A Novel Conflict Resolution Strategy in Multi-agent Systems: Concept and Model

Ghusoon Salim Basheer[1], Mohd Sharifuddin Ahmad[1], Alicia Y.C. Tang[1], Azhana Ahmad[1], Mohd Zaliman Mohd. Yusoff[1], and Salama A. Mostafa[1]

[1] Universiti Tenaga Nasional, Jalan IKRAM-UNITEN, 43000 Kajang, Selangor, Malaysia
rawagy2013@gmail.com, semnah@yahoo.com, {sharif,aliciat,azhana,zaliman}@uniten.edu.my

Abstract. In this paper, we present the concept and model of a conflict resolution strategy for a multi-agent system that covers all aspects of conflict processing, from collecting agents' opinions, recognition of possible conflict status, and through a joint final decision. Our approach is to specify a novel structure for classifying conflict states in decision-making in which related factors, such as number of conflicting agents, agent's confidence level and strength of conflict play essential roles in guiding and selecting the conflict resolution strategies. We provide an example scenario as a proof of concept to show the model's applicability in multiple conflict situations.

Keywords: Software Agent, Multi-agent System, Conflict Resolution.

1 Introduction

In multi-agent systems, agents must communicate with each other and resolve conflicts between them [1]. To do so, the agents must be able to select one of multiple strategies to eliminate conflicts between them. Conflict resolution in multi-agent systems entails a comprehensive investigation of factors that relate to the cause, identification and resolution of conflicts [2].

In this paper, we examine conflicts between agents that have different confidence levels about a particular problem domain. We assume that the confidence levels of agents are given, and that each agent has a different opinion about the domain that generates the conflicts. We seek an optimal algorithm to classify the conflict states by considering our model that resolves conflicts between two agents discussed in [3]. In this paper, we extend the model to include conflicts between three or more agents.

While we assume that the confidence value for each agent in the domain is known, the confidence value is different from other agents. The objective is to develop an optimal solution to the conflict classification problem, which provides a procedural approach to the classification and resolution of conflicts leading to a final decision. To this end, we construct a model that considers three factors: number of conflicting agents, strength of conflict, and confidence level of agents. We firstly consider the states of two-party conflicts, and followed by more than two-party conflicts.

J. Sobecki, V. Boonjing, and S. Chittayasothorn (eds.), *Advanced Approaches to Intelligent Information and Database Systems*, Studies in Computational Intelligence 551,
DOI: 10.1007/978-3-319-05503-9_4, © Springer International Publishing Switzerland 2014

The first part of this paper contains a review of the previous classifications of conflicts in humans' and agents' societies. The review discusses the proposed model of conflict classification. We then propose our technique, in which we suggest a new classification of agents' conflicts based on their confidence and numbers. We organize the rest of the paper as follows: Section 2 reviews the type of conflicts in humans and multi-agent systems. In Section 3, we propose a framework for classification and resolution of conflicts in multi-agent systems. Section 4 elaborates an example scenario of multiple conflict resolutions for our proposed framework and Section 5 concludes the paper.

2 Types of Conflict Resolution Strategies

2.1 Conflicts in Humans

Conflicts in humans occur for many reasons. However, resolving conflicts depends on the nature of the conflicts, the number of stakeholders involved in the conflicts and the interest of each stakeholder has on the outcome of the conflicts. Crawford et al. [4] proposed that stakeholders have two choices, either continue with the conflict or resolve it. Tessier et al. [2] classified the types of conflict in human as shown in Figure 1. He mentioned that only parts of these types have been modeled in multi-agent systems environment due to two reasons. Firstly, the basis of these conflict types is emotions, but the realization of emotional agents is so limited. Secondly, these conflicts types need reflection content in the agents, which current theoretical models of multi-agent system lack.

