

A Multi-Thread Auto-Negotiation Method for Value Conflict Resolution in Transboundary Service Design

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Abstract

When designing transboundary services, designers need to reasonably optimize the configuration of the service quality and service resources of each service participant to satisfy the value expectations of multiple parties. However, due to the constraints of the service quality offered, and resources owned by participants, the designed configuration may sometimes not meet all the value expectations. At this time, it is need to persuade the relevant parties to lower their value expectations, so as to realize resolution of value conflict. Therefore, for transboundary service design, a reasonable conflict resolution method is one of the key points. This paper proposes a multi-thread automatic negotiation method based on Stackelberg game theory and swarms intelligence algorithm to solve the problem of multi-party value conflicts. A numerical simulation on real-world transboundary service design was carried on to validate The rationality and validity of the proposed model.

Keywords

Transboundary Service Design, Multi-Party Value Conflicts, Automatic Negotiation, Swarm Intelligence Algorithm, Stackelberg Game

1. Introduction

The transboundary service has become an important innovation mode to promote the development of the modern service industry. It deeply integrates several independent services from different industries, different organizations, and different value chains, and provides users with multi-dimensional, high-quality, and valuable services (Wu et al., 2016). When designing transboundary services,

based on the understanding of domain knowledge and personal experiences of the designer, with the help of specific service design tools, and under the constraint of the real service capability of multiple service providers, the value expectations of many stakeholders must be converted into the configuration for the quality parameters attached to service functions (Xu et al., 2018; European Commission, 2014). This is to find a reasonable configuration scheme of quality parameters within the feasible region limited by constraints such as the real service capability of multi-party service providers and the value expectation of service participants.

As shown in Figure 1, because the service capability (i.e., quality parameter QP of service functions) of the service participants has been fixed during the design of the transboundary service, there will likely be conflicts between the value expectations of each participant and the service capabilities that each participant can provide, and also internal conflicts between the value expectations in the process of configuration. The value conflicts can be classified into two types:

1) Conflict_Type_1: single value conflict. The value expectation of one participant is too high. Even if no other value expectation is considered, the existing service capability cannot meet the current value expectation. It is a conflict between the value expectation and the service capability of the service participant.

2) Conflict_Type_2: associated value conflict. There is a conflict between multiple value expectations, which makes the existing service quality and service capability unable to meet all value expectations at the same time. It is a conflict among value expectations.

As the transboundary service involves multiple participants, each participant has their bottom lines of acceptance of the value expectations they care about in the cooperation. In order to find a reasonable scheme of concession as soon as possible, an effective automatic negotiation model is established in this paper to resolve the existing value conflicts.

With the emergence of the concept of negotiation, negotiation has gradually become the main means to resolve conflicts and contradictions between participants (Fatima et al., 2014; Faratin et al., 1998). With the rapid development of internet

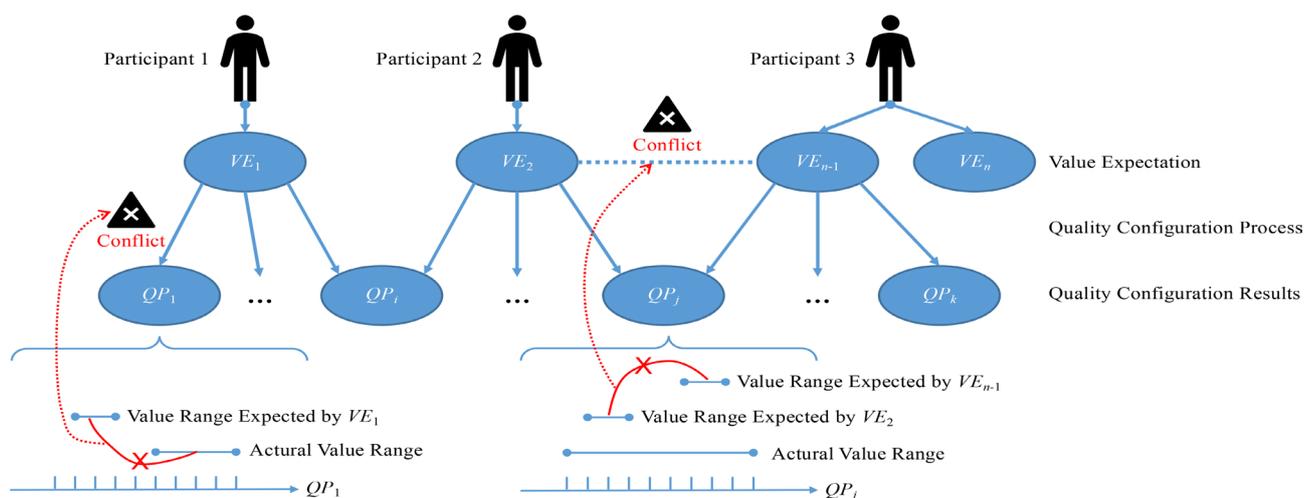


Figure 1. Value conflicts in the configuration of transboundary service.

technology, the automatic negotiation method based on multi-agent technology has been widely studied and applied (Eshragh *et al.*, 2015). Sanchez-Anguix *et al.* (2013a; 2013b) studied the impact of the negotiation environment on the performance of several intra-team strategies (team dynamics) for agent-based negotiation teams that negotiate with an opponent. Haleema and Iyengar (2018) proposed a mathematical model with flexible negotiation strategies for agent-based negotiations, which can be applied suitably in bilateral/multilateral multi-issue negotiation environments. Kolomvatsos *et al.* (2016) proposed a model for defining weight values in the calculation process of the utility function. Many negotiations are based on game strategies such as Stackelberg (Liu *et al.*, 2014) and Rubinstein, in which agents guide negotiation strategies according to the changes in the environment. Ray, Khatua, and Roy (2014) proposed a game model of automatic SLA negotiation between consumers and providers, trying to provide the best price and quality value for both participants. Tian, Li, and Yang (2018) proposed an automatic negotiation model based on the Stackelberg game, which solved the reasonable distribution of profits problem from collaborative logistics transportation. However, its negotiation result was too dependent on the initial parameters, and the negotiation was slow and easy to fail.

