating in a multi agent environment.

Since AutoMed operates in bilateral human environments, rather than in a MAS, some of the defined functionalities are not implemented as part of its system. For example, the storage of the dialog protocol and its specifications as well as resolving disputes over the protocol's rules are irrelevant since AutoMed uses a pre-defined protocol (in section 3.3).

The basic functionalities defined in the above work which are relevant to AutoMed are: (1) The ability to receive and store confidential information from the negotiators, (2) Store the complete history of the dialog as it proceeds and (3) Provide automated alerts to the negotiators regarding different states of the dialog, in this case, the passage of time.

2.2 Preferences representation models

There are many approaches to representing and eliciting user preferences [35, 4, 33, 47, 2, 8]. Elicitation is the process by which the user's preferences are obtained. It usually involves very long and thorough questioning, making the elicitation a heavy burden on the user.

An interesting elicitation algorithm is used in the POET system which tries to simplify the process. POET [33] is used as a tool which attempts to automate academic advising. The preferences are represented as a set of decision trees built by the user, referred to as *dependency trees*. A leaf in a dependency tree consists of an issue value and a utility function which applies to the path represented by that leaf.

In the PANDA system [8], elicitation is dealt with as a classification problem. The researchers focused on a prenatal testing domain. In the PANDA system existing users' utility functions stored in a database are divided into non-overlapping groups, clusters, of functions. Given that k clusters were found, the problem of finding the corresponding cluster for a new user's utility is a classification problem. To solve this problem a decision tree is constructed, and when a new user's utility function is determined to belong to a given cluster, the strategy of the said cluster is associated with that user.

Utility functions [35] are an ideal tool for representing and reasoning with preferences but they can be very difficult to elicit. Moreover, they can be very difficult to calculate, especially in disputes which might include possible loss of lives, imprisonment or serious injuries.

3 Negotiation Environment

Before detailing the models and algorithms used by AutoMed as a mediator in bilateral negotiations, some definitions as well as the negotiation protocol used must be specified. The protocol specified is based on the one used by the negotiation support system SmartSettle [37]. Formally, there is a set of negotiating agents $Ag = \{1, 2\}$ that can take actions at the time interval allocated for the negotiations $\mathcal{T} = [t_0, ..., dl]$. Intuitively, dl is the deadline by which the negotiation will end.

3.1 Issues and agreements

Let $\mathcal{I} = \{I_1, I_2, \ldots, I_m\}$ be a finite set of *issues* over which the negotiators disagree. Each I_j can be assigned a *value* from a finite domain of I_j, $dom(I_j) = \{v_1^j, v_2^j, \ldots, v_{b_j}^j\}$ of possible values, where b is the maximum number of values in all issue domains and $b_j \leq b$.

Use $\vec{a} \in dom(I_1) \times dom(I_2) \times \cdots \times \ dom(I_m)$ to denote a possible *agreement* reached in the negotiation.

Use $\mathcal{A}$ to denote the list of all possible agreements and the number of agreements in $\mathcal{A}$ by k, that is, $|\mathcal{A}| = k$. The status quo is also an agreement and thus it is a member of $\mathcal{A}$. We refer to this agreement as SQ.

A *partial agreement* is an assignment of values to issues, where not all issues are assigned a value. The unassigned values are annotated with the empty value ε. We use $\mathcal{A}^-$ to denote the set of partial agreements.

Example 1 *We will demonstrate the concepts associated with agreements with an example we used in one of our experiments that concerns a job interview at a software company. The job applicant desperately wants the proposed job, while the potential employer has an urgent project for which he needs to hire a new employee.*

In this scenario a set of issues may include the salary, whether the employee will receive a company car, the pension program, the promotion possibilities and the number of work hours per day. The values for the salary issue, for example, could be 7K, 12K or 20K, the values of the company car could be true or false, the promotion could be fast, slow and with no commitments and the pension program could be an insurance pension program, a regular pension program or no pension. The possible values for the working hours could be 7, 8, 9 or flexible.

3.2 Messages

The syntax of the messages that could be sent during the negotiations is defined according to Oliva et al. [28] with some necessary modifications. In addition to the set of negotiating agents, $Ag = \{1, 2\}$ there is a mediator that denoted m. $\vec{a}$ denotes an agreement (possibly, a partial one).

The legal locutions of the bilateral negotiation protocol are:

L1: a-propose(i,j,m,$\vec{a}$,t): negotiator $i \in Ag$ proposes an agreement (possibly partial) $\vec{a} \in \mathcal{A} \cup \mathcal{A}^-$ to negotiator $j \in Ag$, $j \neq i$, at time $t \in \mathcal{T}$.

L2: a-accept(i,j,m,$\vec{a}$,t): negotiator $i \in Ag$, $i \neq j$ accepts the offer, $\vec{a} \in \mathcal{A} \cup \mathcal{A}^-$, proposed by negotiator j at time $t \in \mathcal{T}$.

L3: a-reject(i,j,m,$\vec{a}$,t): negotiator $i \in Ag$ rejects the offer, $\vec{a} \in \mathcal{A} \cup \mathcal{A}^-$, proposed by negotiator $j \in Ag$, $j \neq i$ at time $t \in \mathcal{T}$.

L4: m-propose(m,i,j,$\vec{a}$,t): AutoMed proposes the full agreement $\vec{a} \in \mathcal{A}$ to both negotiators $i, j \in Ag$ at time $t \in \mathcal{T}$.

L5: a-m-accept(i,j,m,$\vec{a}$,t): at time $t \in \mathcal{T}$, negotiator $i \in Ag$ accepts the full agreement, $\vec{a} \in \mathcal{A}$, proposed by AutoMed.

L6: a-m-reject(i,j,m,$\vec{a}$): at time $t \in \mathcal{T}$, negotiator $i \in Ag$ rejects the full agreement, $\vec{a} \in \mathcal{A}$, proposed by AutoMed.

3.3 Negotiation protocol

The negotiations are managed by a computer program acting as a server. Both negotiators connect to a web based interface, invoking the mediator which acts as a third client on the server.

First, negotiations regarding the issues and possible values to be discussed are conducted through the negotiation interface. Following the conclusion of these negotiations, the preference elicitation interface is presented to the negotiators. The negotiators need to rank the issues (possibly with ties) and then to order the possible values of each issue. In cases where the set of issues and possible values is predefined, the preliminary negotiation is skipped and the preference elicitation interface is presented first. With the completion of this stage, the negotiation interface is displayed, enabling an exchange of messages between the negotiators.

The negotiation protocol allows each negotiator to propose possible agreements to the other side. A proposal can be sent to the other negotiator anytime - there is no predefined order. An offer is constructed by choosing a value for each issue from a list of all the values defined for that issue. Each list of values also includes the "not under discussion" value, serving as the empty value ε, which indicates a certain issue is not under discussion in this offer, that is, the offer is partial.

Agreed upon issues are accumulated to finally achieve a full agreement.

If the time limit is reached before a full agreement has been agreed upon, the values representing the status quo are assigned to every issue not yet agreed upon. Also, if one side opts out the full status quo serves as the reached agreement.

Notice that the mediator acts as a formulating mediator. It proposes solutions but has no power to enforce any of them.

For the description of the protocol, we will add one legal locution:

L7: opt-out(i,t): negotiator i elects to opt out of the negotiations at time $t \in \mathcal{T}$.

The protocol satisfies the following combination of rules, which control the order in which particular locutions may be made:

CR1: The utterances **a-accept**(i,j,m,$\vec{a}$,t) and **a-reject**(i,j,m,$\vec{a}$) can be made at any time $t \in \mathcal{T}$ by negotiator i only if there is $t' \in \mathcal{T}$ such that the utterance **a-propose**(j,i,m,$\vec{a}$,t'), $t' < t$, $i \neq j$ was made.

CR2: The utterances **a-m-accept**(i,j,m,$\vec{a}$,t) and **a-m-reject**(i,j,m,$\vec{a}$,t) can be made at time $t \in \mathcal{T}$ by negotiator i only if there is $t' \in \mathcal{T}$ such that the utterance **m-offer**(m,i,j,$\vec{a}$,t') $t' < t$, was made.

At any time in t $\mathcal{T}$, if the negotiation has not terminated earlier, any agent in the set Ag and the mediator can send an offer message. The agents in Ag can send an accept or reject message according to the CR1 and CR2 rules. The agents can opt-out at any time.