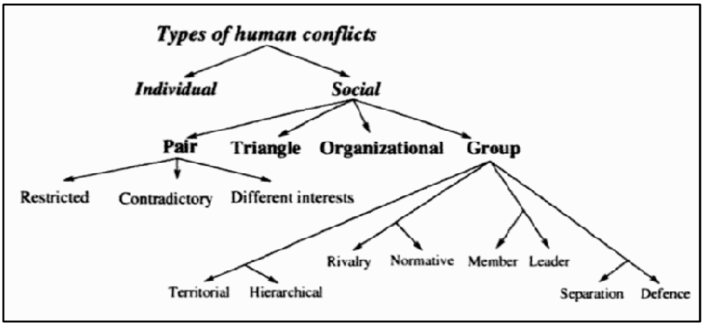

Fig. 1. Human Conflict Types [2]

Rummel [5] detected power as a source of social conflict, and he classified conflicts into three types. The first type is when two individuals are interested in the same thing and to solve this conflict one of them must be excluded (conflict of appropriate interests). The second type of conflict includes *i* wants *x* that *j* does not wants (inverse interest). The third type involves two individuals *i* and *j*, and *i* wants *a*, but *j* wants *b*, where *a* and *b* are opposed (incompatible interests).

2.2 Conflicts in Multi-agent Systems

Conflicts between agents occur in multi-agent environment in many instances and are resolved depending on their types and dimensions. Many factors can lead to conflicts in multi-agent environments, like differences in goals, disputes in preferences, changes in expectations about behaviors of others, and conflicts in mental attitudes [5].

Many researchers have proposed different strategies to resolve conflicts in multi-agent systems. Some of these typical strategies include negotiation by Sycara [6], which provided a model for conflict resolution of goals. She proposed a program that resolves labor disputes. Her model performs the negotiation through proposal and modification of goal relaxations, which she proposed by using Case-Based Reasoning with the use of multi-attribute utilities to portray tradeoffs. Barber et al. [7] produced multiple strategies for conflict resolution such as negotiation, self-modification and voting. Selecting each one of these strategies depends on several characteristics like cost and required time.

Ioannidis et al. [8] studied the problem of resolving conflicts of rules that assign values to virtual attributes. They assumed that the set of rules defined by a user is consistent, which means that there is no fact that can be obtained by the rules. They proposed a new model that subsumes all previously suggested solutions, and suggests additional solutions. Jung [9] attempted to solve agents' conflict problem by implementing a new system called CONSA (Collaborative Negotiation System based on Argumentation) based on agent negotiation strategy. Through negotiation, agents propose arguments as justifications or elaborations to explain their decisions.

Tessier et al. [2] classified conflicts into several types: conflicts of ideas, facts, practices, and goods. Müller et al. [10] classified conflicts into three types:

- Conflicts within an individual when he/she is torn between incompatible goals.
- Conflicts between individuals when they want different things, and they must reach an agreement about the same thing.
- Conflicts between individuals when they want the same thing and must reach an agreement of selecting a different thing.

2.3 Classification of Conflicts in Multi-agent Systems

Classifying conflicts is an essential part of realizing and understanding the nature of conflicts. Understanding the nature of conflicts reduces the search space of potential resolution strategies and enables agents to focus on behaviors that are most important for the type of conflict they are attempting to resolve [10].

Tessier et al. [2] classified conflicts into two main classes: Physical Conflicts - conflicts of external resources; and Knowledge Conflicts - agents conflict in beliefs, knowledge and opinions. Liu et al. [11] opined that agents should select an appropriate strategy for conflict resolution depending on three factors: type of conflict, agent's rule, and preference solution. They classified conflicts into three classes: Goal conflicts, Plan conflicts, and Belief conflicts.

3 The Proposed Conflict Classification Framework

In our earlier work [3], we analyzed the social theory of conflict and proposed a conflict resolution model depending on conflict classification. In our approach, agents assign confidence values to their opinions from domain specific pre-defined factors. Our model is developed based on six types of conflict resolution model identified by Tessier et al. [2] as follows:

1. **Flight**: Represent fleeing by one of two opponents.
2. **Destruction**: Takeover one of opponents.
3. **Subservience**: Gives up by one of opponents.
4. **Delegation**: Add a third party to judge between opponents.
5. **Compromising:** Obtain the result of negotiation.
6. **Consensus**: Obtain the agreement of opponents.

Inspired from human's conflict resolution strategies, we proposed a framework for conflict resolution as shown in Figure 2 [3].

