# A Conflict Resolution Approach using Prioritization Strategy

Hojjat Emami*
Computer Engineering Department, Islamic Azad University, Miandoab Branch
hojjatemami@yahoo.com
Kamyar Narimanifar
Civil Engineering Department, Islamic Azad University, Miandoab Branch
kamyar1360@yahoo.com

Received: 27/Sep/2012 Accepted: 16/Dec/2012

**Abstract**
In current air traffic control system and especially in free flight method, the resolution of conflicts between different aircrafts is a critical problem. In recent years, conflict detection and resolution problem has been an active and hot research topic in the aviation industry. In this paper, we mapped the aircrafts' conflict resolution process to graph coloring problem, then we used a prioritization method to solve this problem. Valid and optimal solutions for corresponding graph are equivalent to free conflict flight plans for aircrafts in airspace. The proposed prioritization method is based on some score allocation metrics. After score allocation process, how much the score of an aircraft be higher its priority will be higher and vice versa how much the score of an aircraft be lower its priority will be lower. We implemented and tested our proposed method by different test cases and test results indicate high efficiency of this method.

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

## 1. Introduction

Air traffic management is a very difficult, dynamic and complex problem [1]. Nowadays, the airspace management system has high flight capacity, therefore control of existing enormous volume of flights is very difficult [2, 3]. Current air transportation systems are faced with many problems. The aviation industry introduced a new approach called free flight for solving various problems in current air traffic management [4, 5]. Free flight or user preferred trajectories, is an innovative method introduced to improve the safety and efficiency of the national airspace system. Currently free flight method is technically practical because exist its required technologies. Free flight method has many advantages such as less fuel consumption, reduction of flight times, flights' delays and reduction the workload of air traffic controllers. Despite many advantages of this method, free flight imposes some problems for air traffic management system that one of the important of them is the conflict problem between different aircrafts' flights [6, 7]. Conflict detection and resolution is one of the major and fundamental challenges in safe, efficient and reliable air traffic management system. In this paper, conflict is defined as: "*the event in which two or more than two aircrafts experience a loss of minimum separation from each other*" [8]. Also the conflict detection process is defined as: "*the process of deciding when conflict between aircrafts will occur*", and conflict resolution process is considered as: "*specifying what action and how should be to resolve conflicts*" [8]. Annually Conflicts between different aircrafts causes many losses for aviation industry.

Generally many researchers have been presented various models to automate conflict detection and resolution system (e.g. in [9, 10, 11]). In reference [8] Kuchar and Yang provided a review of some of proposed conflict detection and resolution modeling methods. Also in reference [12] we presented an overview of a number of multi-agent conflict detection and resolution methods.

* Corresponding Author

This paper presented a conflict resolution methodology for aircrafts' flights in airspace. This method has high efficiency, flexibility and reliability. In this paper we used concept of graph coloring problem [13]. In fact we mapped congestion area to a corresponding state space graph. Each vertex of this graph indicates an aircraft in airspace and each edge of this graph indicates a predicted conflict between two aircrafts in future times. Also in this paper we proposed a new prioritization method for solving conflicts problem. By using prioritization algorithm we make a priority list for aircrafts that exist in congestion area. In our proposed model, after mapping congestion area to a corresponding graph we used this priority order for coloring this graph (i.e. solving conflicts between aircrafts). A valid and optimal coloring for this graph is equal to a new free conflict flight plan. The simulation results indicate this algorithm has high efficiency and it is sound.

The organization of this paper is as follows. In Section 2, graph coloring problem is described. Section 3 describes prioritization method. In Section 4 we explain our proposed model. Section 5 discusses experiments and simulation results and finally in Section 6 we make some conclusion and present an outlook of future works.

## 2. Graph coloring Problem

Graph coloring problem (GCP) [13, 14] involves labeling each vertex of given graph G, so that no two adjacent vertices have the same colors. One of the goals of graph coloring problem is to minimize the number of colors used in the coloring process. Graph coloring problem is a practical method and is a NP-hard problem [15]. Graph coloring problem arises naturally in many real world application fields such as register allocation, frequency assignment, time scheduling, and circuit board testing.

