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A New Prioritization Method for Conflict Detection and Resolution in Air Traffic Management

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ABSTRACT

The current air traffic management systems are not able to manage the enormous capacities of air traffic perfectly and have not sufficient capability to service different types of flights. Free flight is a new concept presented potentially to solve problems in the current air traffic management system. 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 efficiently, and also plan for their flight with high performance themselves. Despite of many advantages of free flight (such as less fuel consumption, minimum delays and the reduction of the workload of the air traffic control centers), it cause many problems such as conflicts (collisions) between different aircrafts. In this paper, we presented a model for conflict detection and resolution between aircrafts in air traffic management using graph coloring problem's concept. In fact, we mapped the congestion area to a corresponding graph, and then addressed to find a reliable and optimal coloring for this graph using a prioritization method.

Keywords: *Air Traffic Control, Free Flight, Conflict Detection and Resolution, Graph Coloring Problem, the Prioritization Method*

1. INTRODUCTION

Having a reliable, safe and efficient air traffic management is a fundamental and critical need in aviation industry. 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"; [1] and Air Traffic Control as: "a service operated by appropriate authority to promote the safe, orderly, and expeditious flow of air traffic." [1]. Air traffic management is a very complex, dynamic and demanding problem which involves multiple controls and various degree of granularity [2]. Generally, the main goals of air traffic management systems are as follows: providing safety (separate aircraft to prevent collisions - to observe the reliable minimum distance allowed between aircrafts), performance and high efficiency for the flights, detecting and resolving conflicts, reducing travel time (minimum delay) with highest possible accuracy, organize and expedite the flow of traffic, and providing information and other supports for pilots when able [3, 4]. There are many reasons for the need of presentation of new approaches in air traffic control that include: the number of flights are increased and this high air traffic needs more reliability and high performance, currently the issue of hijacking and terrorist attacks is more serious and important and human errors in the process of information gathering is inevitable; that automated systems are able by gathering the necessary data (through facilities such as sensors) detect the possible conflicts and suggest detailed instructions or a accurate solution to solve these conflicts for help humans. This problem leads many researchers (e.g. in [5, 6, 7]) in the field of aviation industry to provide innovative solutions for safe and efficient air traffic management.

The current air traffic management systems are not able to manage the enormous capacities of air traffic perfectly and have not sufficient capability to service different types of flights. Because of these problems, the Aviation industry has turned towards a new concept called free flight [8]. Free flight is a new concept presented potentially to solve problems in the current air traffic management system. Free flight means that, pilots or other users of the air traffic management systems 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) [9, 10].

It is worthwhile to mention that free flight concept is potentially and technically practical nowadays, because currently there exist its required and background technologies such as global positioning systems (GPS), Data Link communication systems and enhanced computational capacity in cockpits. Despite many advantages of this method, free flight imposes some problems for air traffic management system that one of the most notably of them is the occurrence of conflicts between different aircrafts' flights. Conflict detection and resolution is one of the major and fundamental challenges in safe, efficient and optimal air traffic management.

So far, various models are proposed for conflicts detection and resolutions in air traffic. Also we are presented an organized and systematic model for conflicts detection and resolution between aircrafts in air traffic management that has high efficiency, flexibility and reliability. In this paper with mapping congestion area to corresponding graph, we converted the problem of solving conflicts between aircrafts to a Graph Coloring Problem (GCP) [11]; then by using a prioritization method we solved the graph coloring problem. An efficient and reliable coloring for this graph is a solution to solve the conflicts between different aircrafts. In fact, it is for the first time, we use of GCP to solve conflicts between different aircrafts and we believe that if we use this model beside of new technologies such as multi-agent systems [2] we can obtain promising efficiency in air traffic management systems.

2. CONFLICT DETECTION AND RESOLUTION PROCESS

As we mentioned, conflict detection and resolution is an important challenges in air traffic management systems. Many researchers focused on solving this problem and attempted to present the efficient models. Kuchar and Yang [12] presented an overview a number of conflict detection and resolution models. Most of these models are based on the classic methods (such as Lagrangian models or Eulerian models and other mathematical methods). 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" [12]. In other words, the distance between aircrafts violates a criterion defining what is considered unwanted; that we should avoid of these conflicts during a fast and accurate process otherwise air traffic management may be deal with difficult and also risk of any plane collide increases. Also In this paper, conflict detection process is defined as "the process of deciding when conflict - conflict between aircrafts- will occur" [12], and conflict resolution process is considered as: "specifying what action and how should be to resolve conflicts" [12].