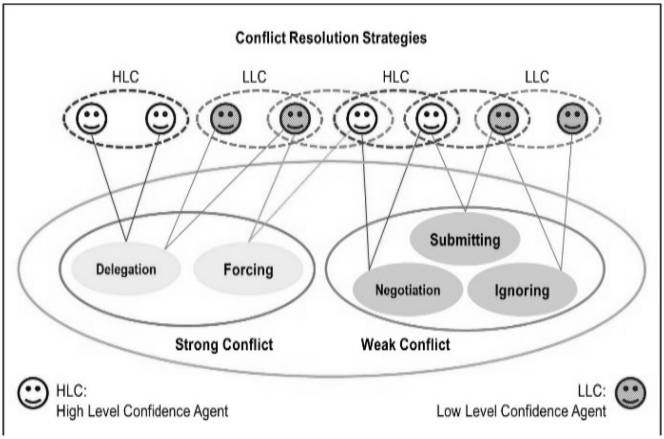

Fig. 2. Selecting Appropriate Conflict Resolution Strategy [3]

- **Forcing**: Corresponds to **Destruction/Flight** in some conflict state. We recognize that there is no chance to resolve the conflict.
- **Submitting/Ignoring**: Corresponds to **Subservience**. In this case, there is no force, but inducement between both sides.
- **Delegation**: Corresponds to Delegation when the conflict cannot be resolved, both opponents request a third party that has deep knowledge to judge.
- **Negotiation**: Corresponds to **Compromising** through negotiation when one of the opponents is willing to yield. This state includes an agreement in a different style.
- **Agreement**: Corresponds to **Consensus**. Each opponent must give all details about its decision to a third party. For this reason, this process comes as a result of a delegation process.

In this paper, we expand the framework of conflict classification in multi-agent systems based on three dimensions:

- Number of conflicting agents, which includes:
  - Conflicts between two agents.
  - Conflicts between three or more agents.
- Confidence level of conflicting agents, which includes:
  - Conflicts between two agents that have the same level of confidence, e.g., both agents have high level of confidence (HLC/HLC), or both have low level of confidence (LLC/LLC).
  - Conflicts between two agents that have different level of confidence, e.g., a high level of confidence against a low level of confidence (HLC/LLC).
- Conflict strength between agents, which includes:
  - Strong Conflict (SC), when more than 50% of agents conflicts in opinions with another agent.
  - Weak Conflict (WC), when less than 50% of agents conflicts in opinions with another agent.

Figure 3 depicts the analytical process of classifying a three-dimensional conflict. The framework consists of three stages:

- Collect agents' opinions and detect conflicting agents in the system.
- Use confidence table to detect confidence value for each agent.
- Classify conflicts states based on three factors:
  - Number of conflicting agents.
  - Conflict strength.
  - Confidence value of conflicting agents.

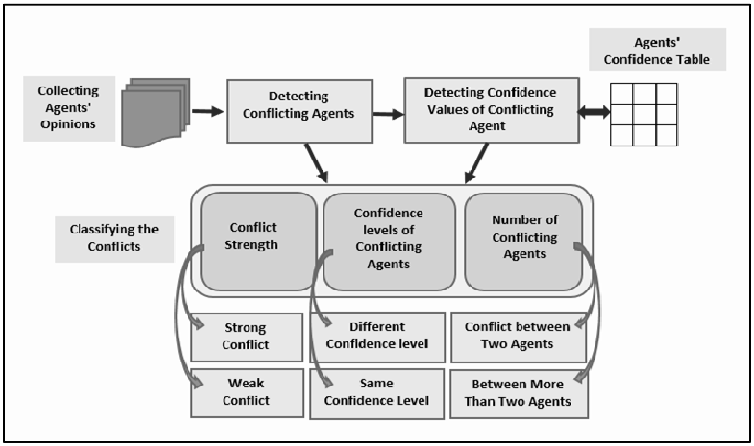

Fig. 3. A Framework for Classifying Conflicts in MAS

3.1 Classification of Conflicts

The conflict classification model proposed in this paper is based on the following definitions:

Definition 1: Given a set of agents, $A=\{a_1, a_2, \ldots, a_n\}$, each agent $a_i \in A$ has a set of specification, S_i, that includes Opinion, O_i, and Confidence, C, i.e., $S_i=(O_i, C)$. An agent's opinion, O_i may conflict with another agent's opinion, O_j, or a set of other agents' opinions $\{O_k, \ldots, O_x\}$.