Assume an undirected graph G = (V, E) with a set of vertices V, and a set of edges E, a k-coloring of G include assigning a color to each vertex of V such that no two adjacent vertices have the same color. In other word, a k-coloring of G = (V, E) can be stated as a function C from V to a set of colors K such that |K|=k and C (u) ≠ C (v) whenever E contain an edge (u, v) for any two vertices u and v of V. The minimal number of colors k for which a k-coloring exists is called the chromatic number of G. Optimal coloring is one that uses exactly the predefined chromatic number for that graph.

For example assume we have a graph G as illustrated in fig. 1.a. This graph has four nodes (i.e., |V| = 4) and four edges (i.e., |E| = 4). The chromatic number for this graph is equal to two (i.e., |K| = 2). For coloring this graph we use two colors (red and green). The colored graph indicated in fig. 1.b.

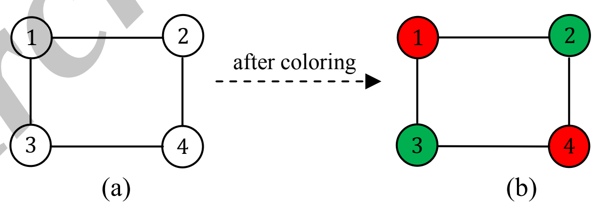



Fig. 1 A simple example of graph coloring process.
(a) graph G before coloring; (b) graph G after coloring.

There are many methods presented for Graph Coloring Problem such as: evolutionary methods (e.g. genetic algorithm [16, 17]), local search algorithms (e.g. Tabu search [18] or simulated annealing [19] and etc). In this paper to solve the graph coloring problem we used a prioritization method described in next section.

## 3. Prioritization Method

In this section, we introduce a prioritization method to solve conflicts between different aircrafts. We assign a (unique) priority for each aircraft based on its scores. The scores of each aircraft are specified based on situation of that aircraft in airspace. So that in priority allocation process if an aircraft has higher score, its priority will be higher and vice versa if total score of an aircraft be lower its priority will be lower.

We used simple score allocation criterions for each aircraft. These criterions are as follows:

- The score of an aircraft will increase if it had least distance to destination.
- This criterion is defined for prevention of congestion in airspace.
- The score of an aircraft will increase if it flies in the satisfactory weather condition.
- This criterion defined to consider environment conditions.
- The score of an aircraft will increase if it had higher speed (under valid speed).
- This criterion causes the traffic rate increases.
- The score of an aircraft increases, when the aircraft flies at higher altitude (under valid altitude).
- When aircrafts fly on higher altitude their fuel consumption decreases.
- The score of an aircraft increases, when its distance (horizontal or vertical) from the other aircrafts is higher.

In conflict resolution process, the aircraft with a lower priority must change its original flight path in order to prevent of occurring conflicts. In fact, we use a hierarchy method to resolve conflicts. Perhaps, this prioritization method seems very similar to the greedy method but this method is general and reasonable. For example, when an aircraft is closer to its destination, and had appropriate speed and minimum deviation from the mainstream, it must be serviced in first and then other aircrafts must be serviced. 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 flight paths, so these aircrafts also service immediately in least possible time. It is worthwhile to mention that we can use the prioritization method to solve conflicts without using of graph coloring problem.

## 4. Our proposed model

The block diagram of our proposed model is shown in fig. 2. As shown in fig. 2, firstly the traffic environment must be monitored and appropriate traffic information must be collected. This information provides an estimation of current traffic situation (such as, the position, direction, destination and speed of the aircraft).