Although the use of automatic negotiation to resolve conflicts has received extensive attention, there is no research on resolving value conflicts of transboundary service design based on automatic negotiation theory. Whether the value conflicts existing in the design of transboundary services can be resolved successfully is related to the concession of value expectations made by participants of transboundary services. However, the correlation is difficult to quantify, and it is infeasible to find a suitable equilibrium point.

Value conflict resolution in transboundary service design is different from the problems previously solved by automatic negotiation. As there is a complex correlation between various service capabilities and value expectations in transboundary services, it is not only necessary to design a reasonable automatic negotiation model but there is also a need to develop a reasonable scheme of concession of value expectation in the negotiation process, to consider the global utility and individual benefits on the premise of eliminating all conflicts.

The global utility is calculated according to the weights and values of value expectations. The weights of value expectations are different in different periods of the transboundary service and are determined by the global strategic plans of the transboundary service. The global utility of the transboundary service represents the realization effect of the current strategy of the transboundary service. The higher the utility value, the greater the possibility of the realization of the current strategic purpose. In the design of transboundary services, their whole utility is the main concern of the transboundary service organizer.

Individual benefits are determined by the ultimate values of value expectation after the negotiation of transboundary service participants. The loss of individual benefit results from the concession of value expectation of transboundary ser-

vice participants. The main concern of each participant is the loss of their own benefit. Participants are willing to make a partial concession to resolve the conflict, but they hope that the concession will cause the least loss of benefits. If some participants concede too much, they will feel unfair and will probably refuse to continue to resolve the value conflict, which causes the transboundary service design to fail. The satisfaction degree of individual benefit determines the success rate of value conflict resolution.

This paper proposes an auto-negotiation method for a multi-party value conflict resolution in transboundary service design. First, the mathematical programming algorithm is used to calculate the global optimal scheme of concession of value expectations, and the swarm intelligence negotiation algorithm based on the Stackelberg game is then used to carry out negotiation between the centre agent (*CA*) and the agent of each service participant. Then, the feasibility of the negotiation result is tested, and this resolution process is repeated for multiple rounds until all value conflicts are resolved. This model aims to maximize the global utility of transboundary services on the premise of ensuring the individual benefits of all participants.

The main contributions of this paper are summarized as follows:

- 1) Multi-party value conflict resolution in transboundary service design is a new negotiation scenario. There are strong correlations among the value expectations of many stakeholders in transboundary services, and the globally optimized concession of value expectations will be affected by other value expectations.
- 2) The mechanism of locking and unlocking is proposed to calculate the globally optimized concession scheme of value conflict resolution, which ensures the fairness of negotiation.
- 3) This paper proposes a multi-thread swarm intelligence algorithm based on the Stackelberg game theory, which takes into account global utility and individual benefits, and ensures the success rate of negotiation and the realization of a transboundary service strategic plan.

2. Negotiation Framework and Process of Value Conflict Resolution

2.1. Scenario Description

The transboundary service is provided by multiple participants. Each participant has its value expectations and service capabilities. One participant can have multiple value expectations and service capabilities. The value expectation and service capability of the participants should be proposed by the participants according to the actual business situation of the participants and determined in the initial stage of transboundary service construction.

In the actual design of transboundary services, the following constraints are mainly imposed: (1) the configuration of quality parameters should be able to support the realization of value expectations; (2) the configured quality parame-

ter value should be within the reasonable value range of the quality parameter. When the above two constraints cannot be satisfied at the same time, the feasible domain of the solution is empty, and the configuration fails.

As shown in **Figure 2**, each service participant has its own value expectations and fixed service capability. Due to the constraint relationships between different value expectation and the ones between value expectation and service capability, the existing service capabilities may not meet all the value expectations, and the service capabilities required under the current value expectations do not match with the actual service capabilities. However, because the service capabilities can no longer be improved, service participants must reduce their own value expectations, so that under the existing constraints, the service capabilities can meet all the value expectations. Through the multi-thread and auto-negotiation method for resolving multi-party value conflicts, each participant reduces their own value expectations, so that the service capabilities of participants can meet all the value expectations.

As a lot of negotiation information involves enterprise privacy, in many cases, participants are not willing to expose their negotiation information in the negotiation process. Therefore, this study assumes that all the negotiation information is private, and participants do not know each other, so participants can only rely on their cognition to estimate.

2.2. Design of Framework of Value Conflict Resolution

According to the characteristics of the multi-party value conflict problem in transboundary service design, the automatic negotiation framework of value conflict resolution is analysed and designed.

The CA is the agent instantiated by the transboundary service organizer in the

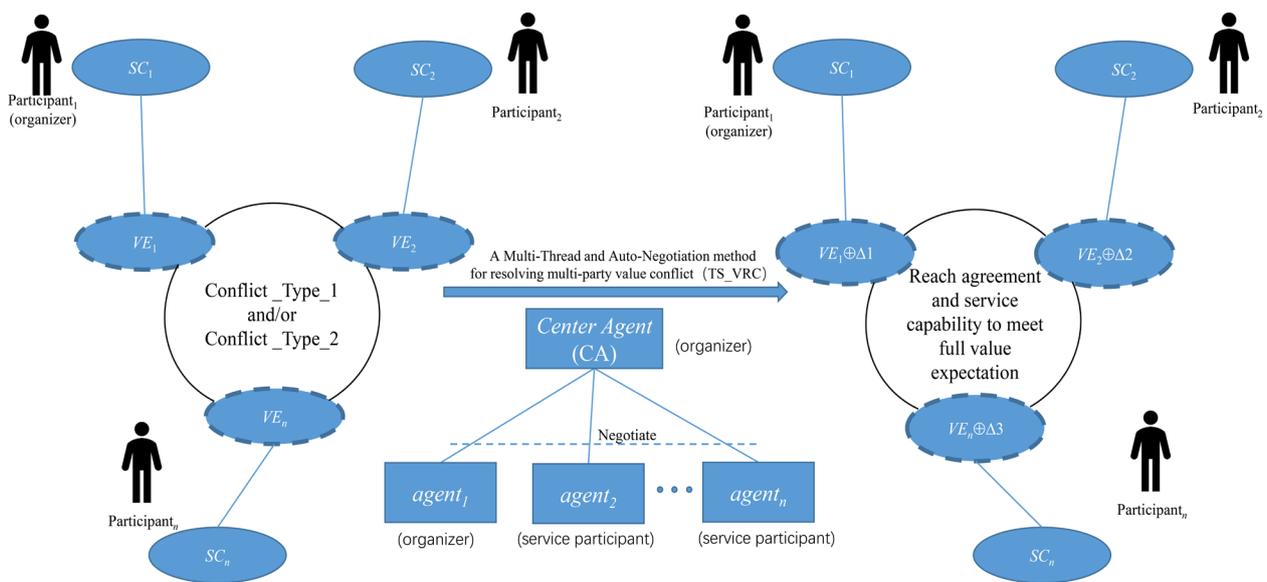


Figure 2. Resolution in the design of transboundary service.

negotiation platform. It is not only the regulator in the process of value conflict resolution but also the participant of negotiation. In the negotiation, it represents the global benefit of the transboundary service participants and pursues the maximization of the global utility. Therefore, CA can also be regarded as the negotiation agent of the global benefit of transboundary services.