Definition 2: Let a_i be an agent, such that $a_i \in A$. Each agent in A has an *agent Confidence Value*, C, as a positive integer in an *Agent Confidence Table*, ACT that represents the confidence levels which are determined by the agents themselves.

Definition 3: A Conflicting Agent Set, CAS, is a set of pairs of conflicting agents, i.e., if a_i conflicts with a_j, then $CAS=\{(a_i, a_j)\}$.

Definition 4: For each pair of conflicting agents $(a_i, a_j) \in CAS$, their *Conflict Strength* is represented by CS_{ij} with two levels of agent's confidence, e.g., High Level Confidence (HLC) and Low Level Confidence (LLC). Three situations are apparent: $C_i = C_j$, or $C_i > C_j$, or $C_i < C_j$.

Definition 5: Referring to Figure 2, for each pair of conflicting agents $(a_i, a_j) \in CAS$, we define six possible Conflict Resolution Strategies, CRS_{ij}, by detecting the conflict strength, CS_{ij}, and the agent's confidence level (C_i, C_j).
If $C_i = C_j$ and both are HLC agents and CS_{ij}=Strong, then call Evidence Function, EF, and third party Mediator to judge (CRS_{ij}=Delegation).
If $C_i > C_j$ and CS_{ij} = Strong, then (CRS_{ij}=Forcing).
If $C_i = C_j$ and both are HLC agents and CS_{ij}=Weak, then CRS_{ij}=Negotiation).
If $C_i < C_j$ and CS_{ij} = Weak, then (CRS_{ij}=Submitting).
If $C_i = C_j$ and both are LLC agents and CS_{ij}=Weak, then (CRS_{ij}=Ignoring).
If $C_i = C_j$ and both are LLC agents and CS_{ij}=Strong, then (CRS_{ij}=Delegation).

3.2 The Proposed Algorithm

The conflict resolution algorithm considers all the agents and conflict states in the system. Classifying conflicts states can be used for conflict resolution enhancement.

For each agent a_i, in the system, we define the following:

```
Define a set of agents' opinions, O,
Define a set of Conflicting Agent in the system, CAS,
Define a set of Conflict Resolution Strategies as the set of all
possible strategies that include {Delegation, Ignoring, Forcing,
Submitting, Negotiation},
Define the Conflict Strength as the set of two levels {Strong
Conflict (SC), Weak Conflict (WC)},
Define Confidence Level as an array of two levels {High Level
Confidence (HLC), Low Level Confidence (LLC)} for each agent in CAS,
```

```
Evaluate the Confidence values for each agent in CAS,
Classifies conflicting agents array into groups depending on conflict
points,
Calculate a confidence value for each group in the CAS,
While CAS is not empty, Do
 Find two groups conflicts weakly, then
 If the conflict state is between HLC and HLC Then Return Delegation
 If the conflict state is between HLC and LLC Then Return Forcing
 If the conflict state is between LLC and LLC Then Return Delegation
  Delete these two groups from CAS and add a dominant agent
  (depending on the    result from each selecting strategy) to CAS
  For each two groups in CAS
  If conflict strength is strong, Then
  If the conflict state is between LLC and LLC Then Return Ignoring
  If the conflict state is between HLC and HLC Then Return
Negotiation
  If the conflict state is between HLC and LLC Then Return Submitting
   Delete these two groups from CAS and add a dominant agent
   (depending on the result from each selected strategy) to CAS
```

4 An Example Scenario of Conflict Classification and Resolution

We clarify our approach through a scenario in which our proposed model helps to coordinate and manage conflicts states. In this scenario, we consider a commercial company, in which a Manager meets with his/her Head of Departments to decide on a strategic plan for the company's development. He/She requests their opinions to select an appropriate plan for each stage (of five stages). What strategies could be adopted if there are conflicting views?

