Conflict Resolution in En Route Traffic – A Draft Concept for an Assistance System Compatible with Solutions of Air Traffic Controllers

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1. Introduction

The primary goal of air traffic control (ATC) is safety of the flights under the controller's responsibility (Mensen 1989, pp. 3-25; Eurocontrol 1999). Such safety requires reliable detection and effective resolution of impending intersections of aircraft trajectories, which are termed 'conflicts' if aircraft do not remain separated for at least 5 nautical miles laterally[1] (Mensen 1989) and for 1000 feet vertically[2] (Eurocontrol 1998, Mensen 1989). While conflict detection has been repeatedly subjected to research and succeeds in Middle Europe practically without devastating errors, very little is known about the controller's reasons of choosing specific conflict resolutions. This situation characterises also the development of technical systems for conflict detection, and for conflict resolution: Several tools for conflict detection have been described, but there seems to exist no technical system for the support of conflict resolution that works in a controller compatible way. All known resolution

[1] This depends on radar availability and accuracy (quality of signal).
[2] That is to say, in Lower Airspace and in Upper Airspace regions with RVSM (Reduced Vertical Separation Minima).

tools work on the basis of mathematically optimising techniques (e.g. genetic algorithms, cf. Durand & Alliot 1997; Granger, Durand & Alliot 2001) and produce interesting solutions from the mathematical viewpoint, but are mostly not accepted by controllers in a real Air Traffic Control environment.

In inquiries of our research group (Fricke, Jungermann & Eyferth 2000; Fricke, Hüttig, Jungermann, Eyferth, Friesdorf, Timpe 2001), experienced controllers proved to be quite reluctant to accept proposals for conflict resolutions mediated by a system that proposed an intervention for a given conflict after calculating the feasibility of a multitude of trajectories resulting from alternative resolutions. Apparently, controllers rely on quite specific criteria in selecting one of the aircraft involved for intervention, and in choosing an appropriate change of its trajectory. They do not accept proposed solutions neglecting these criteria. This discrepancy between a technically calculated conflict resolution and the corresponding strategy of experienced controllers suggests a new approach.

In the following chapter we will sum up all alternatives for solving an obvious conflict. Then, the criteria discerning the functional quality of alternative solutions will be discussed, including the problem of optimising the screening of all alternatives. In the fourth paragraph we will depict our model of strategies for conflict resolution, generalising our observations of the controllers' solutions in such a way that a comprehensive algorithm results for a computerised support system, which is in accordance with the expectations of controllers. This algorithm will be described in the fifth paragraph.

2. Alternatives of Conflict Resolution

Controllers have different ways to handle the situation of two aircraft which approach each other, threatening to fall short of minimal distance requirements. Very rarely a controller will change the course of both conflicting partners. An alternative trajectory for one of the planes will be chosen by changing either the flight level, the speed, or the heading. Changing the course by the instructions to climb, to descent, or to change the speed does not change the projection of the course on the radar screen. However, any change of the heading results in a visible deviation from the planned trajectory and this leads to the following consequences:

1. The flight plan, defined by way points, becomes now invalid. Therefore the corresponding flight plan data on the flight strip planned in advance become invalid for further prediction of the flight path.
2. The flight requires at least one further instruction leading back to the planned route,
3. Additional mental effort and attention are required for controlling this flight, since the planned way points and the corresponding 'times over' are not available any longer for control, and new conflicts may arise if the second instruction should be retarded.
4. In many cases time and position of the entrance of the changed flight in the adjacent sector have to be negotiated with the respective controller.

An alternative to changing single flight parameters renders the more complex 'direct routing', allowing for heading directly to a distant way point, or even to the approach of the destined airport. This instruction avoids some of the problems of other heading changes, though it also implies a lateral change of the trajectory.

For a couple of years air traffic control has used ‘directs’ as standard routing alternatives, avoiding a second instruction for the return to the planned route. The input of directs are provided and supported by flight management systems in modern aircraft. However, directs have to be negotiated in many cases with the adjacent sector controller.