The negotiation terminates in one of the following cases:

- **a-accept**(i,j,m,$\vec{a}$,t), $i, j \in Ag$, $i \neq j$, $t \in \mathcal{T}$, $a \in \mathcal{A}$ is sent.
- **a-m-accept**(i,j,m,$\vec{a}$,t) and **a-m-accept**(j,i,m,$\vec{a}$,t), $i, j \in Ag$, $i \neq j$, $t \in \mathcal{T}$, $\vec{a} \in \mathcal{A}$ are sent.
- The time is dl.
- **opt-out**(i,t), $i \in Ag$, $t \in \mathcal{T}$ is sent

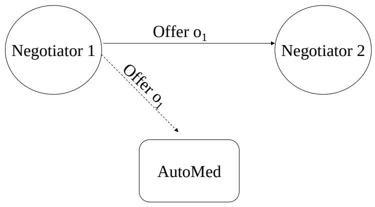
3.4 Preference Representation Method

Prior to engaging in the negotiation, both negotiators must provide their preferences to AutoMed. AutoMed separately orders all possible agreements according to each of the negotiators' elicited preferences. This order is only an estimation of the actual negotiator's order as explained below. After removing the non-Pareto optimal agreements according to its estimation, AutoMed forms a combined list of agreements ordered according to the original positions of the agreements in the separate lists. The combined list is used for the suggestion of solutions.

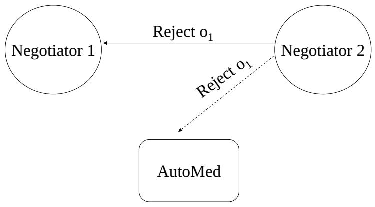
When deciding on the way to represent and elicit the negotiators' preferences we had to balance between two issues. On the one hand, the representation should provide an easy way for the negotiators to express their preferences, but on the other AutoMed must be able to order the possible agreements. For this, we chose the following method based on [44].

Definition 1 *(issues and values ranking - IVR). Given a set of issues,* $\mathcal{I} = \{I_1, I_2, \ldots, I_m\}$ *and a set of values* $dom(I_j) = \{v_1^j, v_2^j, \ldots, v_{b_j}^j\}$ *for each* $I_j \in \mathcal{I}$*, an IVR preference assigns an importance level to each issue,* $\lambda : \mathcal{I} \rightarrow \{1, ..., m\}$*. It also provides a full order,* $\prec$*, over the values of* $dom(I_j)$*.*

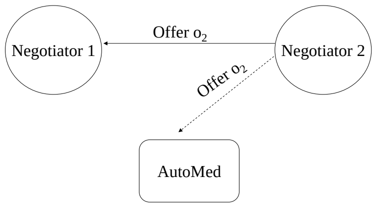
When using utility functions, an exact numerical valuation is associated with each outcome. These utility values indicate not only that one outcome is preferred over another, but also to what extent. IVR merely captures the



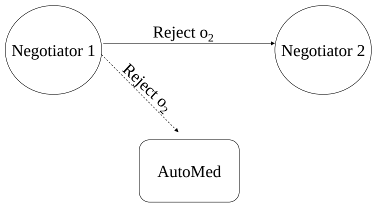
(a) Negotiator 1 makes an offer to negotiator 2 while AutoMed is listening.



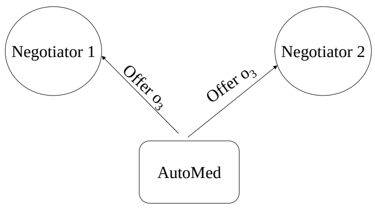
(b) Negotiator 2 rejects the offer made by negotiator 1 while AutoMed is listening.



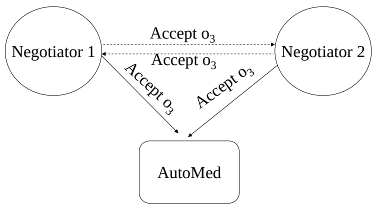
(c) Negotiator 2 makes an offer to negotiator 1 while AutoMed is listening.



(d) Negotiator 1 rejects the offer made by negotiator 2 while AutoMed is listening.



(e) AutoMed intervenes and makes a (full) offer to the negotiators.



(f) Both negotiators accept AutoMed's offer thereby concluding the negotiations.

Figure 1: An example of a negotiation. A circle signifies a person, a circled rectangle signifies a software agent, an arrow signifies the transfer of a message and a dashed arrow signifies the side effect of the message transfer.

concept of "more important than". There is no need to assign relative valuations to different issues or numerical valuations to values at all.

Given an IVR preference, when comparing two possible agreements it is not always possible to decide which agreement is preferred by a negotiator as demonstrated in the following example.

Example 2 *In the job interview of example 1 there are 5 issues under negotiations. A possible IVR for the job candidate would be to assign 5 to salary, 3 to the pension program and promotion possibilities, 2 to the company car issue and 1 to the number of working hours. The values for the salary issue are clearly ordered 7K $\prec$ 12K $\prec$ 20K and the pension program is ordered as an insurance pension program is preferred over a regular pension program which is preferred over no pension at all. Receiving a car is preferred over not receiving one, fast promotion is preferred over no commitment which is preferred over slow promotion and working 8 hours a day is preferred over 7 hours which is preferred over flexible hours which is preferred over 9 hours.*

It is easy to see that the best agreement according to the IVR above is a salary of 20K, an insurance pension program, receiving a company car, fast promotion and working 8 hours a day.

However, consider two possible agreements, in the first agreement the salary is 12K, insurance pension program, no car, fast promotion and 7 hours while in the second agreement the salary is 20K, regular pension program, no car, fast promotion and 9 hours. It is not possible to determine which agreement of the two is preferred over the other.

4 AutoMed

4.1 Design

AutoMed has to address several tasks. The first is to allow the negotiators to *define* the issues to be resolved and the values which they can be assigned in the final agreement. Second, it enables the negotiators to *elicit* their preferences expressing it via IVR and using a graphical interface. The IVRs remain confidential throughout the negotiations.

Given the two IVR preferences, AutoMed has to order possible agreements according to each of the negotiators preferences, to *identify* and eliminate the non-Pareto optimal agreements and to *find* what it believes to be the fairest agreement to resolve this dispute. When using utility functions as the basis for mediation, two functions are defined, U_1 which represents the first negotiator's preferences and U_2 which represents the preferences of the second negotiator [35]. A "fair" agreement is defined as the combination of these two functions, $U_1 \circ U_2$. Then the comparison of different agreements is done by calculating the composed function's value. For example, Nash [27] proposed to use $U_1 \circ U_2(\vec{a}) = [U_1(\vec{a}) - U_1(SQ)] * [U_2(\vec{a}) - U_2(SQ)]$. The proposed agreement is the one that maximizes $U_1 \circ U_2$.

Since AutoMed does not use utility functions, function composition is not an option. The only information AutoMed can use is the IVRs. In order to compare two agreements AutoMed assigns a scoring value to each agreement assuming that the distances between values of the same issue are the same.

Definition 2 (scoring an agreement) *Given an IVR, suppose* $v_1 \prec v_2 \prec .... \prec v_{b_j}$ *are the ordered values of an issue* I_j *according to the IVR, and a ranking value of* v_i*,* $r^j(v_i)$ *is a number between 0 and 1 such that for the least preferred value* v_1*,* $r^j(v_1) = 0$*. For* $1 \leq i \leq b_j$ $r(v_i) = \frac{i-1}{b_j-1}$*. Finally, a scoring value of an agreement,* $\vec{a} = (v^1, ..., v^m)$ *is* $s((v^1, ..., v^m)) = \sum_{i=1}^{m} \lambda(i) r(v^i)$*.*

Given two agreements $\vec{a}_1$ and $\vec{a}_2$, AutoMed estimates that $\vec{a}_1$ is at least as good as $\vec{a}_2$ according to negotiator i, denoted $\vec{a}_1 \succeq_i \vec{a}_2$ if $s^i(\vec{a}_1) \geq s^i(\vec{a}_2)$. If $s^i(\vec{a}_1) > s^i(\vec{a}_2)$ AutoMed will assume that $\vec{a}_1$ is better than $\vec{a}_2$ according to negotiator i, denoted $\vec{a}_1 \succ_i \vec{a}_2$.

Example 3 *We continue with our example and consider the two possible agreements mentioned in example 2*

The agreement of salary 12K, insurance pension program, no car, fast promotion and 7 hours will be assigned a score of $\frac{1}{2} * 5 + 3 + 0 + 3 + \frac{2}{3} * 1 = 9\frac{1}{6}$*. The second agreement of salary 20K, regular pension program, no car, fast promotion and 9 hours will be assigned the score of* $5 + 0 + 0 + 3 + 0 = 8$*. Thus, AutoMed will assume that the first agreement is considered better by the relevant negotiator.*

The score of an agreement is used to compare two agreements and to sort all the possible agreements. Each resulting list is an estimation of the actual preferences of a given negotiator. However, AutoMed needs to offer agreements based on the preferences of both negotiators. Therefore, AutoMed sorts the possible agreements in a descending order twice - once according to one negotiator's preference and once according to the second negotiator's preference. After the agreements are sorted, the position of an agreement in the lists can serve as a substitute for its utility value. We refer to the position of an agreement $\vec{a}$ in a sorted list L as its *rank* in L.