Agent_{*i*} represents the negotiation agent of the *i*th value expectation. **Figure 3** describes the overall negotiation framework of value conflict resolution in transboundary service design.

At the beginning of the resolution, CA uses a mathematical programming algorithm to find the globally optimized scheme of concession $\varepsilon = (\varepsilon_1, \varepsilon_2, \varepsilon_3, \dots, \varepsilon_n)$ for value expectations and the reserve concession RC_{CA} of CA, which is the bottom-line value of the concession of CA. CA takes this scheme as the initial scheme and conducts one-to-one negotiations with the agents involved in the scheme. At this time, the number of negotiation rounds *r* is 1. After the negotiation, a local optimized scheme of concession is obtained.

The negotiation result is returned to CA, which then tests the feasibility of the configuration of the transboundary service under the current scheme of concession. If the configuration is available, it means that the value conflict has been successfully resolved, the final scheme of the concession of value expectation is then output, and the resolution of conflict ends. If the configuration fails, the concession of the negotiated value expectation will be retained, and the value expectations that have made concession will be locked. The locked value expectation will not be required to make a concession in the future globally optimized

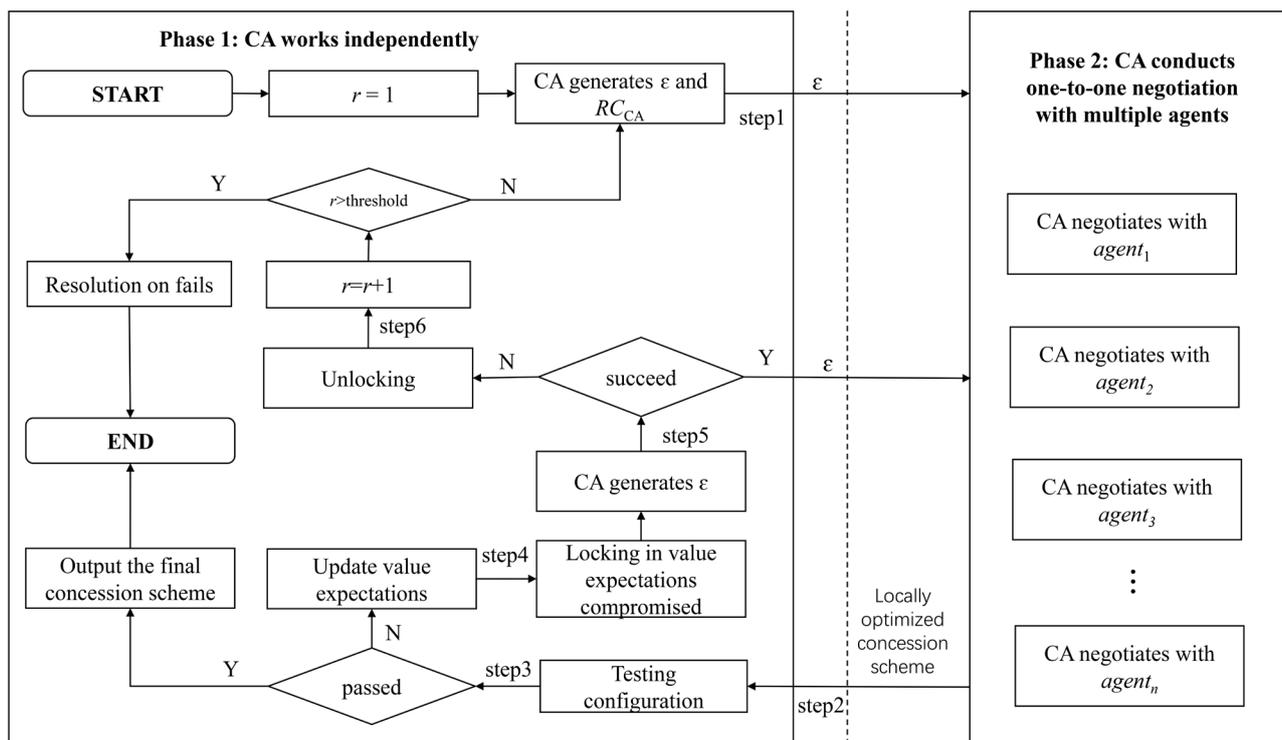


Figure 3. Overall negotiation framework of value conflict resolution in transboundary service design.

scheme of concession before unlocking the lock. On this basis, the globally optimized scheme of concession is recalculated, and a new negotiation is carried out according to the calculated scheme. The result is sent to *CA* to test the feasibility of the configuration until the configuration is available or the calculation of the globally optimized scheme of concession fails.

If the calculation of the globally optimized scheme of concession fails, the lock of all value expectations will be removed. This round of negotiation will end and the next round of negotiation will begin. The globally optimized scheme of concession will be recalculated. The number of unlocking is not infinite. When the number of rounds exceeds the threshold R , it means that the negotiation result is close to the bottom line of each participant. If the negotiation still fails, there is no need to continue, which means that conflict resolution fails.

3. Automatic Negotiation Method of Value Conflict Resolution

3.1. Generation of the Globally Optimized Scheme of Concession and Reserve Concession of *CA*

In the process of making a value expectation concession, only the truly appropriate concessions can resolve conflicts and exert a positive effect on the success of configuration. Therefore, how to obtain an initial scheme of concession with minimal global utility loss is a key step. In addition, it is a constrained optimization problem.