As said before, nearly always the course of only one partner of an impending conflict will be changed. Therefore, the decision which one of the conflicting flights should be changed, deserves special consideration. A conflict resolution, acceptable to all participants, presupposes primarily the selection of the flight to be manipulated, and secondly the choice of the parameters of this flight that should be changed. Today, air traffic control is seen as a service provider to airlines and to their customers that expect efficient and individual treatment.

In order to meet the demands of air traffic control, a multitude of flight characteristics have to be taken into account for conflict resolution. The safety of air traffic, its economy and the chance to adapt the given control procedures to the steadily increasing frequencies of air traffic demand unanimously a system of conflict resolution strategies. In the following sections we will propose such a system.

3. Dimensions and criteria for conflict resolution

Which alternatives will be considered by the controllers depends completely on the momentary traffic situation. For this reason we conducted an inquiry (Fricke, Jungermann & Eyferth 2000; Fricke et al. 2001) during a sequence of simulated frequent conflict situations to determine which parameters are used to argue about the best solution. The following parameters have been found:

Conflict Resolution = f (destination, *
aircraft (a/c) performance, *
vertical distance to sector boundary *
(ability to climb due to sector),
lateral distance to sector boundary,
attention stress,
coordination effort,
motivation,
sectorload,
weather,
procedures with adjacent sectors,
distance between conflicting a/c,
time to separation minima undershooting,
airline,
more...)

The three parameters marked with asterics (*) were judged to be of dominant importance. A special role will be assigned to these parameters in the conflict model, which we will describe in the next chapter. The most important input is ‘destination’, since this parameter determines the feasibility of further climb or descent and direction under a long term perspective. The actual chance of an aircraft to climb depends on the given sector structure, and on technical performance characteristics which can only be guessed by the controller according to his experience, except he would request such information from the pilot via radio communication. In future air traffic management systems the specific performance parameters of a given airplane will be kept available by data link (D/L). The climbing parameter is indispensable for the decision which of the conflicting courses should be manipulated, since for some planes climbing may be temporary impossible due to actual gross weight, while others may even prefer a step climb.

The knowledge of the vertical distance to the sector boundary was mentioned by the controllers as an important fact, since in the considered sector, which belongs to the lower airspace, domestic flights are not allowed to climb to the upper airspace in order to minimize coordination efforts between upper and lower sector for short distances. Due to this fact, climbing solutions can be dismissed a priori for aircraft flying on the top level of the sector.

For a systematic treatment of conflict resolution it is important to realize that not all parameters are independent from each other. The feasibility of a solution depends, for instance, on the temporal distance between the conflicting partners. A moderate change of heading is possible only if this distance between the aircraft is still large. The closer the partners are to each other the more considerable a change of the lateral course has to be. A distance of 10 nautical miles (nm) may, in the case of crossing traffic, leave not enough time for quite a number of solutions, which may however work perfectly, if 10 nm are left, in the case of catch up traffic. Generally, there exists practically no chance to develop a general mathematical formula for optimal solutions since each situation is characterized by always new combinations of temporal, spatial, and technical parameters. It seems more promising to construct a classification of situations and to provide for each situational class a number of conflict solutions which are valid for a fixed temporal distance to the timing of an impending conflict.

In our conceptual model we decided to optimize by time and not by geographic distance. All solutions are timed 12 minutes before the aircraft fall short of the legal minimal distance. This timing was chosen according to the results of an experiment determining the times of conflict recognition and conflict resolution under numerous conditions (Fricke, Jungermann & Eyferth 2000; Fricke et al. 2001). Nearly all resolutions were realized only in the last 12 minutes before falling short of the minimal distance, the vast majority occurred in the interval between 12 and 7 minutes. It seems plausible to adjust a system assisting conflict solutions rather to the timing of these actions than to the timing of conflict recognition.

4. The conceptual model

As we argued above, devising a general, weighted formula optimizing conflict resolutions for all temporal, situational and technical conditions seems neither feasible nor possible. Therefore in this chapter we will expand the Eurocontrol conflict classification (cf. table 1; Eurocontrol 1996 in Bierwagen 1999, p. 51) by adding the before mentioned criteria which proved empirically most relevant, which are destination, and performance characteristics or vertical sector limits, both defining the aircraft's chance to climb.