In this case, we assume that the Manager has high confidence level due to his experience and knowledge, while the other members of the meeting (i.e., Head of Departments) have varying levels of confidence depending on their confidence factors.

Initialized in the first stage with five agents and five choices, at each stage, the algorithm determines: a set of conflicting agents, the total of its confidence value, and the conflict strengths. Let a_M be the Manager agent and a_1, a_2, a_3, and a_4 be the Head of Departments agents and that the agents select the five plans for the five stages. Figure 4 shows the five agents (a_M, a_1, a_2, a_3, a_4) and their selected plans (P1–P5) in five stages. Notice that the paths from Stage 1 to Stage 5 may have several strong conflicts (SC), e.g., a conflict state at Stage 4 when one agent (a_M) conflicts with four other agents (a_1, a_2, a_3, a_4), or a weak conflict (WC), e.g., the conflict state at Stage 1 when two agents (a_1, a_3) conflicts with three other agents (a_M, a_2, a_4).

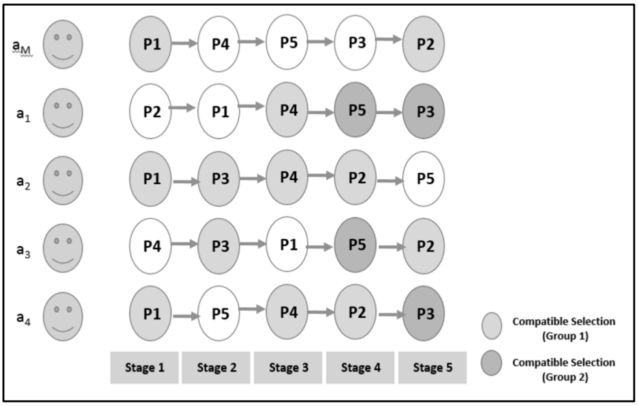

Fig. 4. Five Agents with its Selected Plans

In Stage 1, as shown in Table 1 and Figure 4, in iteration 1, there are two conflict cases, i.e. CAS={(a_1, a_3); (a_1, [a_M, a_2, a_4]); (a_3, [a_M, a_2, a_4])}. In the first case, agents a_1 conflicts with a_3 and the confidence value for a_1 is 4 and for a_3 is 3. Since the conflict between them is weak, the selected strategy based on the conflict resolution model of Figure 2 is **Submitting** leaving the selected plan as P2**. A**gent a_3 is then removed from the set, eliminating the third conflict case.

In the second iteration, the second conflict case is resolved, in which agent a_1 conflicts with the agent group (a_M, a_2, a_4). As shown in Table 1, the confidence value for the group is equal to (6+3+2)=11. Referring to the conflict resolution model that is proposed in Figure 2, we discovered that the conflict is strong, dictating the selected strategy as Forcing, leaving the selected plan in Stage 1 as **P1**.

Table 1. Selecting a Conflict Resolution Strategy

Stage No.	Iteration No.	Conflicting Agents	Confidence Value of Conflicting Agents	Conflict Type	Conflict Resolution Strategy	Contents of CAS at each Iteration	Selected Plan
1	1	a_1 a_3	4 3	Weak	Submitting	a_1, a_3,(a_M, a_2, a_4)	P2
	2	a_1 a_M, a_2, a_4	4 6+3+2 =11	Strong	Forcing	a_1, (a_M, a_2, a_4)	P1
2	1	a_M a_1	6 4	Weak	Submitting	a_M , a_1,a_4,(a_2,a_3)	P4
	2	a_M a_2, a_3	6 3+3=6	Weak	Negotiation	a_M, a_4, (a_2, a_3)	P3, P4
	3	a_M a_4	6 2	Weak	Submitting	a_M, a_4	P4
3	1	a_M a_1, a_2, a_4	6 4+ 3+2 = 9	Strong	Forcing	a_M,(a_1, a_4 a_2), a_3	P4
	2	a_1, a_2, a_4 a_3	9 3	Strong	Submitting	(a_1, a_4 a_2), a_3	P5
4	1	a_M a_1, a_3	6 4+3=7	Weak	Submitting	a_M,(a_1, a_3), (a_4,a_2)	P5
	2	a_1, a_3 a_2, a_4	4+3=7 3+2=5	Weak	Forcing	(a_1,a_3), (a_4,a_2)	P5
5	1	a_M, a_3 a_1, a_4	6+3= 9 4+2=6	Weak	Submitting	(a_M,a_3),(a_4, a_1),a_2	P2
	2	a_2 a_M, a_3	3 6+3= 9	Weak	Submitting	(a_M, a_3), a_2	P2

