A COMPARISON FRAMEWORK FOR CONFLICT DETECTION AND RESOLUTION MULTI AGENT MODELING METHODS IN AIR TRAFFIC MANAGEMENT

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ABSTRACT

Nowadays air traffic density increased, thus existing air traffic management systems are not able to manage the massive capacities of air traffic perfectly. To solve problems in current air traffic management systems, the aviation industry focused on a new concept called Free flight. Nonetheless, the most important challenge in current air traffic management and especially in free flight is conflict detection and resolution between different aircrafts. So far a number of methods have been presented in order to automate air traffic management using multi agent systems technology. However, there has been a little discussion about the efficiency of these methods. Also, there has not been created a comprehensive comparison of these methods.

In this paper, we presented a clear framework to categorization and comparing different multi agent models for conflict detection and resolution in air traffic management. Then, using this framework, we evaluated various proposed models. Our comparison framework is based on characteristic such as: agent selection (the entity which selected as Agent), agent's actions, agents' interaction method in the process of conflict detection and resolution, the strategy used in agents' implementation, type of the multi agent system (pure multi agent system or combined), conflict detection method, conflict resolution method, Plan Dimensions, Maneuvers, and management the multiple aircrafts' conflict.

KEYWORDS

Air Traffic Management, Free flight, Multi Agent Systems, Conflict Detection and Resolution Methods, Comparison Framework.

1. INTRODUCTION

Currently, the aviation industry envisages with most fundamental and important problems include safety, reliability, delays (reduction of delays in airspace and in airports), saving in fuel consumption, adaptability with unpredicted situations and conflict detection and resolution problem. Among these problems the conflict detection and resolution problem is the most important issue. This problem imposes many losses, include: long delays in aircrafts' flight, inefficiency of managing of air traffic, high fuel consumption and many other important challenges. Alternative approaches have proposed for overcome these problems; that one of these methods is the free flight concept. Free flight means that, pilots or other users of the air traffic have more freedom for selecting and modifying their flight paths in airspace during flight time. The free flight concept changes the current centralized and command-control airspace system (between air traffic controllers and pilots) to a distributed system that allows pilots choose their own flight paths more efficient and optimal, and plan for their flight with high performance themselves. Free Flight, also called user preferred traffic trajectories, is an innovative concept designed to enhance the safety and efficiency of the National Airspace System (NAS). Despite many advantages of this method, it imposes some problems for air traffic management system which the most notable one is the occurrence of conflicts between different aircrafts' flights.

Many researchers focused on conflict detection and resolution problem and proposed various methods to solve this problem. One of the successful methods is the multi agent systems technology. Agents are appropriate tools for analyze, implementation and development of complex systems. The application domains of agents are very wide and their high performance in various applications is inevitable. A multi agent system involves a number of autonomous and intelligent agents that these agents can work together in order to achieve their goals. Use of multi agent systems for solving large and complex systems are one of the most successful and efficient solutions for these problems. Also he airspace (air traffic) management system could suppose as a multi agent system in which different agents working together in order to managing air traffic in reliable, safe and efficient way.

As we mentioned, since the conflict detection and resolution is one of the fundamental challenges in safe, efficient and optimal air traffic management, in this paper, we provide a general overview of the existing multiagent-based models for conflict detection and resolution problem in air traffic. In our research, firstly, we studied the different proposed models having different performance criterions. Then, we made a precise comparison of different models summarized in a table. To do so, we need to perform a specific structure and framework for comparing different models. In order to have an accurate comparison, we considered appropriate features to compare various types of proposed models and selected the best model based on the specified features. Finally, we summarized our results in table 2 and showed the advantages and disadvantages of each model.

The rest of this paper is organized as follows: in Section 2 and 3 we explain the air traffic management system and multi agent systems respectively. In Section 4 we explain the conflict detection and resolution process. In Section 5 and 6, we present respectively an overview of the categorization of the proposed models for air traffic management and some characteristics of agents that must have in air traffic management system. Then, in Section 7, we explain various features which used for comparing air traffic management models based on agents. In Section 8, we present some important remarks about proposed conflict detection and resolution models. Finally, Section 9 makes some conclusion.