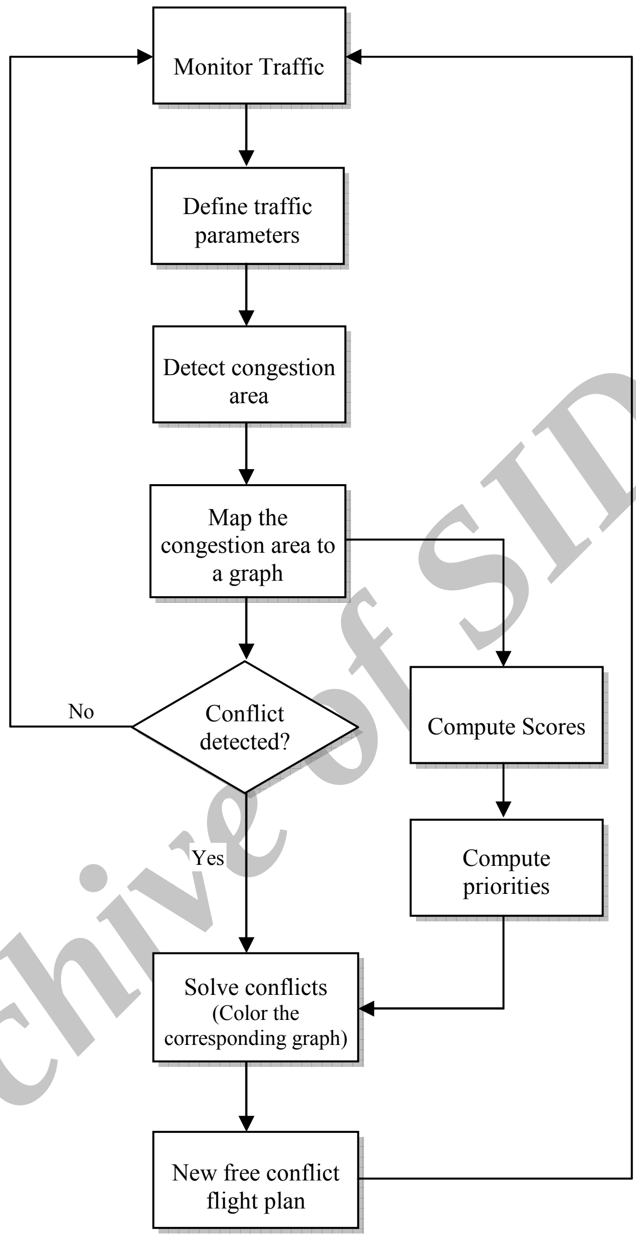



Fig. 2 our proposed model.

After this stage we specify domain of congestion area and then we map this area to a corresponding graph. Each vertex of this graph indicates an aircraft in congestion area and each edge in this graph indicate a predicted conflict in future states. In other words in this stage we map the congestion area to a state space graph.

In next step, the scores of aircrafts in congestion area are computed based on some score allocation criterions. Then based on allocated scores to aircrafts, the priority of each aircraft is specified.

In the third stage, the corresponding graph is colored using prioritization method. The output of the algorithm 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. Then, we send the new free conflict flight plan to the aircrafts on flight paths. Here we emphasize that our proposed model can interact with innovative technologies (such as multi-agent systems technology) to conflicts detection and resolution in air traffic management and also in ground traffic and related applications.

## 5. Experiments and Results

To evaluate our proposed model explained in previous sections, we used randomly generated test cases. Each test case consists of several aircrafts with different or same velocity, altitude, position and heading. These scenarios based on a test case used by krozel et al. [20, 21], and hill et al. [22], comprise of two concentric circles in open airspace. All aircrafts appears at random points on the outer circle with 100 miles, and destination of each of aircrafts at random point on inner circle with 80 miles.

We have used supposed test cases to test our proposed conflict resolution model, but we attempted to test samples very similar to the real world patterns. These test cases provide a wide range of conflict patterns that any conflict detection and resolution method must be evaluated across these test cases. Conflict resolution maneuvers used in our proposed model include small altitude and heading changes.

Table 1 shows the average of system efficiency from five simulation runs of the proposed model at each reported density. In table 1, column 1 indicates the number of aircrafts in airspace, column 2 indicates the average number of predicted conflicts and last columns indicate the efficiency of our proposed conflict detection and resolution model. The results of simulations show proposed model has high efficiency; this means our proposed model decrease flight delays and increases passengers' comfort.

Here we used a simple efficiency metric. This metric is same as the metric used in reference [20, 21]. This metric measure the degree to which an aircraft are able to track direct and optimal flight path from origin to its destination. In fact in conflict resolution process some aircrafts (in general aircrafts with lower priorities) should be deviate from their optimal and ideal mainstream in order to prevent of conflicts. In conflict resolution process our proposed model tries to decrease the number of deviations for aircrafts.