Table 1: Eurocontrol Conflict Classification (Eurocontrol 1996 in Bierwagen 1999, p. 51)

Typ of conflict	**direction**	**pair of a/c**	
		a/c 1	a/c 2
Typ of conflict 1	same	same level	
Typ of conflict 2	same	climb/ descent	at level
Typ of conflict 3	same	climb/ descent	climb/ descent
Typ of conflict 4	crossing	same level	
Typ of conflict 5	crossing	climb/ descent	at level
Typ of conflict 6	crossing	climb/ descent	climb/ descent
Typ of conflict 7	opposite	same level	
Typ of conflict 8	opposite	climb/ descent	at level
Typ of conflict 9	opposite	climb/ descent	climb/ descent

These criteria constitute the three dimensions of our classification scheme that will be represented as a cube (cf. figure 1). This cubic space is divided in sub-cubes, each representing a combination of parameters characterizing a specific type of conflict. The parameters characterizing the sub-cubes are systematically repeated over the axes of the total cube, depicting always four relations between two conflicting partners.

For instance, in the case of catch up conflicts on the dimension ‘destination’ the following combinations are provided as alternatives:

- the plane in front and the plane behind are both close to destination,
- the plane in front is close to, the plane behind is farther from destination,
- the plane in front is farther from, the plane behind is close to destination,
- both planes are far from destination.