2. AIR TRAFFIC MANAGEMENT

In this paper, we define the air traffic as: "*aircraft operating in the air or on an airport surface, exclusive of loading ramps and parking areas*" [2], also we use the definition of air traffic control as: "*A service operated by appropriate authority to promote the safe, orderly, and expeditious flow of air traffic*" [2]. Air traffic management is a very complex, dynamic and demanding problem which involves multiple controls and various degree of granularity [1]. Currently, the airspace system has high flight capacity; therefore, the management of the current enormous volume of flights is very complicated. In general, the goal of air traffic management systems would be, firstly, providing safety in air traffic which means keeping aircrafts separate, secondly, growing up the performance and efficiency of the current systems, and also increasing the speed of flights, detecting and resolving conflicts and reducing travel time (minimum delay).

3. MULTI AGENT SYSTEM

In this paper we use the definition of an agent as: "*an agent is a computer system that is capable of autonomous and independent actions in some environment, in order to achieve its delegated goals*" [3]. We can say the main point about agents is they have the ability of autonomy. An agent analyses inputs from its environment, then makes decisions according to inputs, and then use those decisions to take actions in its environment. The multi agent system contains a number of agents, which these agents can communicate, collaborate, and compete with one another in order to achieve their goals [3]. Agents are appropriate tools for implementation and development of complex systems. The application domains of agents are very wide and their high performance in various applications is inevitable. Agents have many applications in education, military environments, networking, business process management, industrial, information recovery and management, simulation of social and political relations and many other areas [3]. Using of multi agent systems for solving large and complex problems are one of the most successful and efficient solutions. In some cases using of multi agent systems (e.g. distributed problem solving systems) are the best and well-known way for solving a variety of human processes. In general, one could say that a multi agent system is used in domains in which:

- Data, control and expertise is distributed (e.g. in the geographic scope, the problem is distributed).
- Centralized control is impossible or impractical.
- Subsystems of a large system require interacting with each other in more flexible manner [3].

The airspace (air traffic) management system could also suppose as a multi agent system in which different agents working together in order to managing air traffic in reliable, safe and efficient way.

4. CONFLICT DETECTION AND RESOLUTION PROCESS

In this paper, the conflict is defined as: *"conflict is the event in which two or more than two aircrafts experience a loss of minimum separation from each other"* [4]. Also in this paper, conflict detection process is defined as *"the process of deciding when conflict - conflict between aircrafts- will occur"* [4], and conflict resolution process is considered as: *"specifying what action and how should be to resolve conflicts"* [4]. In general, we summarized the process of conflict detection and resolution in Figure. 1.

5. CATEGORIZATION OF PROPOSED AIR TRAFFIC MANAGEMENT MODELS

In this section, we categorize existing models for air traffic management into two models: classic Models and multi agent based Models.

5.1 Classic Models

The problem of air traffic management was the attention of many researchers, and many classical methods for this problem have been proposed so far. Various models such as Lagrangian models [5, 6, 7], Eulerian models [6] and other mathematical models; that widely were used and several researchers have proposed various solutions [6, 8].

5.2 Air Traffic Control Based on Agents

Agent based methods are a natural tool to automate air traffic management. As we mentioned, according to the capabilities of multi agent systems in solving complex, dynamic and large problems, some of researchers paid attention to research on air traffic by using multi agent systems. Some of these methods are implemented and currently are used [9].

The presented agent-based methods, involve a set of intelligent and autonomous agents which the aim of these agents is to optimize and to achieve some specific goals through learning or negotiation with each others [1]. These systems applied different agents with different strategies. Some of these agents used game theory in conflict resolution process, some others used learning strategies, and some others used specific protocols and strategies for this purpose. Here, the important thing is that autonomous agents attempt to perform their actions properly, improve system performance and finally propose a reliable solution for conflict detection and resolution problem.