For single-value conflict, the relevant value expectation must make a concession; otherwise, the conflict cannot be resolved. For associated value conflict, the concessions of partial value expectations can also achieve the effect of resolving the conflict. Therefore, we calculate the minimum concession of each value expectation under single-value conflict, which represents the minimum concession of the agent acceptable to *CA*. If the concession value of the agent cannot reach it, conflict resolution is bound to fail.

In different periods of the transboundary service, and different strategic purposes, the weights of value expectations will also change. In the process of calculating the globally optimized scheme of concession, the minimum global utility loss is taken as the objective function. This process does not consider the individual benefits of each service participant and the fairness of concession. This globally optimized scheme of concession is only an ideal scheme formulated by *CA*.

In the case of associated value conflict, because the weights of value expectations remain unchanged, the calculation result will remain unchanged. Therefore, some value expectations will be required to make a concession all the time, leading to a serious lack of fairness in the process of resolving value conflict. This would make the value conflict resolution speed slow or even fail.

To avoid this situation, we introduce locking and unlocking methods into the overall resolution framework. According to this strategy, during the period when

the value expectation is locked up after the concession, the concession will not be required until the conflict is completely resolved or the negotiation fails. On the one hand, taking the minimum loss of global utility as the objective function can effectively reduce the loss of global utility and better realize the strategic purpose of transboundary services. On the other hand, it can ensure that the value expectation will not be required to be continuously reduced, protect the rights and benefits of participants, increase the rationality and fairness of the negotiation strategy, and improve the success rate of negotiation.

The objective function in calculating the scheme of concession is

$$\min \sum_{i=1}^n w_i \times \varepsilon_i \times n_i, \quad (1)$$

where ε_i represents the concession of the i th value expectation, w_i represents the weight of the i th value expectation, and n_i represents the normalized factor of the i th value expectation due to the different units of each value expectation.

The objective function to calculate the minimum value of the concession of value expectation acceptable to CA is as follows:

$$\min \varepsilon_i, \quad (2)$$

This objective function ignores other value expectations and only considers the minimum concession expected in the extreme case that all service resources are used to realize the i th value expectation.

This objective function ignores other value expectations and only considers the minimum concession expected in the extreme case that all service resources are used to realize the i th value expectation.

The constraints of the two objective functions are as follows:

$$\begin{cases} y_i(q) + \varepsilon_i \geq vp_i, \varepsilon_i \geq 0, i = 1, 2, 3, \dots, i_0 \\ y_i(q) - \varepsilon_i \leq vp_i, \varepsilon_i \geq 0, i = i_0 + 1, i_0 + 2, i_0 + 3, \dots, m \\ q_j = z_j(q), j = 1, 2, \dots, n \\ q_j \in [tq_j^{lp}, tq_j^{up}], j = 1, 2, 3, \dots, j_0 \\ q_j \in \{tq_j^{lp}, \dots, tq_j^{up}\}, j = j_0 + 1, j_0 + 2, \dots, n \end{cases} \quad (3)$$

where $vp_i (i = 1, 2, 3, \dots, m)$ represents the i th value expectation and the value index is directional. $q = (q_1, q_2, \dots, q_n)$ represents the quality indicator in transboundary services, $y_i (i = 1, 2, 3, \dots, m)$ represents the relationship function between the i th value indicator and each quality indicator in transboundary services, $z_j (j = 1, 2, 3, \dots, n)$ represents the correlation function between the j th quality parameter and other quality parameters, $[tq_j^{lp}, tq_j^{up}]$ represents the value range of continuous quality index q_j , and $\{tq_j^{lp}, \dots, tq_j^{up}\}$ represents the value range of discrete quality index q_j .

By solving the above model, the initial scheme of concession $\varepsilon = (\varepsilon_1, \varepsilon_2, \varepsilon_3, \dots, \varepsilon_n)$ and the minimum concession $\varepsilon^{CA} = (\varepsilon_1^{CA}, \varepsilon_2^{CA}, \varepsilon_3^{CA}, \dots, \varepsilon_n^{CA})$ of the agent acceptable to CA can be solved. Then, we can calculate the RC_{CA} by the formula,

$$RC_{CA} = \varepsilon - \varepsilon^{CA} = (RC_{CA}^1, RC_{CA}^2, RC_{CA}^3, \dots, RC_{CA}^n)$$

After obtaining the globally optimized scheme of concession $\varepsilon = (\varepsilon_1, \varepsilon_2, \varepsilon_3, \dots, \varepsilon_n)$ and the reserve concession RC_{CA} of CA , we will start to negotiate.

3.2. Automatic Negotiation Model

3.2.1. Model Description

Combined with the existing scenario (mentioned in Section 2.1), the original Stackelberg automatic negotiation model is improved, and the automatic negotiation model can be defined as a multi-tuple:

$$(N, m, M, A, Action, t, T, RC, C^t, \beta(t), V^t, border^t)$$

1) N is the number of threads. Negotiations take place simultaneously in N threads.

2) m is the number of searching for better parameters among N threads after negotiation, and M is the threshold that represents the maximum number of m .

3) A is the set of agents participating in the negotiation. This paper discusses bilateral negotiation and defines $A = \{agent_p, CA\}$. $agent_i$ represents the negotiation agent of the i th value expectation, and the negotiation parameters of $agent_i$ are set by the service participant related to the i th value expectation. CA represents the global benefit of the transboundary service.

4) Action represents the set of actions of CA and $agent_p$, including Accept, Reject, Offer, and C_offer. Agents act according to current quotes and rules.

5) t is the time of negotiation between CA and $agent_i$, and T represents the maximum number that can be accepted of t . If the two parties still fail to reach an agreement after reaching T , it means the negotiation fails.

6) RC represents the reserve concessions acceptable to negotiation participants, which are bottom-line values of the concession of negotiation participants and can be expressed as $RC = \{RC_i, RC_{CA}^i\}$. RC_i represents the maximum concession value of $agent_i$ acceptable to $agent_p$, and RC_{CA}^i represents the maximum concession value of CA acceptable to CA .

7) C^t is the concession value of participants at time t . C_{CA}^t represents the concession value of CA in the scheme of concession at time t , and C_i^t represents the concession value of $agent_i$ in the scheme of concession at time t .