In the proposed models by researchers is used of different criterion to identify conflicts and subsequently to resolve conflicts. Some of these models have used a criterion of temporal interval for conflict detection, some others have used of a criterion of a safe distance for conflict detection so that if distance between two aircraft is less than a certain threshold it is said that a conflict exists between these two aircrafts. In the proposed model in this paper, conflict detection criterion is set reducing the distance between the aircrafts of a certain limit.

Our proposed model is based on the prevention method of conflicts. In this model the congestion area is mapped to a corresponding graph. In fact, we make a state space graph from congestion area. Each node of this graph indicates one aircraft in congestion area and each edge between two nodes represent the conflict that may be occur between two aircrafts in future, and the colors used for coloring this graph indicates an air line. In fact, for each aircraft, we allocate an airline in which this aircraft have a reliable distance with each other aircrafts and there will no risk of conflict; then we compute scores and subsequently priorities for aircrafts in congestion area; after this step, we are coloring this graph by using of prioritization method as optimal and with least cost. In this model, Global approach is used to resolve the multiple conflicts between aircrafts in congestion area.

3. GRAPH COLORING PROBLEM

Graph Coloring Problem (GCP) is an optimization problem that includes finding an optimal coloring for a given graph G. GCP is one of the most studied NP-hard problems. Coloring a graph involves assigning labels to each graph node so that adjacent nodes have different labels. A minimum coloring for a graph is a coloring that uses the minimum number of different labels (colors) as possible [13].

GCP is a practical method of representing many real world problems including time scheduling, frequency assignment, register allocation, and circuit board testing. In GCP the fundamental challenge for any given graph is to find the minimum number of colors for which. This is most often implemented by using a conflict minimization algorithm [14].

The graph coloring problem can be stated as follows: Given an undirected graph G with a set of vertices V and a set of edges E (G= (V, E)), a k-coloring of G consists of assigning a color to each vertex of V; such that neighboring vertices have different colors (labels). Formally, a k-coloring of G= (V, E) can be stated as a function F from V to a set of colors K (in our implementation, we represent the colors by integer numbers that each integer number represent a color for vertices) such that $|k|=k$ and $F(u) \neq F(v)$ whenever E contain an edge (u, v) for any two vertices u and v of V. The minimal number of colors allocated to a graph is called the chromatic number of G. Optimal coloring is one that uses exactly the predefined chromatic number for any given graph. Since the GCP is NP complete [11, 13], we need to use heuristics methods to solve it. As we know there are many methods that proposed for Graph Coloring Problem such as: evolutionary methods (e.g. GA [15, 16]), local search algorithms (e.g. Tabu search [17] or Simulated Annealing [18]) or other mathematical and optimization methods. If we assume various assumptions in GCP there will be many type of this problem. In this paper, we use the Prioritization Method for solving the GCP.

4. OUR PROPOSED MODEL

In this proposed model, the main strategy is based on: "Prevention is better than cure". If we use the prevention strategy and not allow the complex conflicts occur; in this case, firstly, it is not essential to have a plan for detecting conflicts, and subsequently, it is not necessary to resolve the conflicts. Although in this model we tried to have a preventive approach, we attempted to present a method with high performance for conflict detection and resolution. In our proposed model, the criterion of conflict detection is the reduction of the distance between aircrafts of a certain limit. The advantage of this model is the high flexibility, and same as other models (that proposed for conflict detection and resolution in air traffic) tries to present a method to conflict detection and resolution between aircrafts in airspace. The diagram of our proposed model is shown in Fig. 1.

As shown in Fig. 1, the traffic environment must first be monitored and appropriate current state information must be collected (using proper equipment [12]). These states provide an estimate of the current traffic situation (such as, aircrafts' position, aircrafts' direction, destination and velocity). Then the congestion area is detected based on state information of current air traffic. Also in this stage, the minimum reliable distance threshold can be determined to detecting conflicts. In the second stage, the congestion area (that determined in previous stage) is mapped to a corresponding graph based on minimum reliable distance threshold; in other words, in this stage a state space graph is created from congestion area. In third stage, the scores of aircrafts in congestion area is computed and then based on these scores the priority of each aircraft is computed. Computation of these scores and priorities is described in next sections.