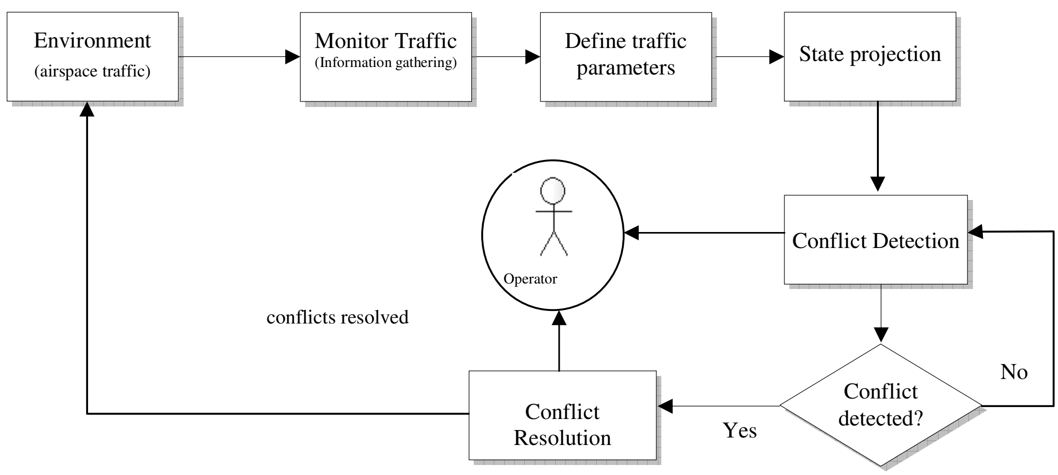

Figure.1. Conflict detection and resolution (general view)

6. COMMON FEATURES OF AGENTS IN AIR TRAFFIC MANAGEMENT SYSTEM

Here, we consider some of general features for Agents and multi agent system in air traffic management process. These features are as follows:

- A multi agent system is a dynamic, non-deterministic and complicated system which includes a number of agents.
- No agent has perfect knowledge of the entire system (i.e. doesn't have complete information from all of traffic environment).
- Agents in multi agent system can be optimal agents. This means agents not only tries to provide an acceptable flight plan which covers the system's restrictions in terms of the system performance, accuracy and speed, but also provide optimal cost for system.

- An agent should perform a reasonable action and not perform the activity that imposes lots of costs for the system.
- If an agent in a multi agent system behaves coordinated with other agents, the expected system's utility would be maximized and will do things more quickly [3].
- An agent should not be tricking other agents and it is assumed that agents are honest.
- All agents in multi agent system should be intelligence, autonomous and independent.

7. Compare Air Traffic Management Models based on Multi Agent Systems

Various criterions can be used for analyzing, comparison, and classification existing models for air traffic management. Here, we try to choose the well-known and best characteristics. Kuchar and Yang [4] have used a series of benchmarks to compare the classical presented models. Their study was based on more classical and mathematical methods and has paid very little attention to distributed artificial intelligence methods and multi agent systems technology. Of course, in this paper, we used some of presented criterions in Kuchar and Yang paper [4] to compare proposed air traffic management models. Moreover, in following sections, we proposed some other novel criterions based on multi agent systems [35].

7.1. Agent Selection

The proper selection of an entity as an agent and also determining the type of activities which agent can perform, are very important in air traffic management system which the performance of the model is mainly depends on. An entity should be chosen as an agent that provides the highest performance for the system and also the highest accuracy and speed in performing operations (e.g. in aircrafts' congestion area, when conflict resolution process an agent should perform the activities that impose the minimum delay for each aircraft). As is shown in Table 1, many of proposed models have selected an aircraft as an agent and some others selected a fixed location as an agent. The important issue in agent selection is that , firstly, it should be have all features which an agent must be have in multi agent system, secondly, the selected agent must be able to perform best action in the least possible time with highest accuracy under any circumstances.