8) $\beta(t)$ represents the satisfaction parameter as follows:

$$\beta(t) = \begin{cases} (1 - \min(t, T_{\max})/T_{\max})^\lambda \times w, & \text{Active} \\ (\min(t, T_{\max})/T_{\max})^\lambda \times w, & \text{Negative} \end{cases} \quad (4)$$

Participants are divided into active participants and passive participants. λ is a real number that represents the eagerness of the participants, and the larger lambda is, the more anxious the participants are to make the negotiation successful. $w \in (0, 1]$ determines the maximum value of $\beta(t)$.

9) V represents the satisfaction function of the participant at time t . In the

Negotiation is executed in multiple threads simultaneously. In each thread, CA and $agent_i$ negotiate, and the negotiation agents of both parties will predict the reserve concession and negotiation parameters of the other party according to the scheme proposed by the other party, to constantly revise their subjective judgment of the other party, while considering the synergy effect, and modify their own quotation scheme and counter quotation scheme to improve their own interests as much as possible. After the negotiation, the optimal result will be saved, and information exchange among multiple threads will be carried out to search for better negotiation parameters. Until the number of searches reaches the threshold, the negotiation stops and the optimal negotiation result is output. The algorithm is as follows:

Step 1: Initialize multiple threads and generate negotiation parameters of CA

This is to input the obtained initial scheme of concession and the reserve concession of CA into the thread. The service designer sets the value range of negotiation parameters of CA according to the actual situation, within which N groups of negotiation parameters $\theta_i (i = 1, 2, 3, \dots, N)$ are randomly generated and input into N threads:

$$\theta_i = (\alpha_i, \lambda_i, w_i, T_i), i = 1, 2, 3, \dots, N, \quad (7)$$

α is actually an adjustable parameter, which affects the range of strategy change in the game process. The negotiation parameters and reserve concession of $agent_i$ are set by service participants in N threads, respectively. As the value expectation may be negotiated more than once, $agent_i$ itself records the negotiation data and automatically adjusts its own reserve concession during initialization based on the value expectation that has been conceded.

Step 2: Start negotiation in N threads at the same time, and output negotiation results and negotiation parameters of CA

Step 2.1: The current number of negotiations $t = 0$, $border^0 = \{\varepsilon_i, \varepsilon_i\}$, $C^0 = \{\varepsilon_i, 0\}$, and negotiations start at the same time in multiple threads. At the initial stage, the concession value of CA is 0. The default judgment is that CA is the passive negotiator and agent is the active negotiator.

Step 2.2: According to the current scheme of concession and negotiation role, the above satisfaction function V^t is used to calculate the satisfaction degree parameters of both parties, and then the satisfaction degree of both parties is calculated.

Step 2.3: If the degree of satisfaction of CA and agent is 1, both CA and agent are satisfied and the scheme would be accepted, the negotiation is successful, and the negotiation result is output. Then, go to Step 3. Otherwise, someone who is dissatisfied will reject the scheme, and go to Step 2.4.

Step 2.4: The party with the lower degree of satisfaction becomes the active negotiator, while the party with the higher degree of satisfaction becomes the passive negotiator. For any participant $a \in A$, if satisfaction is less than 0, there are:

$$border_a^{t+1} = \min(C_a^t, border_a^t), \quad (8)$$

Step 2.5: If the number of negotiations is $t > T$, the negotiation fails within the specified time, the negotiation is over, and no information is sent.

Step 2.6: After carrying out the role determination of each negotiation, if the active negotiator is still the active negotiator, it means that the current value α is low, and then k represents the number of times the active negotiator has been the active negotiator continuously.

$$\alpha = \min(\alpha + 0.01k, 1), \quad (9)$$

Step 2.7: $t = t + 1$. Estimate the minimum concession of active negotiators acceptable to passive negotiators, and the active negotiator offer:

First, we calculate the constraint interval of negotiation according to $border^t$. The new negotiation scheme must meet the requirements $C_i^t < border_i^t$ and $C_{CA}^t < border_{CA}^t$. Otherwise, this time of negotiation will not succeed and will not be meaningful. The negotiation concession constraint interval of $agent_i$ is

$$(lc_i^t, uc_i^t) = (\varepsilon_i - border_{CA}^t, border_i^t), \quad (10)$$

The negotiation concession constraint interval of CA is

$$(lc_{CA}^t, uc_{CA}^t) = (\varepsilon_i - border_i^t, border_{CA}^t), \quad (11)$$

Then, the new estimated concession is calculated according to the obtained constraint interval and is taken as the most possible concession of active negotiators acceptable to passive negotiators at this time:

$$\mu_a = \frac{C_i^{t-1} - lc_i^t}{1 + \alpha} + lc_i^t, \quad (12)$$

α is adjusted continuously with the negotiation and tends to the actual value. With the constant adjustment of parameters, the estimated value gradually approaches the real value, so overall, the closer it is to the estimated value, the more likely it is to be the real reserve concession. Therefore, we assume that the distribution of the estimated concession is subject to the normal distribution, and calculate the mathematical expectation of the estimated concession within the constraint interval as the minimum value of concession of the active negotiator acceptable to the estimated passive negotiator.

$$f(x) = \frac{1}{\sqrt{2\pi}\sigma} \exp\left(-\frac{(x - \mu_a)^2}{2\sigma^2}\right), \quad (13)$$

$$MC_i = \frac{\int_{lc_i^t}^{uc_i^t} xf(x)dx}{\int_{lc_i^t}^{uc_i^t} f(x)dx}, \quad (14)$$

where $\sigma = 0.01(uc_i^t - lc_i^t)$. Then, the active negotiator receives a new suggestion: $(MC_i, \varepsilon_i - MC_i)$, and offers new proposals to the passive negotiator.

Step 2.8: After receiving the new proposal $(MC_i, \varepsilon_i - MC_i)$, the passive negotiator puts forward the C_offer in the same manner:

$$(\varepsilon_i - MC_{CA}^i, MC_{CA}^i)$$

Take the counter-proposal as the new negotiation scheme, and go back to Step 2.

Step 3: Document the optimal negotiation results

In this step, the optimal negotiation result of the negotiation among multiple threads is documented. $m = m + 1$. If $m < M$, go to step 4; otherwise, output the documented optimal negotiation result and the negotiation is over. If negotiation fails in all threads, the stored result is null, and the negotiation failure signal is then output.