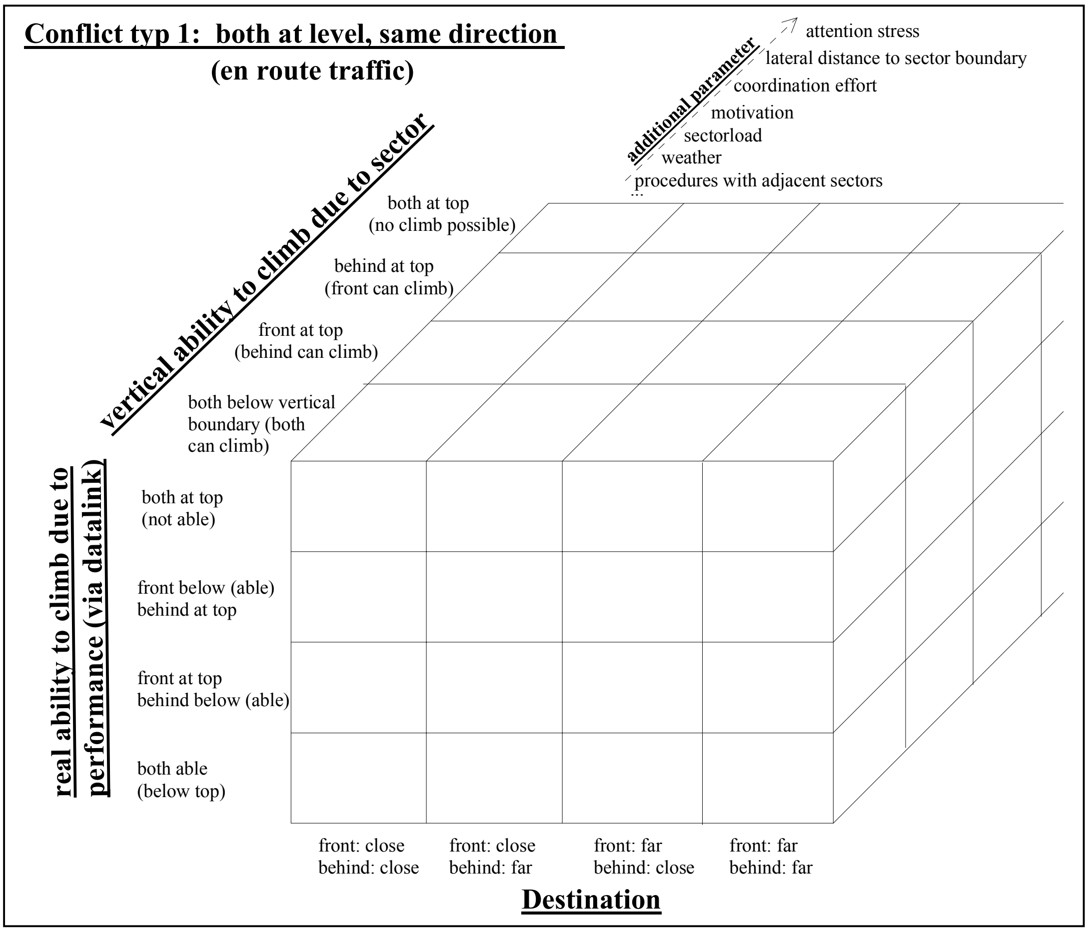

Figure 1: Conflict Classification Cube

In a corresponding way four parameter combinations are devised for the other two dimensions referring to the ability of both planes to climb. As a consequence, for every combination of parameters there exists always one and only one sub-cube. It is the decisive concept of this model to provide for each sub-cube a ranked list of conflict resolutions. These lists refer always to a specific pair of aircraft involved in an impending conflict, without taking into account the surrounding traffic. This elaborated conflict classification drastically narrows the space for searching solutions. Irrelevant options, as for instance impossible orders to climb, are excluded and the most feasible options are focused. It is obvious that the lists of preferred solutions for the numerous sub-cubes, and the differentiation of the model according to further parameters (mentioned in chapter 3) will afford extended tests of feasibility.

5. The comprehensive algorithm

In the following paragraph the capability of the conflict classification system described above will be illustrated in the context of a complex traffic environment. An eligible Medium Term Conflict Detection (MTCD) is the presupposition for an adequate conflict resolution assistance system. Our algorithm (cf. figure 2) of the conflict detection tool starts by reducing the complex traffic scenario to an isolated conflict situation, regarding just the two conflicting aircraft.

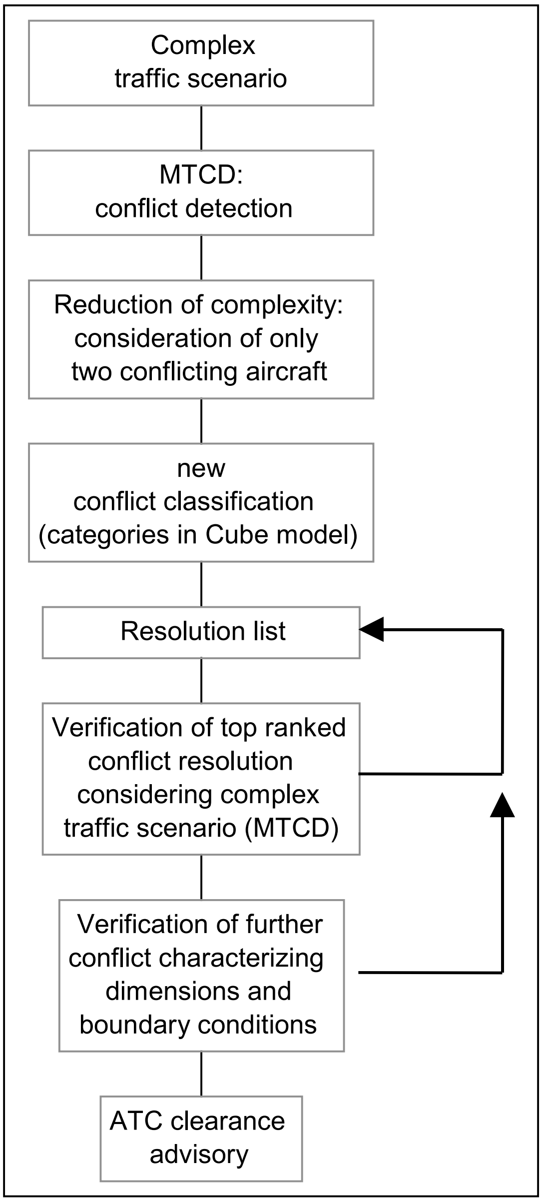

Figure 2: Conflict Resolution Model

The specific features of the conflict situation lead to an unique sub cube, containing the demanded resolution list. The top ranked solution in that resolution list is the first element to be considered. By means of a fast-time simulation tool the primary solution will be checked by the MTCD for future conflict situations. Desirable as a consequence of the applied solution is a conflict free situation, at least for a certain predetermined amount of time. In case of an induced conflict within a short period of time, the simulated solution will be abandoned and the next element in line will be picked. If the result of the verification for choosing a conflict free solution is satisfying, a verification of further conflict characterizing dimensions has to take place.