7.2. Action Selection

Each intelligent agent can perceive data from its environment then analyze these inputs to make decisions and use those decisions to take some actions in its environment. Type of activities that an agent should perform in a multi agent system is very significant. The actions that agents should be performed must be considered in the way, which provide the highest performance and efficiency to the system. Appropriate selection of agents' actions have a direct relationship with the entity selected as agent and these two issues are strongly depends together.

7.3. Agents' Interaction

In a multi agent system, agents can use many methods to interact with each other. If the agents can interact with each other at doing delegated tasks then the efficiency of the system increases. Proposed models based on multi agent systems for air traffic management that use interactional process and negotiation techniques are more efficient than solutions in which agents use non-intractable process or traditional approaches [10], [11]. For example, surely if agents interact and negotiate with each other in conflict detection and resolution process, firstly, the volume of controller workload can be reduced by each agent, and if agents are coordinated with each other, they can distribute the necessary tasks - for example in a particular area - to resolve conflicts and perform things faster and more accurate. If agents work alone they must perform all things alone and obviously it would not be the best solution and it is possible that their goals violate other agents' goals. The second advantage of using interactive process or negotiation strategy between agents is that this method ensures conflict resolution process would not be too long or unreliable and collisions between aircrafts would not be intensified. It should be noted that may be negotiated based models (i.e. models in which agents negotiate with each other in performing their activities) can not be ensure an agreement between agents in appropriate time interval; and this reflects the fact that these agents in the worst case will act as non-agreement.

7.4. The Strategies of Agents

This feature indicates mechanisms used by agents in conflict resolution process. The existing models used different strategies and mechanisms to resolve conflicts. The main strategies include: control strategies, prioritization mechanism [36], teamwork, coordination [14], game theory [4], [16], and other specific strategies [4]. The important issue in the use game theory strategy is that these strategies in the worst conditions work in the worst case scenario [12], [13]; although these strategies can provide a reasonable solution, the solution is not optimal. Using an optimal and comprehensive strategy has significant impact on the efficient management of traffic.

7.5. Type of Multi Agent System

This feature means that whether the proposed multi agent-base model is designed as full automatic (i.e. is a pure multi agent system) or is a model that takes advantage of human operators, and intelligent agents are working with operators to perform their tasks and help operators in management of air traffic. It seems that it would be better that a system is used along with current systems and dose not avoid the current systems (Because in some situations, humans can still do things better than machines). For example, the presented model in Wollkind [14] is designed as a pure multi agent system.

7.6. Plan Dimensions

This property illustrates the state information which is used in proposed model: horizontal plan, vertical plan or combination of them (both vertical and horizontal plans). Most of the proposed models cover both horizontal and vertical plans [4]. Also the models that use one of these methods have the ability to extend if possible, and can support other dimensions which will vary depending on the proposed model. The model is capable to detect and resolve conflicts if it had a full view of the traffic environments. Obviously, if a model had not a suitable view of the traffic environment, it would not be able to detect and resolve conflicts as properly, therefore, that will cause irremediable losses to the air traffic management system.

7.7. Conflict Detection Method

Proposed models for solving conflicts problem in air traffic management based on multi agent systems used different principles for conflict detection. Some of these models used the same metrics for conflict detection between different aircrafts and their differences are just in the solution of these conflicts. For example, most of the proposed models used a minimum reliable and safe distance threshold for detection of conflicts. Therefore when the distance between two aircraft to be lower than a valid threshold (usually use a predefined reliable distance), then there is a risk of conflicts. Consequently, it requires warnings be given to the operators or agents in charge of resolving conflicts; or if an agent which is detected a conflict had capability of resolving conflicts will attempt to resolve those conflicts. Some other models, by using special methods, try to prevent occurrence of conflicts (methods for prevention of conflicts) and not use an explicit criterion for detection of conflicts.