Step 4: Information exchange and search for better parameters in multi-thread

In this step, we introduce the search strategy of the artificial bee colony algorithm to improve the ability of global search. Each thread can obtain negotiation parameters and negotiation results from other threads. After receiving negotiation results sent by other threads, it will learn from these parameters according to the negotiation effect of each thread. For each time, the negotiation parameter p ($p = 1, 2, 3, 4$) is randomly selected for adjustment. The adjustment mode is as follows:

$$\theta_{ip} = \theta_{ip} + \psi(\theta_{jp} - \theta_{ip}), \quad (15)$$

where q_{jp} represents the p th negotiation parameter of the j th thread in the process of stochastic learning, and Y represents the learning rate. When the result of a certain thread still does not improve after a certain number of times, the current parameter is abandoned, and a set of parameters are generated randomly in the domain to join the current thread again. After this step, return to Step 2.

4. Case Study

Online car-hailing is a transboundary service, which is generally formed through transboundary cooperation between app operators, navigation service companies, taxi drivers, and other participants. This section takes the online car-hailing service as an example to verify the proposed method in this paper. The used data given in the following numerical simulation is obtained by conducting the interviews with the practitioners of the online car-hailing service under the help of the domain experts. The proposed method in this paper only needs the basic information of the transboundary service, so it is also applicable to other scenarios of transboundary services and has a strong universality.

Before an online car-hailing service is launched, the service designer needs to configure the quality parameters according to the value expectations of all participants. First, the online car-hailing service participants declare the value expectations, as shown in **Table 1**. The maximum concession value is also determined by the participants, but as private information, it is only sent to their agents and is not disclosed. The weights of the value expectations are determined by the current market strategy of the online car-hailing service.

According to the actual service capability of the service provider, the relevant quality parameters and their value ranges are declared, as shown in **Table 2**.

Combined with the declaration information of value expectation and quality parameters in **Table 1** and **Table 2**, we can obtain the correlation functions between each value index and quality parameter and the correlation functions between quality parameters in the current transboundary service by means of our previous method (Ma et al., 2020). The data of Table 1 and 2 was taken as the input of the VQD/QCD two-phase model, and then by carrying out the fuzzy least absolute linear regression and fuzzy nonlinear programming algorithms, the constraints of all the related functions are given as follows.

$$\begin{cases} 0.00037q_3 + 0.0875q_4 - 0.9845 > 0.8 \\ -17.883q_1 - 0.264q_2 + 0.0018q_3 + 0.52q_4 + 3.495q_5 - 0.1103q_6 + 43.901 > 25 \\ 8.917q_1 - 0.213q_2 - 0.0029q_3 + 4.81q_4 + 2.675q_5 + 0.0068q_6 - 2.386 > 20 \\ -6.15q_1 - 4.42q_2 + 0.0307q_3 + 6.315q_4 + 30.415q_5 - 0.9103q_6 + 113.232 < 235 \\ 126.567q_1 + 71.862 > 300 \\ 0.0004q_3 + 0.065q_4 + 0.125q_5 - 1.487 > 0.5 \\ q_2 = -0.004q_3 + 23.42 \\ q_1 \in [1.4, 2.0], q_2 \in [5, 20], q_3 \in [3500, 5000] \\ q_4 \in \{1, 2, 3, 4, 5\}, q_5 \in \{1, 2, 3\}, q_6 \in [10.50] \end{cases}$$

At this time, the feasible domain limited by the calculation constraints is empty, and it can be seen that there is value conflict, which must be resolved. We use TS_VCR and a traditional auto-negotiation method based on the Stackelberg game (abbreviated as ANBS) [13] to resolve the conflict and compare the effect of the resolution. The negotiation parameter settings are shown in **Table 3**.

Table 1. Value expectation statement.

	Market Share	Daily Order Volume	Average Income per Order	Operation Cost	Average Daily Income	Favourable Rate
Symbol	vp_1	vp_2	vp_3	vp_4	vp_5	vp_6
Operator	>	>	>	<	>	>
Value Expectation	80%	25	20	235	300	50%
Unit	no	million	Yuan	million Yuan	Yuan	no
Weight	0.3	0.15	0.1	0.1	0.15	0.2
RC_i	0.2	5	5	50	50	0.1

Table 2. Declaration of quality parameters.

Symbols and names of quality parameters	Range of quality parameters
q_1 : Average Travel Cost	[1.4 Yuan/km, 2.0 Yuan/km]
q_2 : Maximum Waiting Time during Peak Period	[5 min, 20 min]
q_3 : Quantity of Available Taxis	[3500 vehicles, 5000 vehicles]
q_4 : Drivers' Service Attitude	{1, 2, 3, 4, 5}
q_5 : Security Guarantee Level	{1, 2, 3}
q_6 : Positioning Accuracy	{10 m, 50 m}

CA_1 represents the negotiation agent of the global utility in TS_VCR, and the negotiation parameters are randomly generated according to the value range of parameters. CA_2 represents the negotiation agent of the global utility in the traditional automatic negotiation model based on the Stackelberg game (abbreviated as ANBS). The negotiation parameters are a set of determined values, which are set by the service organizer. In the negotiation, the maximum negotiation round T is decided by CA . For comparison, $agent_i (i = 1, 2, 3, \dots, n)$ is consistent in the two negotiation methods.

The above two methods are respectively used to resolve the above problems, and the results are shown in **Figures 5-8** and **Table 4**. Compared to **Figure 5** and **Figure 6**, we find that all conflicts are resolved through 8 rounds of negotiation in ANBS; while only 3 rounds are in TS_VCR, the number of negotiation rounds in TS_VCR is significantly less than that in ANBS.

When using TS_VCR and ANBS in a negotiation with RC of $\{34, 66.1\}$, $T = 100$, and $C_0 = \{100, 0\}$, the negotiation results are shown in **Figure 7**. Through

Table 3. Settings of negotiation parameters.

Agent	α	λ	w	T
CA_1	[0, 1]	[0.01, 10]	(0, 1]	[50, 300]
CA_2	0.15	1	1	100
$agent_1$	0.1	0.1	1	—
$agent_2$	0.2	0.5	0.8	—
$agent_3$	0.3	1	0.7	—
$agent_4$	0.15	0.5	1	—
$agent_5$	0.2	5	0.8	—
$agent_6$	0.1	7	0.6	—

Table 4. Comparison of negotiation results.