These boundary conditions can be pictured as the remaining elements of the conflict resolution function presented in chapter 3. In different steps the boundary conditions will be examined for compatibility to the complex traffic situation, e.g. sector load, coordination procedures to adjacent sectors or weather. The entire algorithm has to be passed successfully before an air traffic control clearance advisory will be transmitted to the concerned controller. As just mentioned, the controller who is responsible for his assigned sector, has still the possibility to disapprove the advised clearance. A more detailed presentation of the algorithm will be given in the appendix 1a and 1b. It may be recognized in appendix 1a, that there exists for all 9 Eurocontrol conflict classes an explicit cube with it's sub cubes. In appendix 1b it is shown that induced conflicts with a timing more than 30 min. will not be abandoned, because the further the predicted conflicts appear in the future the less is the forecasted accuracy. Without this method the expected complex traffic scenarios which will always induce conflicts after a certain period of time would automatically lead to rejection of all recommended solutions.

As the next step the verification of the boundary conditions will take place. The required termination criteria for each condition to be controlled stem from the resolution list and are linked to every single solution from the list. Is for example a heading solution the favorite conflict free solution on that resolution list, then it is applicable only up to a certain sector load, because heading solutions (as before mentioned) require a lot of attention which leads to mental stress. In case the termination criteria is greater or equal to the threshold value for sector load that certain solution will be condemned and the next in list will be checked for induced conflicts. All solutions which produce new conflicts within the next 8 min. will be condemned immediately and the next element of the resolution list will be examined. All solutions that induce conflicts within the next 8 till 30 min. will evoke a simulation with a variation of the new conflict partner under the primary goal that the new conflict partner has no disadvantage due to the trajectory change. The question which of the listed elements in the conflict resolution formula should be proofed as boundary criteria is still open and requires further inquiries.

The proceeding to reduce the complexity first, search for a predetermined resolution list in a new classification system second and bringing back the considered conflict into reality step by step by means of boundary conditions verification third appears to be an appropriate way to cope with this complex problem. This procedure is based on the idea, that an optimal solution for an isolated conflicting pair of aircraft has to be valid for a complex traffic scenario as well, if the solution has no bad effects on other participating aircraft.

6. Summary

A comprehensive classification of conflicts between aircraft has been developed as a basis of a future assisting system for en route conflict resolutions of air traffic controllers. As suggested by results of empirical studies with air traffic controllers, three parameters were added to the EUROCONTROL conflict classification. These three parameters are ‘destination’, and the capability of the aircraft to climb, as seen under two independent aspects: first, the climbing capability determined by the aircraft's momentary performance characteristics, secondly, the aircraft's distance from the upper sector limit. Since the controller’s order to climb provides usually the most feasible alternative to the momentary trajectory, these three parameters optimally support the choice of the aircraft that should be altered in its trajectory. A model of conflict resolution operating on this classification is proposed. It is indicated that it is necessary to construct feasible solutions for all instances of the conflict classification to precede to a functional assisting system.