Here by using this feature, we compared the proposed models. But we mostly focused on the use of a threshold for conflict detection according to the metric which used. Most of the models use a very simple criterion to conflict detection and others have benefited from a much more complex criterion for this purpose [1], [4]. In general, one can not be claimed which of these methods have higher accuracy; it depends on the type of the proposed model and required strategies to resolve conflicts. Perhaps, it is possible that using a simple metric had a higher efficiency and accuracy than using a complex one.

7.8. Conflict Resolution

Proposed models used different approaches to solve conflicts in airspace. Some models have been used classical methods to resolve conflicts and have been mapped the traditional ways onto actions that agents can perform. Some others used new and innovative methods that both of these methods are trying to improve air traffic management. Several different categorizations for conflict resolution models have been adopted that Kuchar and Yang also used the same classification and have been examined different models. This categorization includes: predefined conflict resolution method, optimization method, automatic and innovative method, manual method and no resolution method. Of course, other classifications can be added to this comparative set. Here we used this provided classification; then compared and divided different models based on these characteristics.

In predefined conflict resolution approach, during system design (e.g. in agent design process) a set of precanned routines and logical rules are embedded in body of agents. When system is dealing with a conflict these predefined commands will be used to solve that conflict. In optimization approach, agents attempt to optimize system performance (or in other words, reduce system costs) by adopting a set of optimal strategies. It seems this criterion as a comparative feature between different proposed models is useful; because costs reduction and increasing the system efficiency has been a serious and critical problem. In conflict resolution process by using optimization method, autonomous agents are trying to use a set of cost functions and environmental conditions (that are perceived through the sensors) to solve the conflicts. In this case, each autonomous agent will be adopted an optimal solution. In “manual conflict resolution method”, agents are not used to resolve the conflicts; instead, users are allowed to provide a mechanism to detect and take action to resolve the conflicts by use feedbacks that receive from the system. This method also has relatively high flexibility, but it needs to accurate and correct policies. In “no resolution method” there is not an explicit output to avoid conflicts. Some models detect conflicts but do not suggest a mechanism for resolving this problem. In fact, such models perhaps are presented only to detect of conflicts (collisions) and are not considered a mechanism for resolving conflicts. Finally, in “Combination Method” proposed models use a combination of other conflict resolution methods. For example, one of the models may be in some cases use predefined actions, then encounter with certain conditions take the optimization procedure.

7.9. Resolution Maneuvers

This feature discusses that during resolving of conflicts what solution or in other words, what type of maneuver will be used to resolve conflicts. To summarize, some of the maneuvers include: speed change (decrease or increase of aircrafts’ speed), changing the angles (horizontal maneuver), change and adjust altitude (vertical maneuvers) and turn maneuver [4], [35]. Some of the models have been used only one of these criterions to resolve collisions and others has used a combination of these criterions. In some models, performing these maneuvers simultaneously is possible; while some other models do not use this maneuver simultaneously. Obviously, if in our model we use more maneuvering dimensions, more efficient solution will be achieved. The horizontal and vertical maneuvers are shown below.

Figure.2. Horizontal Maneuver [13]

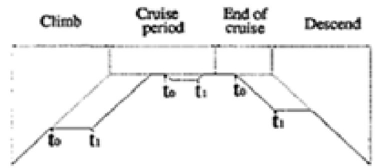

Figure.3. Vertical Maneuver [13]

7.10. Management of Multiple Conflicts

The term management of multiple conflicts describes how the proposed conflict resolution model handles conflict situations in which there is more than two aircrafts. Two general approaches to this problem are using a *Global approach* and *Pairwise approach* [4]. In *Global* approach, the entire traffic environment is examined simultaneously by using determined methods for that. But in *Pairwise* approach collisions between aircrafts are resolved sequentially in pairs manner that has the sequential and hierarchical nature.