In fourth stage, the corresponding graph is colored using prioritization method. In other words, we used of a prioritization method for solving GCP. The algorithm output is an optimal and reliable coloring (an efficient solution for solving conflicts between aircrafts in congestion area). If there is no collision, the algorithm ends. Therefore, each node in this graph indicates one of the aircrafts in the congestion area and the colors used for coloring this graph indicates an airline. In fact, for each aircraft we allocate an airline in which this aircraft will has a reliable distance with each other aircrafts and there is no risk of conflict. Also this model can interact with innovative technologies (such as multi-agent system technology) to conflicts detection and resolution in air traffic management and also in ground traffic and related applications.

Pseudo code of proposed model (solving conflict problem by using graph coloring problem's concept) is shown in Fig. 2. In the first phase, we map the congestion area to a corresponding graph. So we determine the range of congestion zone; for this purpose, we specified the traffic parameters on the environment. Then we map the congestion area to a corresponding graph based on the minimum reliable distance threshold. Then distance matrix between all aircrafts in congestion area is computed, after this stage the adjacency matrix is created based on the distance between aircrafts and determined minimum reliable distance threshold. In the second stage, the score and subsequently priority for each aircraft is computed and then the corresponding graph is colored by using Prioritization method. The output of this algorithm is a colored graph (an optimal solution for conflict problem). Then, the new flight plan sent to the aircrafts on airlines that is free conflict plan.

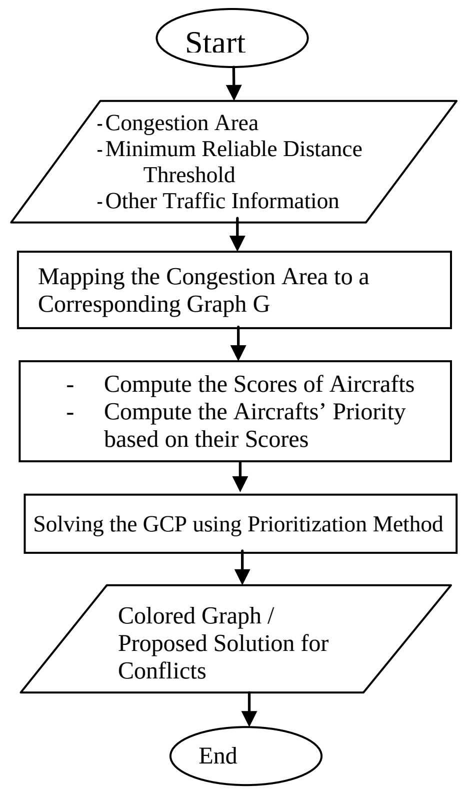

Fig 1: Block diagram of our proposed model.

5. PRIORITIZATION METHOD

Here, we assign the priority for each aircraft based on its conditions in airspace. In this model, the priority of each aircraft is specified based on its score. So that when an aircraft has high score will have a high priority and conversely if an aircraft has a low score then will have a low priority. Score allocation and therefore priority assigning for each aircraft is performed as follows:

- When an aircraft is close to its destination, its score increase.
- Score of an aircraft increase when the aircraft flies in the favorable weather condition.

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- Score of an aircraft increase when the aircraft flies at high altitude (under valid altitude).
- Score of an aircraft increase when aircraft has high (appropriate) speed.
- Score of an aircraft increase when its distance (horizontal or vertical) from the other aircrafts is large.

We assign a priority for each aircraft based on its score. When a conflict occurs, an aircraft which has a low priority must changes its path and deviates from primary and original route for prevention of occurring conflicts. In fact we use of a hierarchy method to resolve conflicts. Perhaps at first glance, this process seems very similar to the greedy method but naturally the priority method is general and it is reasonable; for example when an aircraft that is closer to its destination and has minimum deviation from the mainstream must be service in first and then the other aircrafts must be service. Although, in this case starvation state occurring is not unexpected but we can avoid this problem by allocating scores to the aircrafts that for long time are on the airlines; for that these aircrafts also service immediately in possible time. Pseudo-code of Priority assigning to the existing aircrafts in congestion area is given in Fig. 3.

