Identification of Air Traffic Controller Conflict Resolution Strategies for the CORA (Conflict Resolution Assistant) Project

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Abstract

In order to explore the potential for a human centred design of conflict resolution advisor, or 'assistant', a project has been undertaken to elicit from controllers directly their resolution strategies for a number of scenarios. Since this is a European project, it was necessary to consider a number of different countries. Therefore controllers from seven countries were interviewed individually and in groups, using a standardised set of conflict scenarios. These scenarios ranged from straightforward 'classical' scenarios such as 'head on' and 'catch-up', to multiple aircraft conflicts, and conflicts occurring in constrained airspace.

This work, currently being analysed, will establish the degree of agreement between different countries, and the range of preferable and allowable resolution strategies for a set of scenarios. It will also establish what controllers would *not* do to resolve conflicts, thereby identifying potential advice that would jeopardise the controllers' trust in the CORA support environment.

The paper will outline the methodology used, and will focus on the initial results from the interview process. These results include some of the explicit rules that controllers pay attention to, as well as the implicit strategies they adopt when solving conflicts. It will also show the factors controllers consider when carrying out conflict resolution. This information is intended to inform development of CORA, and may also be of benefit in the training of ab initio controllers.

Introduction

European air travel is predicted to double in capacity over the next ten years, placing considerable burden on the current air traffic management system, and controllers. One approach to alleviate this burden and to reduce controller workload, is to provide automated support, in the form of computerised tools, for key tasks, such as conflict detection, and conflict resolution. Such tools, in theory, will allow the controllers to manage more aircraft and to avoid conflicts, and at the same time to give a better service to aircraft in terms of preferred routes and minimised deviations.

Currently, controllers are masters at real-time conflict detection and resolution, and this expertise in these particular system functions is the result of rigorous selection and intensive training in air traffic control over a prolonged period. Conflict detection and resolution are indeed seen as core functions of the controller today, i.e. controllers, when asked to define their job simply, often say 'separating aircraft'. Any tools that therefore purport to support such functions have two main obstacles to overcome. The first is the development and provision of a viable alternative that is at least as good as controller expertise (and preferably better). The second is ensuring that such tools will be used by controllers, when those very tools can be seen as a threat to those same controllers.

Currently, assistance with conflict detection exists in many places via various forms of short term conflict alert, and in several air traffic centres, medium term conflict detection is now being piloted and implemented. It is too early to say whether the medium term conflict detection tools will be successful. However, assuming they are at least moderately successful (i.e. they enhance air traffic management and are used effectively by the controllers), the next step to consider is conflict resolution.

A prior European study (Nijhuis, 2000) called the RHEA project (Role of the Human in the Evolution of ATM) considered future automation prospects and their likely impact on the controller. The study tried to determine what level of automation would result in best performance. Different levels were considered, from full automation to fully manual, but with many levels in between, such as computer-generated advice, with the controller making the decision, to the computer implementing its own decision unless the controller vetoed it. There were also some flexible levels of automation (e.g. the automation taking over when the controller's workload became too high, or when the controller requested it). These different levels were evaluated qualitatively, and also a predictive error analysis was carried out to try to determine the best level of automation (Kirwan, 2001a). The results were that the best levels involved the computer or machine giving advice, and then the controller deciding to accept or reject it. Furthermore, one condition that favoured particularly well at this level of automation, was called *'cognitive tools'*. The concept of a cognitive tool is that the tool itself, which gives advice to the controller, is derived around the controller's own mental model of how the situation should be resolved, as opposed to being derived from purely mathematical models etc. Such an approach can be seen as a form of 'Human Centred Automation' (Billings, 1996). The EUROCONTROL Conflict Resolution Assistant (CORA) Project aims therefore to produce a controller-centred approach to conflict resolution (for a fuller justification of this rationale, see Kirwan 2001b).

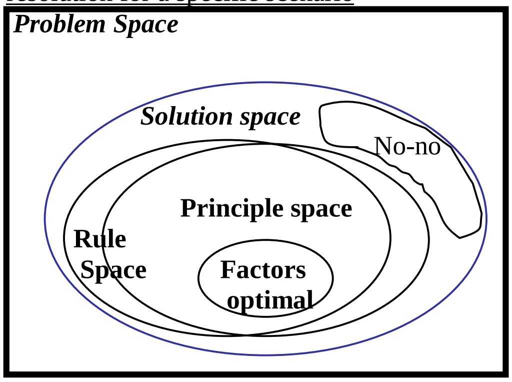
Having decided to develop a controller-centred approach, the next question becomes one of how to elicit the expertise from controllers. This is discussed in the next section.