Definition 3 (rank of an agreement) *If* L *is an ordered list of agreements such that* $|L| = n$ *then the rank of* j*'s agreement in the list denoted* $rank_L(\vec{a})$ *is* $n - j + 1$*.*

After the lists are sorted in a descending order, AutoMed *identifies* the Pareto optimal agreements, and uses their ranks in the separate lists in order to determine which is the fairest agreement. This process is done once at the beginning of the negotiations and is time consuming. But, since this process begins automatically after both negotiators have finished specifying their preferences and is done while they start to exchange proposals, AutoMed has enough time until it actually has to send its own proposal to the negotiators. By then, this process has already been completed.

During the negotiations, AutoMed attempts to find and *suggest an agreement* it believes will be the fairest at that given stage of the negotiations. It must also decide when to *intervene* in the negotiation and when to simply track it. Finally, when a non-Pareto optimal agreement is reached, AutoMed tries to *upgrade* it by suggesting the nearest Pareto optimal one. These features will be discussed in the following subsections.

Notation	Explanation
$\mathcal{I}$	the group of all negotiated issues
I_i	a single negotiated issue, $I_i \in$I
v_j^i	value j of I_i
ε	undefined value for some I_i in a partial proposal
$\mathcal{A}$	the group of all possible agreements
$\vec{a}$	a possible agreement, $\vec{a} = (v^1, ..., v^m) \in \mathcal{A}$
k	maximum number of possible agreements, $\lvert\mathcal{A}\rvert$=k
$\mathcal{A}'$	a subset of possible agreements, $\mathcal{A}' \subseteq \mathcal{A}$
$\succeq_i$	the order defined according to negotiator i's IVR
$r^j(v_i)$	the ranking value of $v_i \in I_j$ according to the IVR
$s(\vec{a})$	a scoring value of an agreement
$PO(\mathcal{A}')$	a set of all the Pareto optimal agreements in $\mathcal{A}'$
$\text{rank}_L(\vec{a})$	the rank of agreement $\vec{a}$ in sorted list L
$\text{Sum}_{L_1,L_2}(\vec{a})$	sum of $\vec{a}$'s rank in sorted lists L_1 and L_2
$\text{Diff}_{L_1,L_2}(\vec{a})$	difference between $\vec{a}$'s rank in sorted lists L_1 and L_2
$\succeq_{1,2}$	the order defined according to the agreements' ranking
$\mathcal{A}'_{sq}$	a set of agreements that are not worse than the status quo
$\varphi(\mathcal{A}')$	a set of possible proposed offers
$\mathcal{A}_{\vec{a}}$	possible agreements with respect to negotiator i, better than $\vec{a}$
$\mathcal{A}_{\vec{a}_1,\vec{a}_2}$	union of $\mathcal{A}_{\vec{a}_1}$ and $\mathcal{A}_{\vec{a}_2}$

Table 1: Notation table.

4.2 Suggesting a possible agreement

To the best of our knowledge, there are no guidelines in the literature concerning which agreement a mediator should suggest and at which negotiation stage it should be suggested. Thus, we have developed AutoMed's approach through trial and error by analyzing preliminary experiments with people.

4.2.1 Combined preference relation

During the negotiation AutoMed considers different subsets of $\mathcal{A}$ from which to choose possible offers to propose to the negotiators. Given a subset of possible agreements, $\mathcal{A}' \subseteq \mathcal{A}$, AutoMed will propose only agreements that are Pareto optimal according to its estimations with respect to these possible agreements.

Definition 4 *Given a subset of possible agreements, $\mathcal{A}' \subseteq \mathcal{A}$, the set of Pareto optimal agreements, $PO(\mathcal{A}')$, contains all the agreements in $\mathcal{A}'$ excluding the non-Pareto optimal ones.* $PO(\mathcal{A}') = \{\vec{a}_j \in \mathcal{A}' \mid \nexists \vec{a}_i \in \mathcal{A}', ((\vec{a}_i \succeq_1 \vec{a}_j) \wedge (\vec{a}_i \succeq_2 \vec{a}_j)) and ((\vec{a}_i \succ_1 \vec{a}_j) \vee (\vec{a}_i \succ_2 \vec{a}_j))\}$.

AutoMed aims to offer fair agreements. When considering a set $\mathcal{A}' \subseteq \mathcal{A}$, it first sorts the list of all the relevant agreements into two lists according to each negotiator and then ranks each agreement according to both lists.

Definition 5 *Let L_1 and L_2 be two lists of the same agreements, where L_1 is sorted according to $\succeq_1$ and L_2 is sorted according to $\succeq_2$.*

$Sum_{L_1,L_2}(\vec{a}) = rank_{L_1}(\vec{a}) + rank_{L_2}(\vec{a})$
$Diff_{L_1,L_2}(\vec{a}) = rank_{L_1}(\vec{a}) - rank_{L_2}(\vec{a})$.

Using the functions Sum_{L_1,L_2} and Diff_{L_1,L_2}, we formally define an order reflecting both negotiators' preferences.

Definition 6 (combined preference relation) *$\vec{a}_i \succeq_{1,2} \vec{a}_j$, with respect to L_1 and L_2, in the following cases:*

- *$Sum_{L_1,L_2}(\vec{a}_i) > Sum_{L_1,L_2}(\vec{a}_j)$ or*
- *$Sum_{L_1,L_2}(\vec{a}_i) = Sum_{L_1,L_2}(\vec{a}_j)$ and $Diff_{L_1,L_2}(\vec{a}_i) < Diff_{L_1,L_2}(\vec{a}_j)$.*

Given $\succeq_{1,2}$ and a set of agreements $\mathcal{A}'$, AutoMed proposes one of the most preferred agreements according to $\succeq_{1,2}$. It will focus only on agreements that are not worse than the status quo. That is, $\mathcal{A}'_{sq} = \{\vec{a} | \vec{a} \succ_i SQ, \text{ for } i = 1, 2\}$.

Definition 7 (possible solutions) *Let $\mathcal{A}' \subseteq \mathcal{A}$ and $\succeq_{1,2}$ be the combined preference relation. AutoMed will propose agreements from the set $\varphi(\mathcal{A}') = \{\vec{a} \mid \vec{a} \in \mathcal{A}'_{sq}$ and $\nexists \vec{a}' \in \mathcal{A}'_{sq}$ s.t. $\vec{a}' \succ_{1,2} \vec{a}\}$.*

We will now discuss several properties of the possible proposed offers.

First we need to show that there is at least one such agreement when considering the entire set of possible agreements.

Observation 1 *$\varphi(\mathcal{A}) \neq \emptyset$.*

Proof According to our assumption there is an agreement that is preferred by both sides over the status quo. Thus, $\mathcal{A}_{sq} \neq \emptyset$ and clearly $\varphi(\mathcal{A}) \neq \emptyset$. $\square$

As demonstrated in the next example, focusing explicitly in the definition of φ on $\mathcal{A}_{sq}$ is necessary.

Example 4 *Consider the case where $L_1 = \{\vec{a}_1, \vec{a}_2, \vec{a}_3, \vec{a}_4, \vec{a}_5, SQ\}$ and $L_2 = \{\vec{a}_5, SQ, \vec{a}_2, \vec{a}_1, \vec{a}_4, \vec{a}_3\}$. $\vec{a}_5$ is preferred by both sides over SQ. However, $Sum_{L_1,L_2}(\vec{a}_5) = rank_{L_1}(\vec{a}_5) + rank_{L_2}(\vec{a}_5) = 6+2$ which is lower than the sum of $Sum_{L_1,L_2}(\vec{a}_1)$ and $Sum_{L_1,L_2}(\vec{a}_2)$ which is 9. Since $Diff(\vec{a}_2) = 1$ and $Diff(\vec{a}_1) = 2$, $\vec{a}_2$ is the most preferred according to $\succeq_{1,2}$. However, the second agent prefers SQ over $\vec{a}_2$.*

According to Definition 7 AutoMed will focus only on $\mathcal{A}_{sq} = \{\vec{a}_5\}$ and thus $\varphi(\mathcal{A}) = \{\vec{a}_5\}$ as well.

Note that the situation presented in the previous example is very rare and did not occur in the scenarios that we considered. Furthermore, as discussed below, during the negotiations AutoMed considered only a subset of agreements $\mathcal{A}'$ that are "between" the agreements proposed (and rejected) by the negotiators. Assuming they only propose agreements that they consider to be better for them than SQ, $\mathcal{A}' \subseteq \mathcal{A}_{sq}$.