We used of this method for solving conflicts between aircrafts in congestion area (in other words, for coloring corresponding graph of aircrafts' congestion area). Also the prioritization method can be use to solve conflicts without using of GCP.

```
// Step 1: Creating the Corresponding Graph of Congestion area

Problem Parameters //Define Problem Parameters - air traffic situation (such as domain of congestion area, velocity of each aircraft in congestion area, altitude for each aircraft, destination of each aircraft and other traffic information)
Reliable_ Treshold=Predefined Value;
Num of Aircrafts = Number of Airplanes in Congestion Area;
Detect the Congestion Area;
Map the Congestion Area to a corresponding Graph;
// Compute distance of all aircrafts in airspace (congestion area)
Distance_ between _Aircrafts (Problem Parameters);

// Make the Adjacency Matrix for Graph (Congestion Area)

// Step 2: Compute the Priority for Aircrafts (in Congestion Area)
Aircrafts _Scores = Compute the Scores of Aircrafts (Problem _Parameters);
Aircrafts _Priority = Compute the Priority for each Aircraft (Aircrafts _Scores, Problem_ Parameters);

// In this phase, we assume that Colors are equivalent the Airlines with five directional options, and we want to Assign each Aircraft to one airline that not occupy by other aircrafts. It is desired to select the best solution that has the lowest Cost.

// Step 3: Solve the Graph Coloring Problem (Conflicts of Aircrafts in Congestion Area) by using the Prioritization Method.

Prioritization_Alg (Corresponding Graph, Aircrafts_Priority)

// New Flight Plan
Send the New Flight Plan to the Airplanes on Airlines that is free Conflict Flight Plan.
```

Fig 2: Pseudo-Code for Our Proposed Model

```
for i=1:ProblemParams.NumOfAirplanes
 {Distance_to_Distination(i) = abs (Problem Params. Airplanes (i).
   Distination - Problem Params. Airplanes (i).CurrentPosition);
   Velocity (i) = ProblemParams.Airplanes(i).Velocity;
   Altitude (i) = ProblemParams.Airplanes(i). Altitude;
   Weather (i) = ProblemParams.Airplanes(i).Weather;}

// Compute Priority for each Airplane
for i=1:ProblemParams.NumOfAirplanes
{Score_DTD=Max_Distance_to_Distination -
  Distance_to_Distination(i);
  Score_Velocity=Velocity (i) - Min_Velocity;
  Score_Altitude=Altitude (i) - Min_Altitude;
  Score_ Weather=a predefined value for specific weather state;
  ProblemParams.Airplanes(i).Score=Score_DTD +
  Score_Velocity + Score_Altitude + Score_ Weather;

  Priority (i) = ProblemParams.Airplanes(i).Score;}
```

Fig 3: Calculate the priority for aircrafts in congestion area

6. CONFLICTS RESOLUTION USING GRAPH COLORING PROBLEM

As we mentioned, the problem of finding chromatic number and a proper coloring for any given graph due its many applications, is very important. Graph coloring problem is a practical problem that is used in many real-world problems. In this paper, our goal is that by mapping the congestion area to a corresponding graph, provide a

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solution to solving the conflicts between aircrafts and represent a safe and effective solution to solve this problem.

Congestion in airlines causes many problems such as creating a long flight delays. Hence, we must try to avoid the congestion area (areas that have high risk of collisions) by using of a fast and accurate process. While one usual application of the graph coloring problem is to solve conflicts, we present a systematic and organized solution to resolve the aircrafts' conflicts with GCP. In fact, after mapping the congestion area to a graph, our goal is to optimize the graph coloring. In this paper, we used of a prioritization method for solving graph coloring problem. This seems to be a systematic, optimal and standard solution for solving conflicts between different aircrafts in air traffic management. In below subsections we explained the process of solving conflicts by using GCP.

a. Creating the Graph

To display and store of a graph on the computer, one can use the adjacency matrix [19]. We also use the same method. The value of each element in the adjacency matrix is "1", if there is an edge between any two nodes in graph; otherwise will be equal to "0". Here, nodes of corresponding graph indicate aircrafts in the congestion area. In this model, we consider each airline as a color. We can assume each airline as five directional options namely: main line, deviation to right of the main line, deviation to left of the main line, top of the main line and bottom of the main line.