	TS_VCR		ANBS	
	Negotiated concession value of the i th value expectation	Negotiated i th value expectation	Negotiated concession value of the i th value expectation	Negotiated i th value expectation
$i = 1$	0.0000	0.8000	0.0156	0.7844
$i = 2$	1.2879	23.7121	1.6677	23.3323
$i = 3$	0.0000	20.0000	0.4161	19.5839
$i = 4$	32.5310	267.5310	19.4706	254.4706
$i = 5$	0.0006	299.9994	0.0036	299.9964
$i = 6$	0.0000	0.5000	0.0000	0.5000
Time of negotiation	72 s		125 s	
Number of failures	0		2	

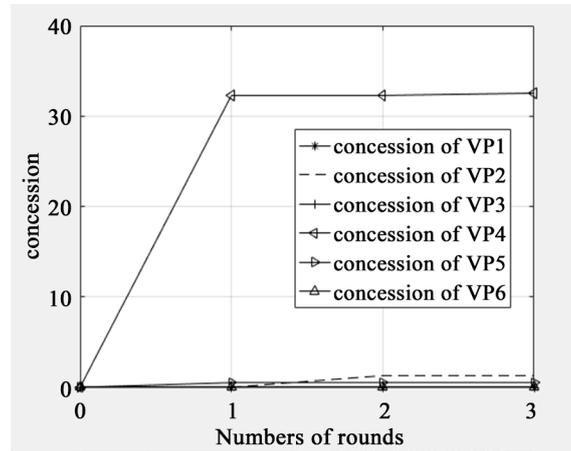


Figure 5. Results of negotiation concession of TS_VCR.

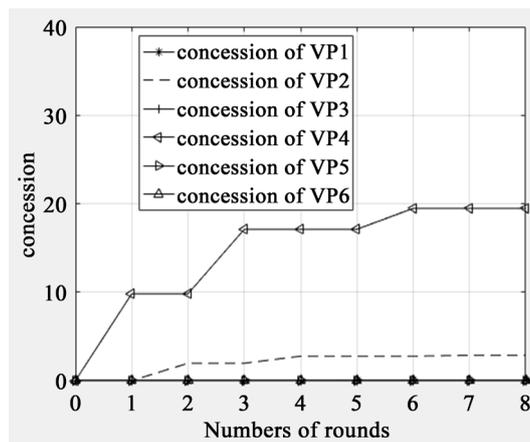


Figure 6. Results of negotiation concession of ANBS.

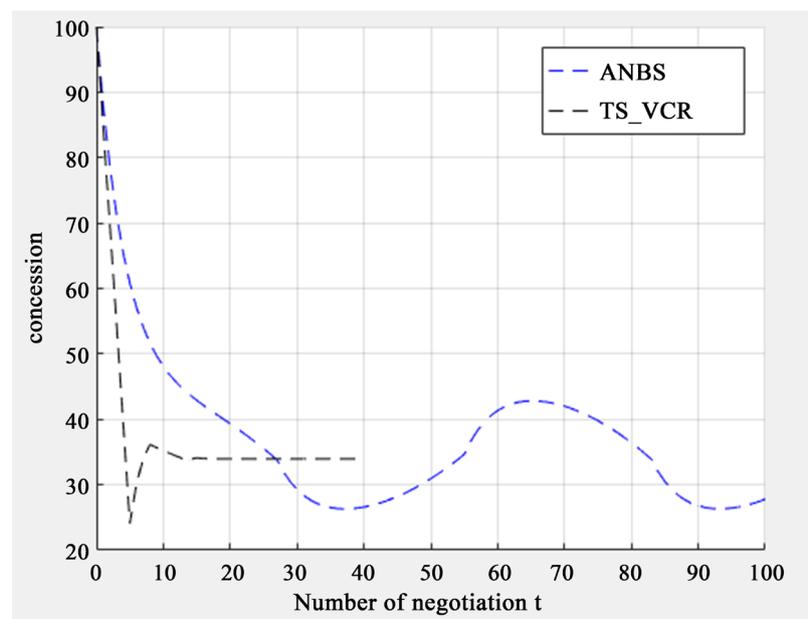


Figure 7. Negotiation effect of the two negotiation methods within a very small feasible range.

Figure 7, we can find that the negotiation in ANBS failed and succeeded in TS_VCR. At the same time, **Table 4** shows that the number of failures of TS_VCR is far less than that of ANBS, which can also prove that TS_VCR has a higher accuracy and rate of success of negotiation than those of ANBS. In **Figure 8**, we find that after the conflict resolution, the global utility loss of TS_VCR is less than that of ANBS, and the strategic plan of transboundary services can be better implemented.

Table 4 shows the value expectation scheme of concession and the value expectations after concession obtained by the two negotiation methods. We can find that the concession value of the fourth value expectation 'input cost' in the negotiation result of TS_VCR is significantly higher than that of ANBS, which indicates that the final result of TS_VCR tends to increase the input cost to ensure the realization of other value expectations.

By observing the weights of current value expectations, it can be found that the weight of the input cost is lower than that of the others. It can be inferred that the current online car-hailing company is in the period of market development. The strategic plan is to increase the input cost to optimize the user experience and seize the market. At this time, the result of the concession of TS_VCR can better achieve the strategic goal of seizing the market.

Table 4 shows that the negotiation time of TS_VCR is less than that of ANBS. Although computing in multiple threads will use more computing resources and time, it reduces the rounds of negotiation, thus reducing the number of scheme calculations and feasibility tests, and the time required for calculating the scheme and testing feasibility is much longer than that required for negotiation, so TS_VCR is more efficient than ANBS. At the same time, TS_VCR can overcome the dependence of negotiation on *CA* initial parameters, and make negotiation more stable, and then effectively reduce the number of failures, to make