By comparison between these two modes, one should conclude that in *Pairwise* conflict resolution approach, if one conflict solution induces a new conflict, the original solution may be modified until a conflict-free solution is found [4]. Although this approach is much simpler than the *Global* approach, it is powerless to solve the conflict problem. The *Global* approach considers multiple collisions simultaneously and offers a global solution to resolve collisions between aircrafts that it shows the high capabilities of this method. But this method requires more computations and is more complex than the *Pairwise* approach. The model will be best (powerful) that use the *Global* approach; but not imposed too much cost and overload on air traffic management system. We can assume that the *Global* and *Pairwise* approaches as finding *local* and *global* optimal in evolutionary algorithms.

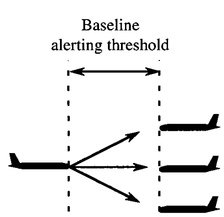

Figure.4. Pairwise approach in conflict resolution process [4]

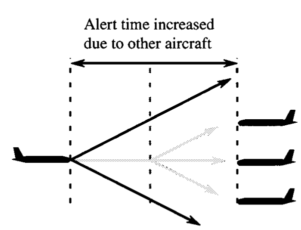

Figure.5. Global approach in conflict resolution process [4]

8. Some Remarks

In previous section we explained the basic characteristics for comparing various multi agent models for conflict detection and resolution problem in air traffic, but there are some other features that are most important in implementing of a conflict detection and resolution model. These features described in follow subsections and discuss how much the proposed models have the ability of adaptability with existing models, what requirements is need for implementation of proposed model, what test cases is used to test the proposed models and also discuss the correctness of the proposed conflict detection and resolution model.

8.1. Computational Complexity

From computational point of view, a model that imposes lower memory and time complexity to the system would be more efficient. Also the algorithms used to manage the existing agents in multi agent system would be important. Since each agent is able to perform some actions in the system, we can generally say that if we have N agents in the system and each agent is capable to perform the K activities, then the expected time complexity will be $O\ (NK^N)$. Obviously if we select aircrafts as agents in the presented multi agent system to the air traffic control, then the computational complexity of the system will be very high. Therefore, we need to pursue exactly from multi agent systems' design principles.

8.2. Implementation and Test of Models

One of the main fundamental and important problems that must be considered in proposed (multi agent) models, is the implementation and testing of them. Some of researchers have used artificial data sets to test their proposed models. However, our goal from presenting of these models is to use and implement of them in the real world environment. Sometimes artificial data sets can not represent correctly display of the real world conditions. Others have been used real data sets to test their models and have been evaluated effectiveness of their method based on this real data [1]. Although some of these models were evaluated only some aspects of the air traffic conditions and very few models are considered all aspects of the air traffic conditions as comprehensive.

8.3. Adaptability with Existing Systems

This feature discusses the adaptability and compatibility of proposed models with the existing air traffic management systems (current conflict detection and resolution systems). In general, a system which is capable to work efficiently with no overall changes in current systems would be better. An example of this case is the proposed model in reference [1]. Clearly, a proposed incompatible model with the current air traffic management system requires a log time and more cost. In this case, system needs to apply fundamental changes, while our general goal is optimization and reduction of costs with the correct solution for conflict detection and resolution problem.

8.4. Accuracy in the Process of Conflict Detection

Conflict detection process is one of the major points. For example, it is possible that the system may be detecting conflicts which will not occur or even does not recognize some of the potential conflicts. A perfect model should be use accurate conflict detection metric with the highest possible speed, in order to ensure an adequate opportunity to prevent and resolve future conflicts. It seems that, the speed and the time are two important features in conflict detection process.

8.5. Agents' Behavior in Conflict Resolution Process

Most proposed conflict detection and resolution models have focused on the free flight topic and have been selected optimization procedures. As already mentioned, the activities that each agent can perform in conflict resolution process are important. In other words, the actions that each of the agents can perform should be such that they mostly prevent conflicts occurring in the future and should have a long-term view of agents' environment. Actions that an agent performs, should accomplish with highest precision, speed and at least possible time to be have an optimal action in contrast the conflicts. Generally, the models have greater flexibility will be more successful and the agents that use learning techniques will act as comparative manner based on the utility functions and will have better performance against predefined solutions.