Proposition 1 *The possible solution agreements are Pareto optimal, i.e., $\varphi(\mathcal{A}') \subseteq PO(\mathcal{A}')$.*

Proof Suppose $\vec{a} \in \varphi(\mathcal{A}')$. Without loss of generality suppose there is an agreement $\vec{a}' \in \mathcal{A}'$ such that $\vec{a}' \succ_1 \vec{a}$ and $\vec{a}' \succeq_{1,2} \vec{a}$. Then $rank_{L_1}(\vec{a}') > rank_{L_1}(\vec{a})$ and $rank_{L_2}(\vec{a}') \geq rank_{L_2}\vec{a})$ and thus $\text{Sum}_{L_1,L_2}(\vec{a}') > \text{Sum}_{L_1,L_2}(\vec{a})$

and $\vec{a}' \succ_{1,2} \vec{a}$; a contradiction that $\varphi(\mathcal{A}')$ members are the most preferred according to $\succ_{1,2}$ in $\mathcal{A}'$. $\Box$

Next we will consider fully competitive situations, that is, situations where the orders of L_1 and L_2 are exactly reversed. For example $L_1 = \{\vec{a}_1, \vec{a}_2, \vec{a}_3\}$ and $L_2 = \{\vec{a}_3, \vec{a}_2, \vec{a}_1\}$. This happens when all the agreements are Pareto optimal. In this case, AutoMed will offer an agreement from the middle of the lists.

Proposition 2 *Denote $|\mathcal{A}'| = n$. Suppose that $PO(\mathcal{A}') = \mathcal{A}'$. For $\vec{a} \in \varphi(\mathcal{A}')$, if n is odd $rank_{L_i}(\vec{a}) = \lfloor \frac{n}{2} \rfloor + 1$. If n is even then $rank_{L_1}(\vec{a}) = \frac{n}{2}$ and $rank_{L_2}(\vec{a}) = \frac{n}{2} + 1$ or $rank_{L_2}(\vec{a}) = \frac{n}{2}$ and $rank_{L_1}(\vec{a}) = \frac{n}{2} + 1$.*

However, if the negotiators are not fully competitive the members of $\varphi(\mathcal{A}')$ will not necessarily be in the middle. We will demonstrate the above proposition and other cases by means of several simple examples.

Example 5 *Consider the case where there are 5 possible agreements: $\vec{a}_1, ..., \vec{a}_5$.*

If the preferences of the negotiators fully conflict (e.g., a zero sum game) then, without loss of generality we can assume that $L_1 = \{\vec{a}_1, \vec{a}_2, \vec{a}_3, \vec{a}_4, \vec{a}_5\}$ and $L_2 = \{\vec{a}_5, \vec{a}_4, \vec{a}_3, \vec{a}_2, \vec{a}_1\}$. The sum of the ranks of all possible agreements is 6, but the one with the lowest Diff is $\vec{a}_3$ which will be offered by AutoMed. $\vec{a}_3$ is in the middle between the agreements most preferred by both sides and thus seems the fairest agreement.

Suppose there are 8 agreements $\mathcal{A}' = \{\vec{a}_1, ..., \vec{a}_8\}$ and $L_1 = \{\vec{a}_1, \vec{a}_2, \vec{a}_3, \vec{a}_4, \vec{a}_5, \vec{a}_6, \vec{a}_7, \vec{a}_8\}$ and $L_2 = \{\vec{a}_8, \vec{a}_7, \vec{a}_6, \vec{a}_5, \vec{a}_2, \vec{a}_3, \vec{a}_4, \vec{a}_1\}$. In this case, the sum of a_1, a_3, a_5, a_6, a_7 and a_8 is 9. The sum of a_4 is 7 and the sum of a_2 is 11. Thus, $\varphi(\mathcal{A}) = \{\vec{a}_2\}$ which is in the middle for the ordered list of the second negotiator but more preferred by the first negotiator than $\vec{a}_5$ which is also in the middle of L_2. It is important to note that in this case $\mathcal{A}' \neq PO(\mathcal{A}')$.

It is also interesting to observe that it is impossible for an agreement that is most preferred by one negotiator and the least preferred by the other to be the most preferred according to the combined preference relation. Suppose, as before, that there are 5 possible agreements: $\vec{a}_1, ..., \vec{a}_5$ and that $\vec{a}_1$ appears first in L_1 and last (less preferred) in L_2. Thus its sum is 6 and the diff is 4. We will show that it is not possible that the sum of all the other agreements will be lower than 6. Without loss of generality, assume that $L_1 = \{\vec{a}_1, \vec{a}_2, \vec{a}_3, \vec{a}_4, \vec{a}_5\}$. First, $\vec{a}_5$'s sum can't be lower than 6. It can be at least 6, if it is located first in L_2. Furthermore, in order for $\vec{a}_4$'s sum to be lower than 6, it must be ordered first in L_2; however, this position is already taken by $\vec{a}_5$. As a result, its sum can be at least 6, but its diff is lower. Therefore, $\vec{a}_1$ will not be in $\varphi(\mathcal{A})$.

4.2.2 Agreement Suggestion

During the negotiations, AutoMed searches for agreements to suggest upon which both sides can agree. According to the negotiation protocol, the negotiators are allowed to propose not only full agreements, but also partial ones. While partial agreements are used by the negotiating parties, AutoMed always suggests full agreements thereby attempting to propose a good trade-off. The definition of the agreement to be suggested is as follows.

The last offers made by each side are considered when searching for the agreement to suggest during negotiations. Use $\vec{a}_1$ to denote the offer suggested by the first negotiator and $\vec{a}_2$ the offer suggested by the second. AutoMed attempts to suggest an agreement that is Pareto optimal which is ranked within the range of agreements constrained by the last offers made by the parties. If the given offers are partial agreements, the empty values are filled with the best value possible, according to the preferences as expressed in the IVR of the corresponding negotiator.

Example 6 *Suppose a partial agreement was proposed by the job candidate negotiator, who is represented by the IVR of example 2. If the partial agreement is missing the value for the car company issue, AutoMed will fill it in by assigning the value of receiving a company car.*

After filling in the empty values, AutoMed searches for an agreement to propose by considering a subset of $\mathcal{A}$.

Definition 8 (Zone of possible agreements) *Let $\vec{a}_1$ and $\vec{a}_2$ be agreements that were offered by the first and the second negotiators, respectively which were rejected by the other side. The possible agreements with respect to negotiator $i \in \{1,2\}$ given $\vec{a}_j$, $j \in \{1,2\}, j \neq i$ is $\mathcal{A}_{\vec{a}_j} = \{\vec{a} \mid \vec{a} \succ_i \vec{a}_j\}$. The possible agreements $\mathcal{A}_{\vec{a}_1,\vec{a}_2} = \mathcal{A}_{\vec{a}_1} \cap \mathcal{A}_{\vec{a}_2}$.*

AutoMed will offer $\varphi(\mathcal{A}_{\vec{a}_1,\vec{a}_2})$. However, $\varphi(\mathcal{A}_{\vec{a}_1,\vec{a}_2}) \in PO(\mathcal{A})$ still needs to be verified. The concern arises from removing some agreements that are better to both sides than the agreements left in $\mathcal{A}_{\vec{a}_1,\vec{a}_2}$.

Proposition 3 *Let $\vec{a}_1$ and $\vec{a}_2$ be agreements offered by the first and the second negotiators, respectively, that were rejected by the other side. Thus $PO(\mathcal{A}_{\vec{a}_1,\vec{a}_2}) \subseteq PO(\mathcal{A})$.*

Proof Suppose there is $\vec{a} \in PO(\mathcal{A}_{\vec{a}_1,\vec{a}_2})$ such that $\vec{a} \notin PO(\mathcal{A})$. That is, there is an agreement $\vec{a'}$ such that $\vec{a'} \succ_i \vec{a}$ and $\vec{a'} \succeq_j \vec{a}$, $i \neq j$, such that $\vec{a'} \notin \mathcal{A}_{\vec{a}_1,\vec{a}_2}$. Since $\vec{a'} \notin \mathcal{A}_{\vec{a}_1,\vec{a}_2}$ either $\vec{a}_1 \succeq_2 \vec{a'}$ and thus $\vec{a}_1 \succeq_2 \vec{a}$ or $\vec{a}_2 \succeq_1 \vec{a'}$ and thus $\vec{a}_2 \succeq_1 \vec{a}$. In both cases $\vec{a} \notin \mathcal{A}_{\vec{a}_1,\vec{a}_2}$; a contradiction. □

4.2.3 Intervention

After finding the agreement believed to be the best one to propose at a given stage of the negotiations, AutoMed should decide whether or not to present it to the negotiators. To the best of our knowledge there are no guidelines on this subject in the literature. Thus, we developed AutoMed's approach through trial and error by analyzing preliminary experiments with people. AutoMed's intervention algorithm is presented below.

AutoMed will intervene only if it has reason to believe that its suggestion will be accepted or at least helpful to one or both negotiators in opening new directions of thought. It will wait until both negotiators have had an opportunity to propose an agreement. If in the last round a partial agreement is achieved or if the calculated suggestion was already presented to the negotiators in the last round it will not offer it again. If, according to its calculations, the potential suggestion improves both parties' position with respect to their own proposals, AutoMed will choose to present the offer. The suggestion will also be presented if AutoMed finds that it will considerably improve at least one side's position.