We tried to keep each aircraft safe in an airline (i.e. each aircraft does not conflict with other aircrafts and ensures reliable distance with other aircrafts). Here, we assign a number for each aircraft in congestion area; in rows and columns of the adjacency matrix, we write the aircrafts' number. The value of each matrix element indicates whether there is an edge between two nodes. If two aircrafts have the same altitude on airline in the airspace, and reliable distance between them is less than a predefined threshold, then we draw an edge between two vertices and the value of corresponding element in adjacency matrix is equal to "1". Otherwise, the value of corresponding element would be equal to "0". The graphical display of creating graph of a supposed scenario is shown in Fig. 4.

b. Solving the Graph Coloring Problem

As we mentioned in previous sections, after mapping the congestion area to a corresponding graph, we start coloring of this graph. Input of graph coloring algorithm is an undirected graph without cycle and the output of this algorithm is a valid coloring for this graph, such that the algorithm assign a color for each node of graph and neither of two adjacent nodes have the same color. Our goal of using the GCP to solve the collision in air traffic management is that: to conduct each aircraft in a safe airline; thus in this airline there is no conflict and every aircrafts is kept in a minimum reliable distance with other aircrafts.

c. System Performance Measures (Problem Cost Function)

In air traffic management systems we deal with a multi objective problem. In this paper, our goal is providing a safe, reliable and efficient strategy for solving conflicts between aircrafts in air traffic. We can use of different metrics to evaluate proposed model. We discuss the most promising of these as follow:

i. Separation Assurance

The number of occurred conflicts is a function of traffic density and physical geometry of intersecting flight paths [20]. Also, in this paper we use of similar type of this metric, thus the number of edges of corresponding graph to a congestion area indicates the number of aircrafts which lose of minimum separation of each other.

ii. System Efficiency

The ideal state in a model for resolving conflicts in air traffic is that the aircrafts are able to track their destination without deviation or with minimal deviation from their original path. Maneuvers that are used in the methods used to solve the conflicts, causes the aircraft to be diverted from the ideal and optimal mainstream. Possible maneuver dimensions include turns, vertical maneuvers (changing aircraft's altitude), and speed changes. System efficiency measures the degree to which the aircraft in the system are able to follow direct and linear flight paths to their destinations [20].

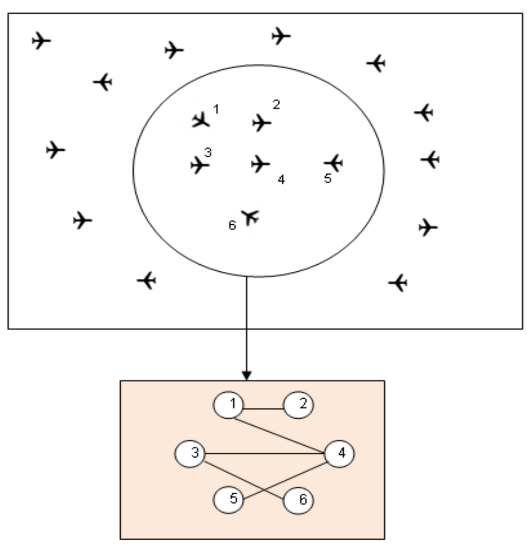

Fig 4: Graphical display of an example conflict resolution scenario, creating the graph

In this paper, we define a simple performance criterion for each aircraft same as follows:

Path length = (length of main path) - (length of revised path)

We try to select routes with lowest cost when we redirect the aircrafts' main routes (i.e. the lowest deviation from the main route for each aircraft). It is assumed that the predefined main routes to fly aircrafts are optimal. We can rewrite this criterion as below:

$$E_i = \left(\frac{P_i}{P_i + P_{d_i}} \right)$$

In which P_i is the ideal and optimal flight path for an aircraft and P_{d_i} indicates amount of deviation from mainstream of aircraft. Then we consider efficiency of the system as follows:

$$\text{System Efficiency (SE)} = \frac{1}{N}\left(\sum_{i=1}^{N} E_i \right)$$

Where N is the total number of aircrafts in the system (i.e. in the congestion area) and E_i indicates the performance of each aircraft. How much this criterion is closer to "1" indicates good performance of the system and how much this criterion is closer to zero indicates poor performance and conflict resolution system is inefficient. Our proposed model for solving graph coloring problem for higher dimensions (for a great number of aircrafts that are in the congestion area) acts as a good way.