We summarized all these metrics in Table 1; then we used them for compare different proposed air traffic management models. In table 1, which has two columns, the "Feature" title in top of columns indicate the criterion's name and "Abbreviation" title indicate the possible states for corresponding features. These two columns are used for categorization and organization of proposed conflict detection and resolution models by researchers. We believe these features create a comprehensive taxonomy for comparing every proposed conflict detection and resolution model. In addition, Table 2 presents a comparison of different models based on multi agent systems technology. Table 2, listed 22 different models classified based on criterions that are presented in Table 1. In table 2, in each cell if the value of a feature not explicitly defined in the proposed model we write the "–" in that cell. The features used to organize these models are as follows: agent selection, agent action, type of interaction, type of multi agent system, multiple conflicts, maneuvers, conflict detection, conflict resolution, plan dimensions, and strategy; that each of which is described in above sections and summarized in Table 1.

Table 1: Proposed Comparing Metrics for models based on multi agent systems

NO.	FEATURE	ABBREVIATION	NO.	FEATURE	ABBREVIATION
1	Agent selection	A = Aircraft AL = Airline AP = Airport F = Fixes Point S = Synchronizer	6	Maneuvers	S = Speed Change H = Horizontal Maneuvers V = Vertical Maneuvers T = Turn C = Combined (S, H, V, T)
2	Agent Actions	RRD = Regulation of Reliable Distance D = Making Delay for reduction of congestion R = Flights Reroute Mostly, depend on the entity that selected as agent	7	Conflict Detection	MD = Minimum Distance (Horizontal,Vertical,Combined) TBT = Time between Trail OIPZ = Overlap In Protected Zone "–"= No Explicit Conflict Detection Threshold
3	Interaction	N = Negotiation C = Cooperation O = Using of Specific Protocols or other methods (e.g. Uniform Concession Protocol)	8	Conflict Resolution	P = Predefined O = Optimization F = Force Field M = Manual "–" = No Resolution
4	Type of Multi agent System	P = Pure System C = Combined (agents helps humans)	9	Plan Dimensions	H = Horizontal V = Vertical C = Combined
5	Multiple Conflict	P = Pairwise G = Global	10	Strategy	L = Learning methods (e.g. Reinforcement Learning) GT = Game Theory ST = Satisfying Theory P = Prioritization C = Cooperation

Table 2: Compare of presented models based on proposed criterions in Table 1

Model	1	2	3	4	5	6	7	8	9	10
Rong [10]	A	as an aircraft	N	C	P	V, S, H	OIPZ	O, F	-	C
Valkanas [15]	A, Auto-pilot Agent	Navigation Behavior and Communication Behavior	N	-	-	–	MD	O	-	Point Utility Function (PUF)
Adrian [1]	F	set reliable distance with other aircrafts, order ground delays, Reroute aircraft	C	-	-	S	–	O	-	L (RL)
Pappas [16]	A	Prediction and solving conflicts by using coordination and game theory strategy	C	C	P	V, S, H	OIPZ	O	-	GT
Oliveira [11]	A, AP, AL, S	Airport:Introduce Aircraft, Synchronizer:Synchronization, Aircraft:Execute Flight operations, Airline: control the flight path	C	C	–	–	–	O	C	–
Samek [17]	A, Flight Agent	-	N	-	G	–	–	O	-	Avoiding of Deadlock Mechanism
Wangermann[21]		-	N		G	C(S, V, T)	–	O	H, V	C

Table 2: Compare of presented models based on proposed criterions in Table 1 (Cont.)