4.2.4 Agreement upgrading

When a full agreement is agreed upon by both negotiators, AutoMed checks for its Pareto optimality. If it finds that the reached agreement is not Pareto optimal, AutoMed consults the $\mathcal{A}_{1,2}$ list. Starting from the highest ranking agreement it searches down the list for the first Pareto optimal agreement which improves both negotiators' outcome and proposes it to them. If the upgraded suggestion is accepted by both negotiators, the negotiations conclude with the mediator's proposal. Otherwise, if at least one of the negotiators rejects the upgraded suggestion, the originally accepted full agreement stands.

4.3 Bargaining Solutions and AutoMed's Proposals

Prominent bargaining solution concepts (such as the Nash solution[27] and the Kalai/Smorodinsky solution) have been considered by researchers in Game Theory as "fair" solutions to the Nash Bargaining Problem and are usually designed for a mediator in an environment with complete information [26, 45, 34]. A bargaining solution, or in our case - a suggestion made by the mediator in order to solve the negotiated conflict - should satisfy a number of properties [30, 39]. However, since there are no utility functions associated with the negotiators it is not possible to express these properties in our settings. Nevertheless, we will consider a few of these properties in an informal way.

Individually rational: In our settings, this means that both parties prefer the possible solutions over the status quo.

This holds in our case by definition.

Symmetry: This property can be defined in our settings as follows. If $\vec{a} \in \varphi(\mathcal{A}')$ such that $rank_{L_1}(\vec{a}) \neq rank_{L_2}(\vec{a})$ then there is $\vec{a}' \in \varphi(\mathcal{A}')$, $\vec{a}' \neq \vec{a}$ such that $rank_{L_1}(\vec{a}') = rank_{L_2}(\vec{a})$ and $rank_{L_2}(\vec{a}') = rank_{L_2}(\vec{a})$.

This property holds for AutoMed's proposed solutions since $\text{Sum}_{L_1,L_2}(\vec{a}) = \text{Sum}_{L_1,L_2}(\vec{a})'$ and $\text{Diff}_{L_1,L_2}(\vec{a}) = \text{Diff}_{L_1,L_2}(\vec{a})'$.

Pareto Optimality: All possible solutions are Pareto optimal according to proposition 1.

Disagreement-Point Monotonicity: This property can be defined in our settings as follows. Consider $\succeq_1$ and $\succeq_2$ the preference relation over $\mathcal{A}$ for negotiators 1 and 2. Let $\succeq_2'$ be the same as $\succeq_2$ but there is at least one agreement $\vec{a} \in \mathcal{A}$ such that $SQ \succ_2 \vec{a}$ though $\vec{a} \succ_2' SQ$. Also assume that the assumption that there is at least one agreement which both sides prefer over SQ holds for both preferences. Let L_1 be the ordered list of negotiator 1 and L_2 and L_2' be the ordered lists of negotiator 2 with respect to $\succeq_2$ and $\succeq_2'$, respectively. Let $\varphi(\mathcal{A})$ and $\varphi(\mathcal{A})'$ be the possible solutions set with respect to $\succeq_2$ and $\succeq_2'$ respectively. Then, $\forall \vec{a} \in \varphi(\mathcal{A})$ and there is $\vec{a}' \in \varphi(\mathcal{A})'$ such that $rank_{L_2}(\vec{a}) \geq rank_{L_2}(\vec{a}')$.

The proof that this property holds is given below. By the definition of φ, $rank_{L_2}(SQ) < rank_{L_2}(\vec{a})$. There are two cases. In the first case $\vec{a}$ is still preferred over SQ according to $\succeq_2'$, i.e., $\vec{a} \succ_2' SQ$ and thus $\vec{a} \in \varphi(\mathcal{A}')$ and its rank has not been changed. In the second case, $SQ \succ_2' \vec{a}$ and thus $\vec{a} \notin \varphi(\mathcal{A}')$. However, given the assumption that there is still an agreement

$\vec{a}'$ that both sides prefer over SQ, either $\vec{a}' \in \varphi(\mathcal{A}')$ or $\vec{a}'' \in \varphi(\mathcal{A}')$ such that $\vec{a}'' \succeq \vec{a}'$. In both cases their rank is higher than that of $\vec{a}$.

We will use the following examples to demonstrate the symmetry and the Disagreement-Point Monotonicity properties.

Example 7

Symmetry: *Let* $L_1 = \{\vec{a}_1, \vec{a}_2, \vec{a}_3, \vec{a}_4\}$ *and* $L_2 = \{\vec{a}_4, \vec{a}_3, \vec{a}_2, \vec{a}_1\}$*. In this example* $\vec{a}_2$ *and* $\vec{a}_3$ *are in* $\varphi(\mathcal{A})$ *and the property holds.*

Disagreement-Point Monotonicity: *Let* $L_1 = \{\vec{a}_1, \vec{a}_2, \vec{a}_3, \vec{a}_4, \vec{a}_5, \vec{a}_6,\}$ *and* $L_2 = \{\vec{a}_5, \vec{a}_4, \vec{a}_3, \vec{a}_2, \vec{a}_1, \vec{a}_6\}$ *such that* $\vec{a}_6 = SQ$*. For this example,* $\varphi(\mathcal{A}) = \{\vec{a}_3\}$*. Suppose that* $L'_2 = \{\vec{a}_5, \vec{a}_4, \vec{a}_3, \vec{a}_2, \vec{a}_6, \vec{a}_1\}$ *then* $\varphi(\mathcal{A})'$ *does not change. However, if* $L_2 = \{\vec{a}_5, \vec{a}_4, \vec{a}_6, \vec{a}_3, \vec{a}_2, \vec{a}_1\}$ *then* $\varphi(\mathcal{A})' = \{\vec{a}_4\}$ *which negotiator 2 prefers over* $\vec{a}_3$*.*

5 Experiments

We conducted two main experiments. In the first, we tested the usability of utility functions vs. that of IVR. In the second, we tested the performance of AutoMed. In these experiments we used typical domains in which negotiations are often used. AutoMed is not domain based, but rather receives the currently used domain as input to the system before negotiations begin.

5.1 Utility functions vs. IVR

In his paper [23], Shih-Kung Lai empirically studied the differences between equivalence and ratio judgments. A *ratio* judgment is used when a decision maker compares different alternatives in terms of ratios, while *equivalence* judgment requires a decision maker to define preference levels, where two issues are equal if they are in the same level. In Lai's paper, ratio judgment is referred to as exact weight, while equivalence judgment is referred to as orderings. He found that defining preference levels outperform ratios where single issues are concerned and are nearly more effective where multi-issues are concerned.

The following experiment strengthens Lai's conclusions by comparing these models in terms of the length of the elicitation process and the participants' testimony concerning their easiness and accuracy.

5.1.1 Domain

The situation presented to the negotiators was that of a job interview at a software company. One negotiator acted as the job applicant desperately wanting the proposed job, while the other acted as the potential employer with some urgent project for which he needed to hire a new employee.

Both sides lose as time goes by - the job applicant obtains no salary until she begins her job and also, if negotiations fail, valuable time will have been spent to no avail whereby she will have to restart the entire process with another potential employer. Furthermore, the potential employer has an urgent project which needs to be implemented and prolonging the negotiations means delaying the project. Needless to say, both sides are interested in the success of the negotiations.

5.1.2 Methodology

The participants in this experiment included 24 pairs of negotiators, all students from the Exact Sciences faculty at Bar-Ilan University. The experiment was conducted in two stages. First, the negotiators were given reading material explaining the domain and their roles were assigned (see appendix A for further details). The negotiators engaged in negotiations concerning the clauses of the final employment contract - if agreed upon - and the potential values they could be assigned. In other words, the negotiations concerned the definition of the issues and values for discussion once the final employment contract would be up for negotiation.

This negotiation was managed by a computer server program to which each of the negotiators connected separately. Messages were sent from one negotiator to the other in the form of a suggestion for a new issue or a new value for some issue, and included the possibility of adding free text to explain the issue or the value. The other negotiator, receiving the suggestion, had the choice of accepting or rejecting the suggestion. At all times, an updated tree of issues and values was presented to both negotiators. Snapshots of the interface used are available in appendix A.

These negotiations had no time constraints. Messages were freely exchanged without the need to wait for an answer from the other negotiator. This feature enabled the negotiators to define the issues and values to be discussed on their own, eliminating the need for pre-definition and enabling them to have better control over the future discussion on the actual agreement itself.

Following the completion of the first stage, the negotiators were asked to elicit their own personal preferences according to the issues and values agreed upon. This was accomplished by the server automatically switching to the elicitation process interface (snapshots of the screens displayed during the elicitation process can also be found in appendix A). Notice that in this experiment the scenario was familiar to the negotiators and they used their own thoughts, beliefs and preferences as guidance both in the issues and values negotiation stage and in the preference elicitation stage.