In the second stage, there are six conflicting cases, i.e. CAS={(a_M, a_1), (a_M, [a_2, a_3]), (a_M, a_4), (a_1, [a_2, a_3]), (a_1, a_4), ([a_2, a_3], a_4)}. Each of a_M, a_1, a_4 agents selects a different plan and the other two agents, (a_2, a_3) select the same plan.

In the first iteration of the algorithm, the conflict between agents a_M and a_1 is resolved by detecting the conflict strength and the confidence value. Since a_M has a higher confidence value and the conflict is weak, the resolution strategy is **Submitting,** leaving **P4** as the selected plan. Agent a_1 is removed from the set, thus eliminating the fourth and fifth conflicts.

In the second iteration, the conflict is between a_M and the agent group (a_2, a_3). The confidence values for each of them are equal (i.e. 6 for a_M and (3+3)=6 for a_2 and a_3). Since the conflict is weak, the strategy to resolve the conflict is **Negotiation,** leaving the selected plan as either **P3** or **P4**.

In the third iteration of Stage 2, the conflict between a_M and a_4 is similarly resolved. Since the confidence value of a_M (i.e. 6) is higher than that of a_4 (i.e. 2), and the conflict between them is weak, then the selected strategy is **Submitting**. Agent a_4 is removed from the set, thus eliminating the sixth conflict.

In the third stage, there are three conflicting cases, i.e. CAS={(a_M, [a_1, a_2, a_4]), (a_M, a_3), ([a_1, a_2, a_4], a_3)}. In the first iteration of stage three, conflict is between a_M and the agent group (a_1, a_2, a_4). In this case, the total confidence value of the triplet (4+3+2= 9) is greater than confidence value of a_M (6), and the conflict is strong. The resolution model suggests that the strategy to resolve this conflict is **Forcing,** so that the selected plan is **P4** favoring the agent group. Agent a_M is removed from the set, eliminating the second conflict case.

In the second iteration, the conflict is between the agent group (a_1, a_2, a_4) and a_3. Since the confidence of the agent group is higher and the conflict is strong, the strategy used is **Submitting,** leaving the selected plan as P**4.**

In the fourth stage, there are three cases of conflicts, i.e. CAS={(a_M, [a_1, a_3]), (a_M, [a_2, a_4]), ([a_1, a_3], [a_2, a_4])}. Clearly, the confidence value of a_M (6) is less than the confidence value of (a_1, a_3) (i.e. 4+3=7) and the conflict between them is weak, so that the strategy to use is **Forcing** and the selected plan is **P5.** Agent a_M is removed from the set, eliminating the second conflict case.

In the second iteration, the conflict is between two agent groups, (a_1, a_3) and (a_2, a_4). Since the conflict between these two groups is weak and the first group has a confidence value (4+3=7) that is higher than confidence value of the second group (3+2=5), the **Forcing** strategy resolves the conflict and the selected plan is **P5**.

In the last stage, there are three conflict cases, i.e. CAS={([a_M, a_3], [a_1, a_4]), ([a_M, a_3,] a_2), ([a_1, a_4,], a_2)}. In the first iteration, the conflict is between two agent groups (a_M, a_3) and (a_1, a_4). The conflict between them is weak and the first group, (a_M, a_3), has a higher confidence value (6+3=9) than that of the second group, (a_1, a_4), (4+2=6). The selected conflict resolution strategy is **Submitting** and a selected plan for this stage is **P2.** The agent group (a_1, a_4) is removed from the set. In the second iteration, the conflict between the agent group (a_M, a_3) and a_2 is weak, and the confidence value of the group (6+3=9) higher than the confidence value of agent $a_{2,}$ so the strategy to resolve the conflict is **Submitting** leaving the selected plan as P2.