7. TEST RESULTS

To evaluate our proposed model described in previous sections, we use simulation environment (especially we use random flights model) that is same to one used in [20]. All aircrafts are constrained to fly at the same altitude and at a constant speed. Small and instantaneous heading changes for each aircraft are the only maneuvers of resolving conflicts. For this reason we use examples and supposed scenarios; these samples contain 2, 3, 5, 6, 8, 12, 16, 20 and 30 aircrafts in congestion area.

As mentioned, we mapped the congestion area to a corresponding graph, and then our problem converted into graph coloring problem. Since each aircraft in the airspace is considered as a node in the corresponding graph, in fact we deal with coloring of graphs with number of mentioned nodes.

We ran the algorithm 10 times for each graph of corresponding congestion area and we concluded based on running algorithm for 10 times. The results are presented in Table I. Also a simple system efficiency average diagram as shown in Fig. 5. The results indicate that the proposed model is often providing optimal and valid solutions for input corresponding graphs (congestion area). We used MATLAB software to implement our proposed model.

TABLE 1: TEST RESULTS OF APPLYING THE ALGORITHM ONTO INPUT GRAPHS (CONGESTION AREAS) WITH SPECIFIED PARAMETERS

No.	N	|V|	|E|	NA	SE (%)
1	2	2	1	1	99.5
2	3	3	3	1	98.5
3	5	5	2	3	98.5
4	5	5	4	3	98
5	6	6	5	3	97.6
6	8	8	4	4	97.5
7	12	12	11	7	98
8	16	16	8	8	98
9	20	20	15	12	97
10	30	30	15	15	96

The following acronyms are used in the above Table:

N: Number of aircrafts in congestion area
|V|: Number of Nodes in corresponding graph of congestion area
|E|: Number of Edges in corresponding graph of congestion area (number of pair of aircrafts that have conflict)
NA: Number of optimal Air lines for aircrafts in congestion area (in fact chromatic number in graph coloring problem)
SE: System Efficiency

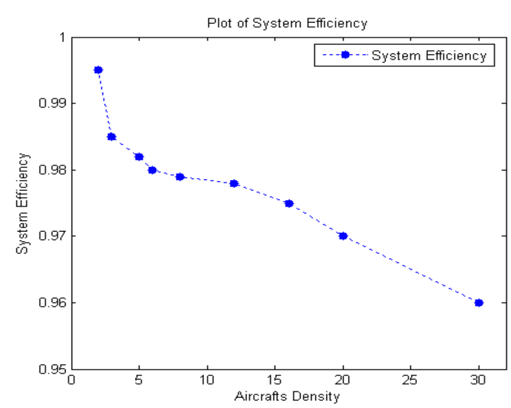

Fig 5: Schema of average of system efficiency

8. CONCLUSION

Conflict detection and resolution is an active research topic in recent years and presenting new algorithms that automate the process of conflict detection and resolution are important as increase of air traffic densities. Free flight is a new concept that as potentially solution is presented for solving the problems in the current air traffic management system. Conflict detection and resolution is one of the fundamental challenges in the current air traffic management and especially in free flight. In this paper, a new approach is presented to conflict detection and resolution in air traffic management. In this approach, we mapped the conflict resolution problem in congestion area to Graph Coloring Problem and then we used of Prioritization method to solve graph coloring problem.

The result of corresponding colored graph of aircrafts' congestion area is presented efficient and reliable solution to conflicts problem. Using of graph coloring problem to solve conflicts between aircraft is systematic and new approach that has high flexibility and can be used with new technologies such as multi-agent systems technology. In this model is used of multiple strategy to resolution of conflicts and has high efficiency compared to other models that don't consider this aspect.

Although, in this paper we presented only an abstract, preliminary and conceptual model for conflict detection and resolution, nonetheless our next goal is that we will focus on using this model with multi-agent systems technology to present a comprehensive model with high efficiency for conflict detection and resolution in air traffic management system.

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