The negotiators were given the following instructions:

- The list of agreed upon issues was displayed on the first screen.
  - The negotiator using the utility functions model was asked to distribute 100 points among the issues, reflecting the weighted importance they associate with each issue.
  - The negotiator using the IVR model was asked to order the issues according to importance. Partial ordering was allowed.
- On the subsequent screens, the lists of values were displayed - each list associated with a separate issue was displayed on a separate screen.
  - The negotiator using the utility function model was asked to use whatever scale she felt comfortable with as long as the proportions of the assigned numeric weights accurately reflected the importance she associated with each value. Zero and negative numbers could also be used in order to reflect loss or neutral situations.
  - The negotiator using the IVR model was asked to totally order the values according to preference.

Both negotiators were asked to be as accurate as possible. The method by which the negotiators were asked to create the utility function corresponds with the method by which Lin et al. [25], created the utility functions in the same domain. The negotiators were also shown the interface and an example of a full negotiation and preference elicitation process.

As mentioned earlier in section 3.4, utility functions and IVR differ mainly in the level of weight accuracy provided in the model. Thus, each negotiator, in fact, elicited her preference using a different model, consequently, enabling us to compare them in respect to several interesting parameters.

In order to ensure that the roles played by the negotiators had no effect on the experiments, in half (12) of the experiments, the job applicant was instructed to use the utility functions model while the potential employer was instructed to use the IVR model. In the other half, the job applicant was instructed to use the IVR model while the potential employer was instructed to use the utility functions model.

Following the completion of the experiment, both negotiators were asked to fill out a questionnaire regarding how accurate they thought they were while assigning the numeric values to the model, and how difficult the task was. Both accuracy and easiness levels were measured using three separate values - one for the task in general, one for the issues screen and one for the values screens. The scale was 1-10, where 1 stood for not accurate at all / very difficult and 10 stood for completely accurate / very easy, meaning the higher the better in both cases.

Another measurement taken was the length of time it took both negotiators to elicit their preferences.

5.1.3 Results

The results of these experiments clearly show that the elicitation process when using the IVR model is significantly less time consuming than the elicitation process when using the utility functions model.

Considering all 24 negotiations, elicitation with the IVR model took 03:32 minutes on average, while the elicitation with the utility functions model took 05:06 on average, namely 31% less. Using the one-tailed T-test on this data shows the difference to be statistically significant ($p < 0.005$). The negotiator using the utility functions model concluded the task before her partner in only 4 cases of all 24 pairs of negotiators, with a time difference average of 0:16 minutes. The time difference in the opposite situation averaged 01:56 minutes.

Other interesting parameters are the levels of easiness and accuracy reported by the negotiator after the experiment had concluded. The averages of the values assigned to the task in general for both accuracy and easiness are presented Table 2. In order to determine the accuracy and easiness measures for each negotiator we averaged all the values assigned by each of them to the accuracy and easiness levels, more specifically for the issues screen and the values screens. These averages are also presented in table 2.

Using the one-tailed T-test we found statistical significance in the general easiness ($p < 0.0025$), in the accuracy measure ($p < 0.015$) and in the easiness measure ($p < 0.009$). In light of these results, we conclude that the IVR model is significantly less time consuming and easier to use as an elicitation method compared to the utility functions model. We can also deduce that even though,

	IVR model	utility functions model
avg general accuracy	8.54	8.04
avg general easiness	8.88	7.46
avg accuracy measure	8.49	7.88
avg easiness measure	8.75	7.75

Table 2: Accuracy and easiness measurements reported by the negotiators

or rather because, the IVR model is mathematically less accurate than the utility functions model, since it ignores relative weights, people find it to be more accurate.

5.2 AutoMed's performance

In order to test the performance of AutoMed, we applied the interface and specific domain used by Lin et al. in [25] (pp.847-849). However, unlike Lin et al., who experimented with a negotiating agent, our experiments were conducted using two sets of negotiating pairs. One set of negotiations was mediated by AutoMed, while the other set served as a control group. A total of 82 participants took part in this experiment.

5.2.1 Domain

In our scenario, Great Britain and Zimbabwe are members of the World Health Organization's Framework Convention on Tobacco Control. In this convention, the world's first public health treaty is about to be established, concerning the trade in tobacco and the industrial countries (tobacco users) support of the non-industrial ones (tobacco growers). Great Britain, representing the industrial countries, and Zimbabwe, representing the non-industrial countries, are negotiating the treaty. The time of the convention is limited. If no treaty is agreed upon while the convention is at session, it will not be implemented at all. Both Great Britain and Zimbabwe have political as well as financial considerations when attempting to agree on the treaty and both prefer to reach an agreement over continuing the current state of affairs.

The subjects in our experiment were divided into pairs, where one negotiator acted on behalf of Great Britain and the other acted on behalf of Zimbabwe. Each was given written material explaining the convention's objective and their own role in the negotiations, including political aspects and the country's goal in participating. Since our subjects were unfamiliar with the economic issues and foreign affairs the preferences were also specified. No information was given regarding the other side's preferences.

Five issues were defined: (a) The total amount to be deposited into the Tobacco Fund to aid countries seeking to release themselves from economic dependency on tobacco production; (b) The impact on other aid programs already agreed upon; (c) Trade issues concerning Zimbabwe; (d) Trade issues concerning Great Britain; (e) Creation of a forum to explore comparable arrangements for other long-term health issues. Each issue had 3 or 4 defined values, one of which represented the status quo. Altogether, there were a total of 432 possible agreements.

All the subjects playing the role of a country (Great Britain or Zimbabwe) were given the same preferences in all experiments. The preferences presented to the negotiators can be found in appendix B. Since the preferences were predefined and were exactly the same in all tests, there was no need to repeat the first phase of IVR specification separately for each experiment. Instead, AutoMed used the same IVR representing the negotiators we specified beforehand. Thus, the first phase in the negotiations, that of preference elicitation using IVR, was omitted and the negotiations actually began with AutoMed processing the IVR and the mutual sending of messages monitored by AutoMed.

The negotiation lasted up to 14 time periods of 2 minutes each. Upon termination of a time period a notification was sent to both negotiators, but the negotiating process was not interrupted. The exchanged messages were composed by selecting values for the different issues from defined lists. Each list included a "not under discussion" value, which enabled the composition of a partial agreement. The negotiator to which the proposal was sent could either accept or reject it.

The messages sent by AutoMed were sent simultaneously to both negotiators and each was able to accept or reject it. Issues agreed upon were accumulated to compose a full agreement, which automatically invoked AutoMed to try to upgrade it. Upon termination of the negotiations, the negotiators were notified of the final agreement reached and its monetary implications.

If no agreement was reached by the deadline - an undesirable situation for both Great Britain and Zimbabwe - the status quo, representing the current situation of no signed treaty and the continuance of Tobacco importing into the industrial countries, would persist. If the time limit was reached but the negotiators reached a partial agreement, status quo values would be assigned to the missing issues. Each party could also opt out of the negotiations if it was not satisfied with its proceeding, again, preserving the status quo. The defined monetary implications of reaching the status quo and of opting out were also specified for each negotiator, along with the monetary effect of time passing. Great Britain gained money from each time step she was not yet supporting Zimbabwe, while Zimbabwe naturally lost the amount of support. All specific definitions are available in appendix B. Further details can be found in [9].

As in the previous experiment, the negotiators were shown the interface and an example of a full negotiation prior to the commencement of negotiations.

5.2.2 Methodology

Two sets of subjects participated in this experiment. The first consisted of 21 pairs of negotiators and the second consisted of 20 pairs. All 82 subjects were students from the Exact Sciences faculty at Bar-Ilan University. The first group's negotiations were mediated by AutoMed while the second group served as a control group in negotiations with no mediation. The instructions and preference ordering given to both groups were exactly the same.

The outcome of each simulation could be a full agreement, opting out - keeping the status quo - or a partial agreement completed by the status quo values due to reaching the time limit. After negotiations ended, both negotiators were required to state their level of satisfaction from the outcome by stating a number between 1 and 10, where 1 represented the lowest possible satisfaction level and 10 represented the highest. The negotiators whose negotiations were mediated were also asked whether they thought AutoMed assisted in finding the solution.

5.2.3 Results

As mentioned before, both Great Britain and Zimbabwe preferred the negotiations to end with an agreement over maintaining the status quo. Since negotiations were time-limited one of AutoMed's goals was to conclude the dispute as soon as possible. Table 3 summarizes the outcomes of the negotiations as well as the average time period until its conclusion.

	mediated nego	unmediated nego
pairs	21	20
ended with full agr	21	15
ended by deadline	0	3
ended with opt out	0	2
avg time nego end	5.9	8.55

Table 3: Outcomes and time of conclusion

All mediated negotiations ended with a full agreement accepted by both sides. Only 75% of the unmediated negotiations were concluded with both sides agreeing fully. Two unmediated negotiations ended with Zimbabwe opting out, and three exceeded the time limit. We used the χ^2 test to analyze this data, and the results show that when AutoMed was used, significantly more negotiations were concluded with a full agreement compared to unmediated negotiations ($p < 0.025$).