For a test case with N aircraft at the end of simulation run the efficiency of the proposed conflict detection and resolution model is as Eq.(1). In the ideal system the efficiency value equals to 1. As traffic density and number of conflicts increases the value of efficiency metric decreases.

$$efficiency = \frac{1}{N}\left(\sum_{i=1}^{N} \frac{t_{ideal}}{t_{ideal} + t_{delay}}\right) \quad (1)$$

$$t_{delay} = t_{actual} - t_{ideal} \quad (2)$$

$t_{ideal}$ = the ideal flight time for aircraft "i" (specified when the aircraft first arrived in simulation)

$t_{delay}$ = the delay time for aircraft "i"

$t_{actual}$ = the actual flight time for aircraft "i"

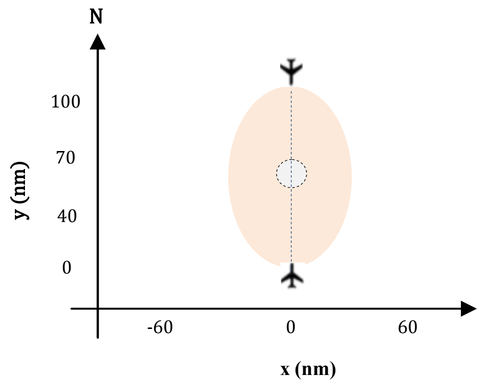
Table 1: Result for the random flight scenarios after five simulation runs.

| Aircrafts | Predicted conflicts | Efficiency (%) |
|---|---|---|
| 24 | 18 | 92.6 |
| 20 | 10 | 95 |
| 16 | 8 | 95.8 |
| 12 | 7 | 96.1 |
| 10 | 6 | 97 |
| 8 | 5 | 98 |
| 6 | 4 | 98.8 |
| 4 | 2 | 99.5 |
| 2 | 1 | 99.8 |
| 2 | 0 | 1 |

In fact our proposed model is a preliminary and abstract conflict resolution methodology; nonetheless this model has high efficiency and works as better.

### 5.1 Example Scenario

To illustrate the process of proposed prioritization method, consider two-aircraft scenario depicted in fig. 3. This example involves two aircrafts A1 and A2 that these aircrafts are headed directly their destination. We supposed these aircrafts restricted to fly in same altitude. As shown in fig. 3, if aircraft A1, A2 continue on their current heading without any deviation from their mainstreams, the aircrafts will collide. In fig. 3, if aircraft A1 and A2 continue on their previous trajectories after 7.5 minutes will collide. Aircraft A1 and A2 have 500 mph speed. These two aircrafts fly at the same altitude. Aircraft A1 has 140nm distance to its destination and distance to destination of aircraft A2 is 200nm.




| A1: | A2: |
|---|---|
| Airspeed: 500 mph | Airspeed: 500 mph |
| Distance to Destination: 140 nm | Distance to Destination: 200 nm |

Fig. 3 Example Scenario

In our proposed model we used nominal state projection method to predict and detect possible conflicts that going to occur. In first step to resolve conflicts we compute scores of aircrafts and then allocate a (unique) priority for each aircraft. For instance, here we only used "distance to destination" score allocation metric. According to this metric the score of aircraft A1 and A2 respectively is equal to 2.43 and 1.7. As we mentioned in our proposed model the aircrafts which had higher score will have higher priority and the aircrafts that had lower score will have lower priority. So aircraft A1 has higher score and subsequently its priority is equal to 1, and aircraft A2 has priority order 2. The lesser number indicates the high priority. Then to resolve predicted conflict between two aircrafts we send a command to aircraft with lower priority to deviate from its original trajectory in order to prevent collision. The aircraft which has lesser priority after receiving the deviation command, according to its conditions reply to other aircrafts acceptance or rejection message. In this scenario aircraft A2 has lower priority therefore this aircraft deviates from its mainstream, hence the predicted conflict resolved.

## 6. Conclusions

In this paper we proposed a systematic conflict resolution approach using graph coloring problem concept and prioritization method. Also in this paper we introduced some score allocation criterions and allocated a priority for each aircraft based on these criterions. The proposed prioritization method is natural, sound and flexible. This method considers traffic conditions to make the best decisions in critical environmental conditions for solving conflicts between aircrafts.

Simulation results on different test cases indicate the prioritization method can offer good efficiency and safety for resolving conflicts in free flight air traffic control method. Air traffic control is a dynamic problem, so that one problem in proposed prioritization method is that we can't accurately adjust the weight of different score allocation metrics, therefore in priority assigning process may be allocated priorities not correct.

Future work will comprise the extension of prioritization method to have high adaptability with traffic situations. Also we will focus on using multi agent systems with prioritization method to present a comprehensive model with high efficiency for conflict detection and resolution in air traffic management system.