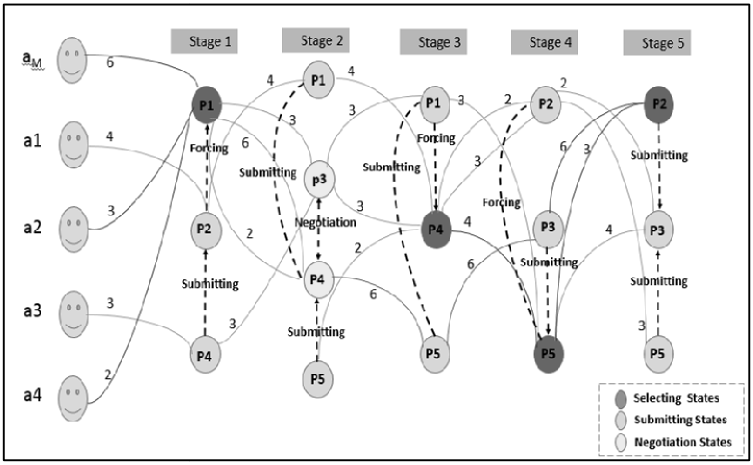

Fig. 5. The Conflict Resolution Model

From the above analysis, it is clear that the most effective plan for the company after resolving all the conflicts is: (Stage 1: P1, Stage 2: P3 or P4, Stage 3: P4, Stage 4: P5, Stage 5: P2).

5 Conclusion

In this paper, we propose a conflict classification algorithm in a multi-agent environment to resolve conflicts between two or more agents or groups of agents. We analyze the social theory of conflict and propose a conflict resolution strategy based on the new conflict classification scheme. The proposed conflict resolution algorithm considers all the conflict states of the agents in a multi-agent system. Classifying conflict states is used for conflict resolution enhancement. We demonstrate that by considering the confidence table as an input to the proposed algorithm, our classification technique is able to resolve multiple conflict situations and arrive at a decision.

References

1. Wagner, T., Shapiro, J., Xuan, P., Lesser, V.: Multi-Level Conflict in Multi-Agent Systems. LNAI, vol. 4386. Springer, Heidelberg (2007)
2. Tessier, C., Chaudron, L., Muller, H.J.: Conflict agents, Conflict management in Multi Agent System, vol. 1. Springer, Heidelberg (2000)
3. Basheer, G.S., Ahmad, M.S., Tang, A.Y.C.: A Framework for Conflict Resolution in Multi-agent Systems. In: Bădică, C., Nguyen, N.T., Brezovan, M. (eds.) ICCCI 2013. LNCS, vol. 8083, pp. 195–204. Springer, Heidelberg (2013)
4. Crawford, D., Bodine, R.: Conflict Resolution Education A Guide to Implementing Programs in Schools. Youth-Serving Organizations, and Community and Juvenile Justice Settings Program Report (1996)

5. Rummel, R.J.: Understanding Conflict and War. In: The Conflict Helix. Conflict in the Sociocultural Field, vol. 2, ch. 27. Sage Publications, California (1976)
6. Sycara, K.P.: Resolving Goal Conflicts via Negotiation. In: AAAI 1988 (1988)
7. Barber, K.S., Liu, T.H., Han, D.C.: Strategic Decision-Making for Conflict Resolution in Dynamic Organized Multi-Agent Systems. In: GDN 2000 PROGRAM. WAP Cellular Walkietalkie (2000)
8. Ioannidis, Y.E., Sellis, T.K.: Conflict resolution resolution of rules assigning values to virtual attributes. ACM 18(2) (1989)
9. Jung, H., Tame, M.: Conflict in Agent Team. Multiagent System, Artificial Intelligent, and Simulated Organizations, vol. 1. Springer, Heidelberg (2002)
10. Müller, H.J., Dieng, R. (eds.): Computational Conflicts: Conflict Modeling for Distributed Intelligent Systems With Contributions by Numerous Experts. Springer (2000)
11. Liu, T.H.A., Goel, M.C.E., Barber, K.S.: Classification and Representation of Conflict in Multi-Agent Systems. The Laboratory for Intelligent Processes and Systems, The University of Texas at Austin (1989)