7. References

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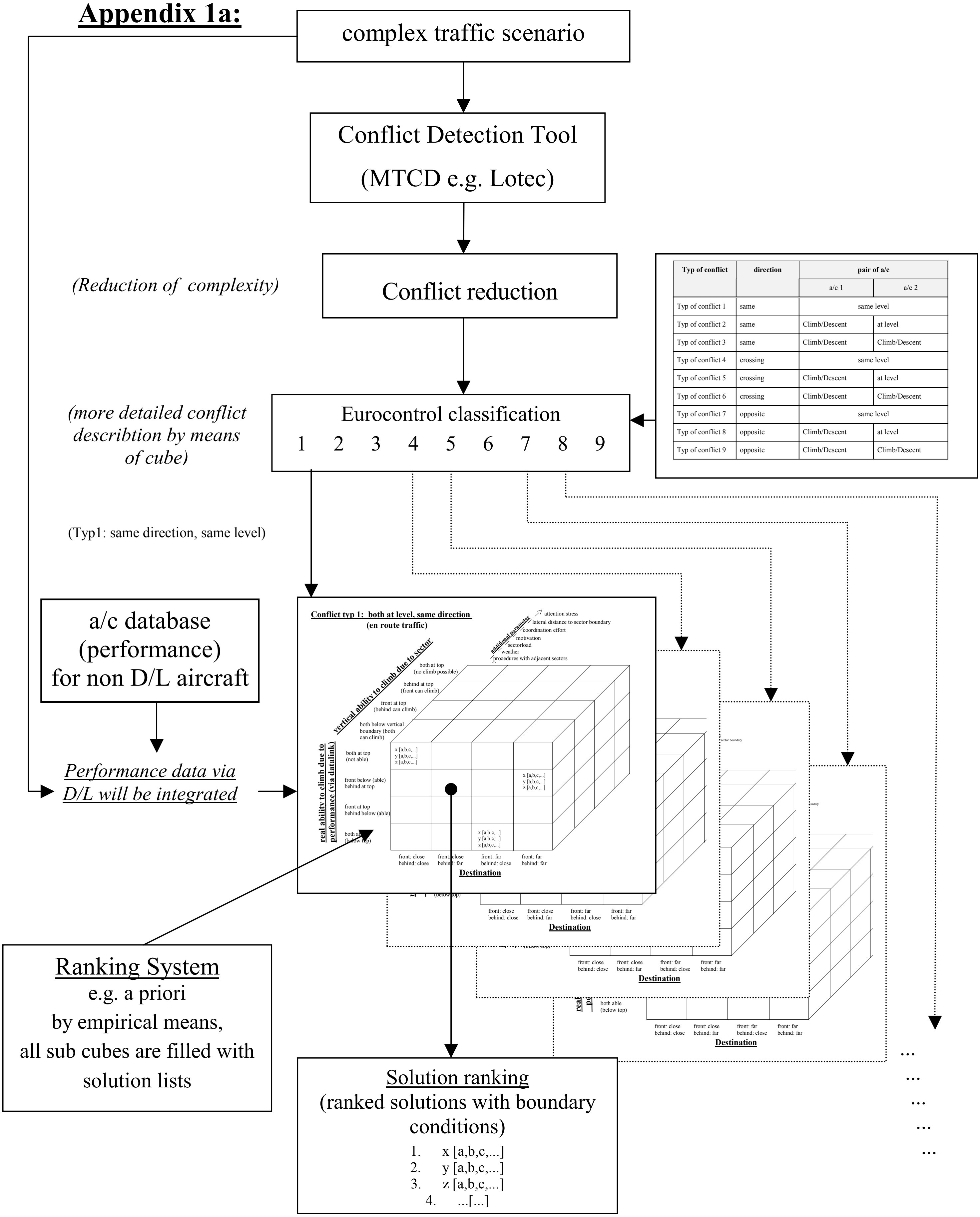
Appendix 1a:



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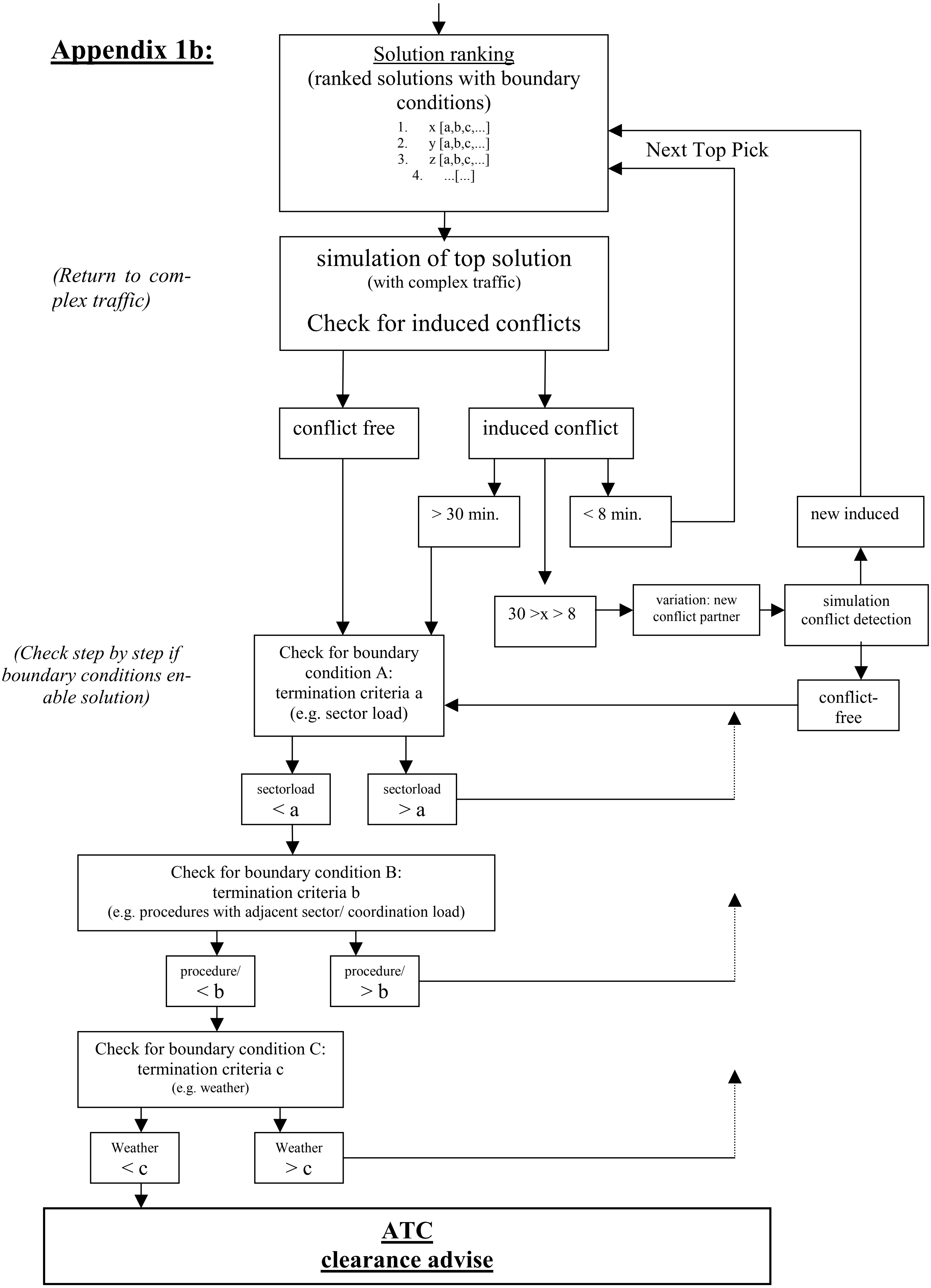
Typ of conflict 6	crossing	Climb/Descent	Climb/Descent
Typ of conflict 7	opposite	same level	
Typ of conflict 8	opposite	Climb/Descent	at level
Typ of conflict 9	opposite	Climb/Descent	Climb/Descent

Appendix 1b:


Solution ranking
(ranked solutions with boundary conditions)
1. x [a,b,c,...]
2. y [a,b,c,...]
3. z [a,b,c,...]
4. ...[...]
Next Top Pick
(Return to complex traffic)
simulation of top solution
(with complex traffic)
Check for induced conflicts
conflict free
induced conflict
> 30 min.
< 8 min.
new induced
30 >x > 8
variation: new conflict partner
simulation conflict detection
conflict-free
(Check step by step if boundary conditions enable solution)
Check for boundary condition A:
termination criteria a
(e.g. sector load)
sectorload
< a
sectorload
> a
Check for boundary condition B:
termination criteria b
(e.g. procedures with adjacent sector/ coordination load)
procedure/
< b
procedure/
> b
Check for boundary condition C:
termination criteria c
(e.g. weather)
Weather
< c
Weather
> c
ATC
clearance advise