Model	1	2	3	4	5	6	7	8	9	10
Gorodetsky [18]	**assistant air traffic control operator, Operator assistant**	**coordinate airliner movements in the arrival zone (separation assurance), minimize the intervention of air traffic operator during air traffic controller in arrival zone,**	**N**	**C**	**–**	**V, H**	**MD**	**P, A**	**-**	**C, P**
Wollkind [14]	**A**	**providing free conflict trajectories by using Monotonic Concession Protocol**	**N, C**	**P**	**–**	**H, V, T, S**	**OIPZ**	**O**	**H**	**Uniform Concession Protocol- Data Link Between Aircrafts**
Tomlin [22]	**A**	**Conflict resolution using control and game theory strategies**	**–**	**P**	**G**	**T**	**OIPZ**	**O**	**H**	**Control Theory, GT**
Adrian [8]	**F**	**set reliable distance with other aircrafts, order ground delays, Reroute aircraft**	**C**	**-**	**–**	**–**	**–**	**O**	**-**	**Rule-Based**
Tumer [12]	**F**	**set reliable distance**	**C**	**P**	**-**	**–**	**–**	**O**	**-**	**Reinforcement**

		with other aircrafts, order ground delays, Rerouting								**learning**
Harper [20]	**–**	**-**	**–**	**-**	**G**	**T, S**	**–**	**O**	**H**	**–**
Tomlin [34]	**A**	**Conflict resolution using control and game theory strategies**	**–**	**P**	**G**	**S**	**OIPZ**	**O**	**H**	**Control Theory, GT**
Wangermann [23]	-	**-**	**N**	**-**	**G**	**C(S, V, T)**	**–**	**O**	**H, V**	**C**
Johnson [24]	**A**		**N**		**G**	**S, H**	**–**	**O**		**ST, C**
Archibald [25]	**A**	**Providing conflict free trajectories by using game theory strategy**	**N**	**P**	**G**	**S, H**	**–**	**P**	**H**	**GT**
Albaker [26]	**A**	**Detecting and resolution of conflicts using cooperation**	**N**	**-**	**P**	**S,H**	**OIPZ**	**P**	**-**	**N**
Vilaplana [27]	**A**	**Autonomous aircraft operations such separation assurance**	**C**	**P**	**–**	**H**	**MD**	**O**	**4D**	**C**
Sislak [28]	**Aircraft Controller**	**-**	**N**		**–**	**H,S,V**	**MD**	**O**	**-**	**C**
Chao [29]	**Flight Agent, Control Agent**	**In general: Navigation, conflict detection, avoid of conflicts and execute flight Plan, set reliable distance, set reliable arrival time interval**	**–**	**P**	**–**	**V, S, T, H**	**MD**	**O**	**4D**	**Control Theory**
Nguyen [30]	**(ATC), Local Flow Manager (LFM), Central Flow Manager (CFM)**	**Mostly Real-time Traffic Synchronization, coordination**	**N**	**-**	**–**	**–**	**–**	**–**	**-**	**C , Team Work, commitment protocol**

9. CONCLUSION

Obviously several methods are proposed for conflict detection and resolution problem in air traffic management which can be a basic structure for future models. Research on air traffic management systems is still regarded as an open and interesting issue that our results prove this remark and the need for new powerful methods that automate conflict detection and resolution will continue to grow as air traffic densities increase. In this paper we are not consider all presented multi agent conflict detection and resolution models, but we believe, the experience of previous researchers helpful to provide a comprehensive solution to safety, reliable, efficient and optimal air traffic management. Each of the researchers in their works has been discussed high potential use multi agent systems to improve air traffic management and have been stressed on the necessity use of multi agent systems in air traffic management. Using of other distributed and new techniques with multi agent systems in air traffic control will be very useful. We believe multi agent systems technology as a powerful computational paradigm is a valuable solution to the air traffic management problem and especially to the conflict detection and resolution problem.

In this paper, we introduced a systematic comparison structure to compare various multi agent conflict detection and resolution models; although this paper is not representing a complete comparison, it is a positive advance to review performance and desirability various models that are presented so far. Also in this study some important remark about implementation of proposed models were reviewed that one of these remarks is the lack of comprehensive and uniform experimental test cases to test these models. Obviously, if we examined the different models based on the same datasets, the strengths and weaknesses of these models will be better evident.

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