We used the 2-independent-sample Wilcoxon test to compare the final time period of negotiations with and without AutoMed. Since 3 negotiations ended when the time limit was reached, we calculated them as if they concluded in time period 15. The test shows significant differences in this case as well, i.e., negotiations mediated by AutoMed were concluded significantly faster than unmediated negotiations ($p < 0.03$). Out of the 21 mediated negotiations, 7 were concluded by both parties consenting to the offer made by AutoMed. Also, an additional 10 negotiators claimed that AutoMed helped them in finding the solution. That is, 24 of 42 negotiators (57%) reported explicitly that AutoMed assisted them.

Table 4 reviews the average level of satisfaction expressed by the negotiators in the feedback. Avg total denotes the average satisfaction level stated by all the negotiators. Avg GB and avg Zim denote the average satisfaction level stated by the negotiators playing the roles of Great Britain and Zimbabwe, respectively.

	mediated nego	unmediated nego
avg total	7.3	6.63
avg GB	7.9	6.65
avg Zim	6.71	6.625

Table 4: Satisfaction level

We can see that in both total satisfaction level and in Great Britain's satisfaction level, the average is much higher when using AutoMed. We can also see that where Zimbabwe's satisfaction level is concerned, the average is slightly higher with AutoMed. The higher satisfaction levels shown for Great Britain can be easily explained by Great Britain's favorable position in the negotiations. In other words, Great Britain was the stronger negotiator with less to lose and more to gain from a good solution than Zimbabwe. Furthermore, after dividing the level of satisfaction into two groups, 1-6 and 7-10, and applying the χ^2 test, we found that AutoMed produced significantly higher satisfaction levels as far as Great Britain's role was concerned ($p < 0.01$).

6 Conclusions and Future Work

In this paper we described the automated mediator AutoMed. We analyzed AutoMed's performance by conducting an experiment, with the participation of 82 people, to compare non-mediated negotiations with AutoMed mediated negotiations. The results show a significantly shorter negotiation process in the mediated ones. They also show that when AutoMed acts as mediator, significantly more negotiations are concluded with a full agreement accepted by both sides at a higher satisfactory level.

AutoMed can either be presented with a pre-defined set of issues and values at the beginning of negotiations, or it can provide a pre-negotiation phase in order to reach an agreement on the issues and values. The ability to add and/or change given values at the time of negotiations will further enhance the richness of possible negotiations and will assist in finding better suited solutions.

A number of questions remain open for future research.

First, AutoMed's current version does not consider the compromises made by the negotiators in their offers. If a certain negotiator is willing to soften his stand, while the other is not, AutoMed, searching for the middle ground agreement will inevitably favor the second negotiator. We plan to extend the middle ground search method used in order to take into account the willingness of a negotiator to compromise.

Second, AutoMed currently suggests full agreements only. Since humans find it much easier to negotiate one or two issues at a time, it is possible that partial agreements suggested by AutoMed might be even more effective than full ones.

A change in the negotiation environment raises another question. AutoMed acts currently in a text-based environment, while the technology today enables negotiations to be managed through a video conference and only actual suggestions are text-based. In such an environment the presence of an automatic mediator increases in importance, but must also increase in dominance. Since the negotiators focus on the video conference, the mediator must attract their attention in some way. Possible solutions might be: bold text massages, the use of an avatar or a vocal presence.

Another interesting point concerns the domains in which AutoMed was tested to date. In the scenarios used in the experiments section of this paper (section 5) both negotiators viewed the same level of importance for the same issues, causing the tradeoff calculated by AutoMed to be between values, rather than between issues. It is customary in Economics [38] to have scenarios where the negotiators have different levels of importance assigned to the same issues, resulting in a tradeoff between issues. We assume AutoMed is fully capable of managing such scenarios since there is no restriction in its design concerning this type of scenario. We leave the conformation of this assumption for future work.

Finally, AutoMed currently acts as a formulating mediator. Designing a manipulative version of AutoMed can be used for interesting studies on the impact of different mediation styles on negotiation. Its manipulation can be applied by using an argumentation framework, as reviewed in section 2.1, in order to persuade a negotiator to agree to some suggestion.

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A Utility Functions vs. IVR Experiment

The negotiation interface, displayed in figure 2, details the list of issues and values agreed upon, in the center of the screen. There are buttons on the right that enable the negotiators to suggest new issues and values.

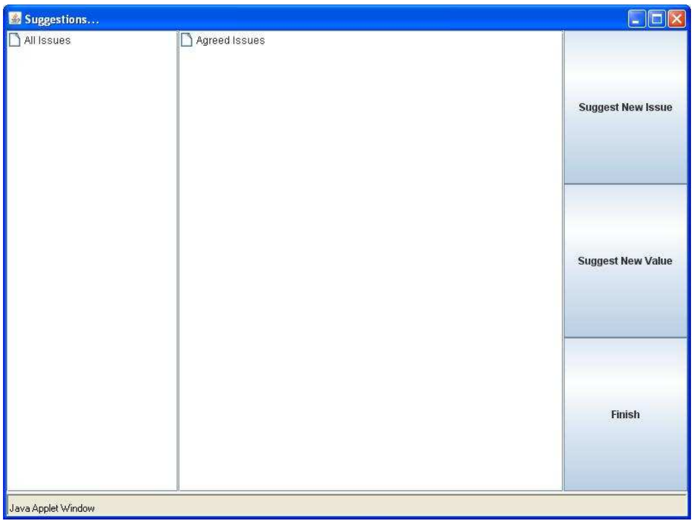

Figure 2: Negotiations Interface.

After an agreement concerning issues and possible values has been reached, both negotiators are asked to elicit their preferences using a similar interface. The interface displayed in figure 3 was used in the first stage, i.e. the issues weighting or ordering stage. The interface displayed in figure 4, namely the values of each issue's weighting or ordering stage, was used in the second stage.

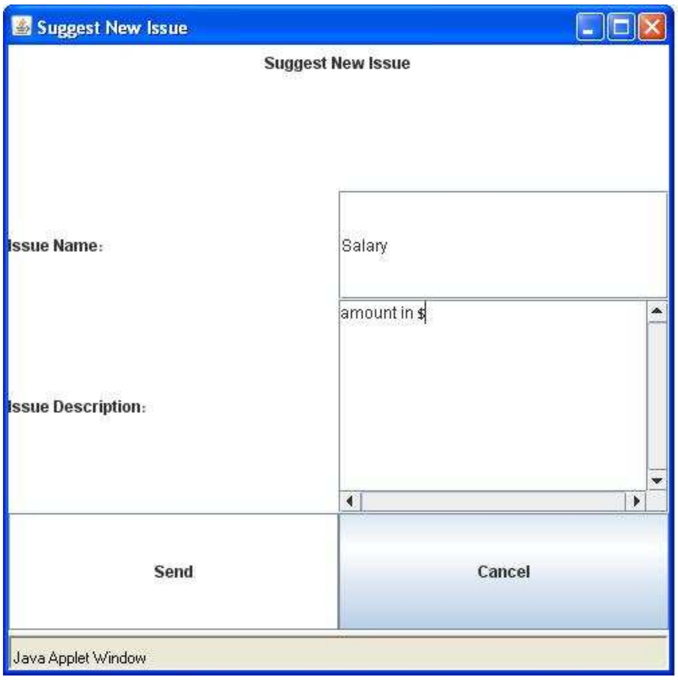

Figure 3: Add New Issue.

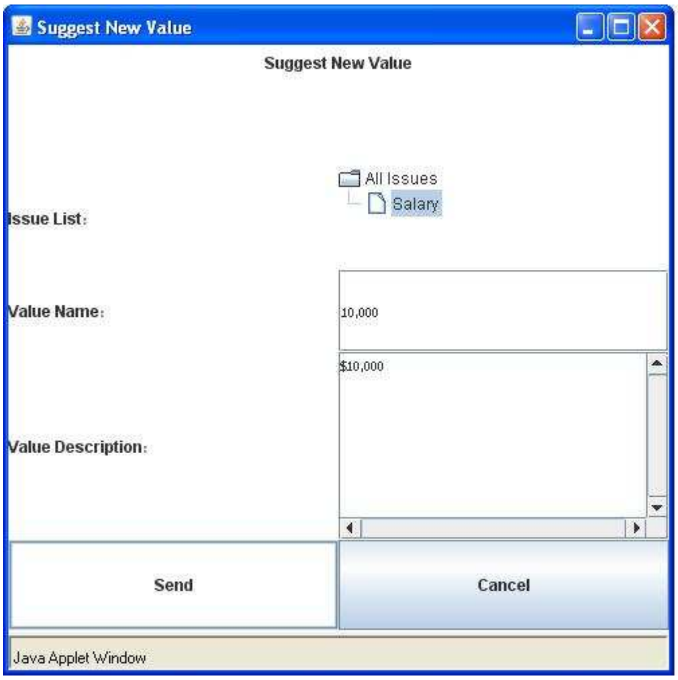

Figure 4: Add New Value.