## References


[1] K. Tumer and A. Agogino, "Improving air traffic management with a learning multiagent system", IEEE Intell. Syst., vol. 24, no. 1, pp. 18–21, Jan/Feb. 2009.

[2] Federal aviation regulations and aeronautical information manual, 2010 edition. 2009 asa, inc. Newcastle, Washington.

[3] Department of Transport, U.K., "Air traffic forecasts for the United Kingdom 1997," U.K. Government, Department of Transport, Tech. Rep., 1997. [Online]. Available http://www.aviation.dft.gov.uk/aed/air/aircont.htm.

[4] Radio Technical Commission for Aeronautics. Final report of RTCA Task Force 3: Free flight implementation, RTCA, Washington DC, Tech. Rep.,Oct. 1995.

[5] Federal Aviation Administration, "Free Flight Introduction", http://www.faa.gov/freeflight/ffov.htm, September 2011.

[6] Federal aviation administration, "advancing free flight through human factors", www.hf.faa.gov/docs/508/docs/freeflt.pdf, accessed 1 august 2011, 1995.

[7] J. Rong, J. Valasek, S. Geng, and Ioerger RT, "Air traffic conflict negotiation and resolution using an onboard multi agent system", Proceedings of the 21st Digital Avionics Systems Conference, 2002.

[8] J. Kuchar and C. Yang, "A Review of Conflict Detection and Resolution Modeling Methods"; IEEE Transactions on Intelligent Transportation Systems, Vol. 1, No. 4, December 2000.

[9] M. Nguyen-Duc, J. Briot, and A. Drogoul, "An application of Multi-Agent Coordination Techniques in Air Traffic Management", Proceedings of the IEEE/WIC International Conference on Intelligent Agent Technology (IAT'03), 2003.

[10] S. Wollkind, J. Valasek, and RT. Ioerger, "Automated conflict resolution for air traffic management using cooperative multi-agent negotiation", AIAA Guidance, Navigation and Control Conference, 2004.

[11] N. Archambault, and N. Durand , "Scheduling Heuristics For on-Board Sequential Air Conflict Solving", IEEE, 2004.

[12] H. Emami, F. Derakhshan, "An Overview on Conflict Detection and Resolution Methods in Air Traffic Management using Multi Agent Systems", Proceeding of AISP 2012, Shiraz, Iran, May 2012.

[13] T.R. Jensen, B. Toft, "Graph Coloring Problems", Wiley interscience Series in Discrete Mathematics and Optimization, 1995.

[14] D. Werra, "Heuristics for Graph Coloring", Computing Suppl. 7, pp. 191-208, 1990.

[15] M.R. GAREY, and D.S. JOHNSON, "Computers and intractability: a guide to the theory of NP-completeness", W.H. Freeman and Company, New York, 1979.

[16] D. E Goldberg. "Genetic Algorithms in Search, Optimization and Machine Learning". Addison-Wesley, Reading, MA, 1980.

[17] C. FLEURENT, and J.A. FERLAND, "Genetic and hybrid algorithms for graph coloring". Dans G. Laporte, I.H. Osman, (Eds.), Metaheuristics in Combinatorial Optimization, Annals of Operations Research, 63 : 437-441, 1996.

[18] M. Kubale, "Introduction to Computational Complexity and Algorithmic Graph Coloring", Gdanskie Towarzystwo Naukowe, 1998.

[19] M. CHAMS, A. HERTZ, D. de WERRA, "Some experiments with simulated annealing for coloring graphs". EJOR 32: 260-266, 1987.

[20] J. Krozel, M.Peters, K. D. Bilimoria,, C. Lee, , and J. S. B. Mitchell, "System Performance Characteristics of Centralized and Decentralized Air Traffic Separation Strategies," Fourth USA/Europe Air Traffic Management Research and Development Seminar, 2001.

[21] H. Emami, F. Derakhshan, S. Pashazadeh, "A New Prioritization Method for Conflict Detection and Resolution in Air Traffic Management". Journal of Emerging Trends in Computing and Information Sciences, VOL. 3, NO. 7, pp. 1042-1049, 2012.

[22] K. Archibald, c. Hill, a. Jepsen, c. Stirling, and l. Frost, "A satisficing approach to aircraft conflict resolution" , ieee transactions on systems, man, and cybernetics—part c: applications and reviews, vol. 38, no. 4, July 2008.