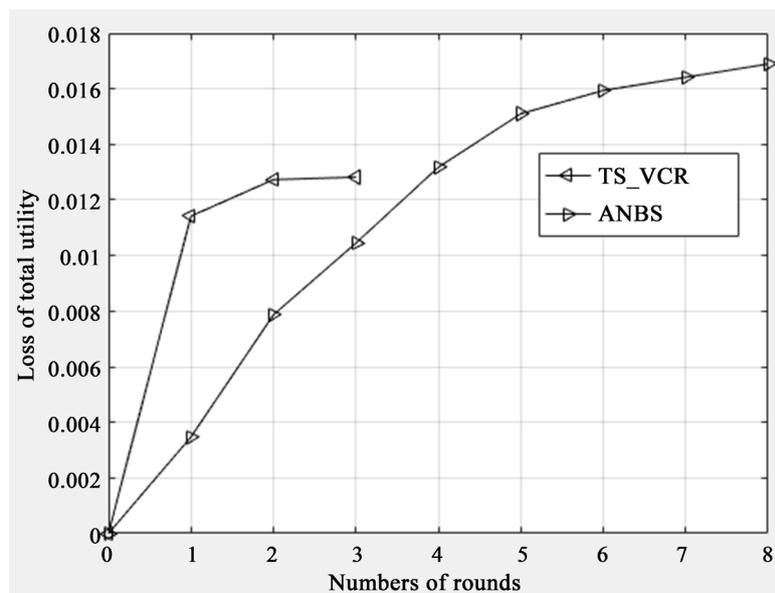


Figure 8. Changes in loss of global utility in the process of value conflict resolution.

negotiation more automatic and reduce the burden of operators.

5. Conclusion

Based on the theory of automatic negotiation, this study resolves the value conflict of multiple parties in transboundary service design. The proposed method not only takes the attitudes and strategies of the participants on the concession into full consideration but also considers both global utility and individual benefits. In the proposed method, the swarm intelligence algorithm based on Stackelberg game theory is used to find better negotiation results for global utility. In order to ensure fairness of the negotiation, a locking mechanism for the value expectations of concession is set-up to avoid the requirement of value expectations to make concessions excessively. As the negotiation parameters of service participants are set by themselves and remain unchanged, the upper limit values of the negotiation concession of service participants are determined by the parameters set by themselves, which ensures that service participants can make concessions independently. In addition, we improve the traditional negotiation algorithm based on the Stackelberg game theory, enhance the search capability and convergence of negotiation, and greatly improve the success rate of negotiation. We take the value conflict resolution in the transboundary service design of online car-hailing as an example, and a numerical simulation experiment is carried out. The results show that the proposed method in this paper can effectively solve the value conflict in the transboundary service design, and is superior to the existing methods. In practical engineering, the proposed method in this paper has a strong universality and could be applicable to many scenarios of transboundary services such as online car hailing, online shopping, cloud manufacturing and online ticket purchasing when there be multi-Party value conflicts. But on the one hand, the time and economic cost of conducting the interviews with the practitioners of the different service scenarios is very high, which have influenced the promotion of the proposed method. On the other hand, the real scenario of the different service is very complex, in the future, we will introduce changeable quality parameters, negotiate on the concession of value expectations and the improvement of service quality, and resolve multi-party value conflicts in more complex and changeable scenarios.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this pa-

per.

References

- Eshragh, F., Pooyandeh, M., & Marceau, D. J. (2015). Automated Negotiation in Environmental Resource Management: Review and Assessment. *Journal of Environmental Management*, *162*, 148-157. <https://doi.org/10.1016/j.jenvman.2015.07.051>
- European Commission (2014). *Towards the Internet of Services*. <http://cordis.europa.eu/fp7/ict/ssai/>.
- Faratin, P., Sierra, C., & Jennings, N. R. (1998). Negotiation Decision Functions for Autonomous Agents. *Robotics and Autonomous Systems*, *24*, 159-182. [https://doi.org/10.1016/S0921-8890\(98\)00029-3](https://doi.org/10.1016/S0921-8890(98)00029-3)
- Fatima, S., Kraus, S., & Wooldridge, M. (2014). Principles of Automated Negotiation. Cambridge: Cambridge University Press.
- Haleema, P. K., Iyengar, N. Ch. S. N. (2018). A Mathematical Model with Flexible Negotiation Strategies for Agent Based Negotiations in Dynamic e-Commerce Environments. *Journal of King Saud University—Computer and Information Sciences*, *30*, 547-560. <https://doi.org/10.1016/j.jksuci.2016.11.004>
- Kolomvatsos, K., Panagidi, K., Neokosmidis, I., Varoutas, D., & Hadjiefthymiades, S. (2016). Automated Concurrent Negotiations: An Artificial Bee Colony Approach. *Electronic Commerce Research and Applications*, *19*, 56-69. <https://doi.org/10.1016/j.elerap.2016.09.002>
- Liu, S., & Xu, Z. (2014). Stackelberg Game Models Between Two Competitive Retailers in Fuzzy Decision Environment. *Fuzzy Optimization and Decision Making*, *13*, 33-48. <https://doi.org/10.1007/s10700-013-9165-x>
- Ma, C., Liu, W. D., Tu, Z. Y., Wang, Z. J., & Xu, X. F. (2020). A QFD-Based Quality and Capability Design Method for Transboundary Services. *Mathematical Problems in Engineering*, *2020*, 1-18.
- Ray, B. K., Khatua, S., & Roy, S. (2014). Negotiation Based Service Brokering using Game Theory. *Applications and Innovations in Mobile Computing (AIMoC)*.
- Sanchez-Anguix, V., Julian, V., Botti, V., & Garcia-Fornes, A. (2013b). Studying the Impact of Negotiation Environments on Negotiation Teams' Performance. *Information Sciences*, *219*, 17-40. <https://doi.org/10.1016/j.ins.2012.07.017>
- Sanchez-Anguix, V., Julián, V., Botti, V., & Garcia-Fornes, A. (2013a). Tasks for Agent-Based Negotiation Teams: Analysis, Review, and Challenges. *Engineering Applications of Artificial Intelligence*, *26*, 2480-2494. <https://doi.org/10.1016/j.engappai.2013.07.006>
- Tian, R., Li, S., & Yang, G. (2018). Research on a Distributed Auto-Negotiation Model Based on Stackelberg Game Theory. *The Journal of Supercomputing*, 1-12.
- Wu, Z., Yin, J., Deng, S., Wu, J., Li, Y., & Chen, L. (2016). Modern Service Industry and Crossover Services: Development and Trends in China. *IEEE Transactions on Services Computing*, *9*, 664-671.
- Xu, X., Motta, G., Tu, Z., Xu, H., Wang, Z., & Wang, X. (2018). A New Paradigm of Software Service Engineering in Big Data and Big Service Era. *Computing*, *100*, 353-368.