B AutoMed's Performance Experiment

B.1 List of issues and values

Below is a complete list of issues and possible values which were used in the Tobacco Control Treaty domain.

1. *Size of the Fund* (SF). This issue has an impact on the budgets of the developed countries and on the effectiveness of economic benefits for the fund recipients.

   - $US 100 billion: this outcome is most beneficial to the fund recipients and most costly to the developed countries.
   - $US 50 billion: this outcome is very beneficial to the fund recipients and imposes significant costs on the developed countries.
   - $US 10 billion: this outcome provides minimal benefits for the fund recipients and is the least costly to the developed countries.
   - No agreement: this outcome postpones creation of the fund; it may create economic hardships for potential fund recipients and delays expenditures for developed countries. Moreover, it could erode the faith in the entire treaty, leading countries to refuse to ratify it so that the convention would never be fully implemented.

2. *Impact on Other Aid Programs* (IOAP). Developed countries may want to pay for the fund by reducing other aid programs. This could affect the net cost that will be incurred by the developed countries and the overall benefit for the fund recipients

   - No reduction in other aid: this outcome will minimize negative consequences for the fund recipients and increase the total cost for the developed countries.
   - Reduction equal to half of the Global Tobacco Fund: this outcome will significantly reduce the net benefit for the fund recipients and the costs that will be incurred by the developing countries.
   - Reduction equal to the size of the Global Tobacco Fund: this outcome is essentially equivalent to eliminating the net benefit for the recipients and the costs that will be incurred by the developed countries, except that this outcome involves a redistribution of aid funds, taken away from existing programs and redirected toward the tobacco export sectors of the recipients' economies.

- *Trade Policy.* The two blocks realize that they can use trade policy to extract concessions or provide incentives to the other party. There are both benefits and costs involved in these policies: tariffs (taxes on imports) may increase revenue in the short run but lead to retaliation by affected countries. Increasing imports can cause problems for domestic industries though it can also lead to lower consumer costs and improved welfare.
  This policy is divided into two different issues -

3. *Zimbabwe's Trade Policy* (ZTP).

- Recipients of the fund will reduce tariffs on imports other than tobacco products from the developed countries: This will reduce revenues but in the long run may also lead to improved trade relations for both countries.
- Recipients of the fund will maintain the current tariffs on imports.
- Recipients of the fund will increase tariffs on imports of products other than tobacco from the developed countries. This will increase revenue but could lead to deterioration in relations and possibly to a "trade war."

4. *Great Britain's Trade Policy* (GBTP)

   - Developed countries will reduce imports of other goods from recipients of the fund. This could further increase recipients' economic difficulties, could lead to deterioration in relations and possibly to a "trade war."
   - Developed countries will maintain current imports of other goods from recipients of the fund.
   - Developed countries will increase imports of other goods from recipients of the fund. This could damage their domestic industries but in the years ahead could lead to improved trade relations and mutual benefits.

5. *Forum on Other Health Issues* (FOHI). If the fund is established, the developing countries will be highly motivated to apply the same approach to other global health agreements. These would be of great benefit to countries suffering from health problems like AIDS and malaria, but would be very costly to the developed countries. New global health funds might be implemented fully in the near term, or the parties might explore preliminary steps such as establishing committees to develop a plan for creating new funds or to explore other issues.

   - Creation of a fund, similar to the Global Tobacco Fund, to provide increased assistance to countries with high incidence of other serious health issues, including malaria and AIDS. (This is in addition to existing international funding for combating these diseases.) This would be highly beneficial to the countries facing these health challenges, and very costly to the countries providing the funds.
   - Establishment of a committee to discuss the creation of a fund as described above. This outcome would create a political momentum for the benefit of potential recipients, and would require the developed countries to develop a strategy for limiting the economic and political costs for future funding agreements.
   - Creation of a committee to develop an agenda for future discussions on global health issues. This would push the issue farther into the future, delaying the benefits for potential fund recipients and the costs that will be incurred by the funding countries.
   - No future fund: Failure to agree on this issue would imply that the Tobacco Control Treaty should not to be considered a precedent for resolving future global health problems.

Denoting each issue by its initial (appearing in brackets after each issue's name), and each value by its number (starting with 1), the status quo agreement in this domain is: SF_4 $IOAP_1$ ZTP_2 $GBTP_2$ $FOHI_4$.

B.2 Negotiators' preferences

Each negotiator was presented with the preferences according to which she should play, detailed in the following subsections. The number appearing in brackets beside the name of each issue implies its importance level. The value 1 represents the lowest level of importance, while 5 represents the highest. Equal importance values mean the issues are of the same importance.

B.2.1 Great Britain's preferences

1. *Size of the Fund* (5).
   - \$US 10 billion $\succ$ No agreement$\succ$ \$US 50 billion $\succ$ \$US 100 billion
2. *Impact on Other Aid Programs* (4).
   - Reduction equal to the size of the Global Tobacco Fund $\succ$ Reduction equal to half of the Global Tobacco Fund $\succ$ No reduction in other aid
3. *Zimbabwe's Trade Policy* (1).
   - Recipients of the fund will reduce tariffs on imports other than tobacco products from the developed countries $\succ$ Recipients of the fund will maintain the current tariffs on imports $\succ$Recipients of the fund will increase tariffs on imports of products other than tobacco from the developed countries
4. *Great Britain's Trade Policy* (1).
   - Developed countries will reduce imports of other goods from recipients of the fund $\succ$ Developed countries maintain current imports of other goods from recipients of the fund $\succ$ Developed countries will increase imports of other goods from recipients of the fund
5. *Forum on Other Health Issues* (2).
   - Creation of a committee to develop an agenda for future discussions on global health issues $\succ$ Creation of a committee to discuss the creation of a fund $\succ$ No future fund $\succ$ Creation of a fund

B.2.2 Zimbabwe's preferences

1. *Size of the Fund* (5).
   - \$US 100 billion $\succ$ \$US 50 billion $\succ$ \$US 10 billion $\succ$ No agreement
2. *Impact on Other Aid Programs* (4).

- No reduction in other aid $\succ$ Reduction equal to half of the Global Tobacco Fund $\succ$ Reduction equal to the size of the Global Tobacco Fund

3. *Zimbabwe's Trade Policy* (1).

   - Recipients of the fund will increase tariffs on imports of products other than tobacco from the developed countries $\succ$ Recipients of the fund will maintain the current tariffs on imports $\succ$ Recipients of the fund will reduce tariffs on imports other than tobacco products from the developed countries

4. *Great Britain's Trade Policy* (1).

   - Developed countries will increase imports of other goods from recipients of the fund $\succ$ Developed countries will maintain current imports of other goods from recipients of the fund $\succ$ Developed countries will reduce imports of other goods from recipients of the fund

5. *Forum on Other Health Issues* (2).

   - Creation of a fund $\succ$ Creation of a committee to discuss the creation of a fund $\succ$ Creation of a committee to develop an agenda for future discussions on global health issues $\succ$ No future fund

B.2.3 Additional data

The implications of time passing, disagreement and opting out are also detailed.

For Great Britain:

- For every time period ending without an agreement, Great Britain earns $US 5 million, due to the fact that it still does not have to start paying.
- In case of opting out, Great Britain will lose $US 43.75 million, due to the need to continue dealing with the unwanted Tobacco trade.
- In case of maintaining the status quo, Great Britain will earn $62.5 million, since there is no need to contribute to the new fund.

The negotiators were asked to keep in mind that Great Britain has other, nonfinancial, interests in reaching a mutual agreement, such as, political, social and long term economic considerations.

For Zimbabwe:

- For every time period ending without an agreement, Zimbabwe loses $US 6 million, due to the fact that it still has not begun receiving the support funds.
- In case of opting out, Zimbabwe will lose $US 198.75 million, due to the expected decrease in Tobacco prices as a result of the one-sided decision to leave the negotiations.
- In case of maintaining the status quo, Zimbabwe will lose $228.75 million, since there is no fund, and its economic state will worsen.

The numbers used were adjusted from the parallel domain used in [25] and are represented by utility functions.

B.2.4 AutoMed's solution

Again, denoting each issue by its initial (appearing in brackets after each issue's name), and each value by its number, AutoMed will calculate the middle-ground agreement in this domain as: SF_3 IOAP_1 ZTP_3 GBTP_1 FOHI_3.