Approach

The basic approach adopted was to elicit the expertise from controllers directly. This followed on from a literature review (Kirwan 2001a) which showed that there was little available and consolidated evidence of how controllers solve the variety of conflict solutions they can be faced with, with the exception of the AERA and PARR programmes of work (see Kirk et al, 2000). Since these works were of US origin, with different operational cultures and constraints than in Europe, it was decided to attempt to elicit the information more directly from controllers.

Before continuing, the types of information useful for a conflict resolution algorithm need to be elaborated. First it is useful to know the rules that controllers apply when carrying out conflict resolution. Second, the types of solutions controllers can make for a range of conflict scenarios, and third, the principles they use to pick between those solutions, are of interest. Fourth, the types of solutions that are theoretically possible, but which real controllers would never do, called 'no-no's' in this project, are important for retaining trust in the CORA support environment. Fifth, the detailed scenario and airspace-specific factors that (along with the principles and rules) determine the exact resolution picked, and its details, are of significant interest. These proposed types of information are highlighted below in Figure 1.

Figure 1: Types of information used in conflict resolution for a specific scenario



Therefore, for a particular scenario, there is a 'solution space' which defines the logical solutions that will avoid the conflict. Some rules may rule out some potential solutions (e.g. the semi-circular rule). However, the principles adopted by controllers are not completely over-lapping with the official rules. For example, many controllers will accept an 'Opposite Direction Level' which violates the semi-circular rule temporarily, to achieve expeditious and still safe conflict resolution. Some potential solutions would be unacceptable to controllers (the 'no-no's'). The controllers will then tend to work within the principle space and optimise factors within that space.

As an example, in a two-aircraft 90 degree crossing situation, there are many potential solutions using turns, speed, and level, applied to one or both aircraft. A controller might elect a solution to turn one of the a/c left. The controller may use the simple principle of turning one a/c behind the other, usually the one to get to the crossing point last. However, the first question is why left and not right, and why a turn and not a climb or descent, or a speed manipulation, or even a combination of these? Perhaps it is because the left turn takes this aircraft closer to its intended destination than a right turn, and that small turns are seen as more efficient for the aircraft than undesired level changes. There could be other factors involved such as wind direction. If there was enough time before the conflict, a mathematically plausible solution might be to accelerate this aircraft and cut across in front of the other one. But it might be that few controllers would countenance such a resolution, seeing it as dangerous and against their training, no matter what the predictions say. This example highlights the size of the solution space (many potential solutions), the application of principles (turn the second one behind), no-no's (don't cut in front), and the factors that fine-tune the resolution type (in this case 'turn') to go left rather than right. The idea behind CORA is that its algorithm should consider such information and narrow down the solution space to a few resolutions that a controller would find reasonable, and hopefully 'smart'. Having defined the types of information desired, the next question is how to elicit such information.

Two methods were considered. The first would have entailed expensive laboratory simulator-based studies of controllers solving conflicts in realistic and dynamic airspace scenarios. The second was usage of relatively simplified scenarios shown statically to controllers. The advantage of the former approach is contextual realism. There were two main potential disadvantages however. The first was the expense, which would be considerable in terms of simulation study preparation and running time and controller resources. The second was that many of the factors that affect and influence conflict resolution might be over-looked, because they are embedded in the scenario context, and would remain implicit. For example, a controller might be using 'wind direction' as a factor, but actually be unaware of the fact. In a simulation it would be hard to realise that such a factor was being used, as the analyst might not spot it, and the controller might not mention it. An alternative approach therefore is to use a simpler set of static scenarios that are generic and minimally described. Then, the controller has to ask questions to determine the status of factors important to that controller. This is known as the 'with-held information technique' and has been used before in air traffic control research (Lamoureux et al, 1999).

Scenarios

A number of scenarios were highlighted in the literature review (e.g. head-on, crossing, catch-up, etc.). These were presented individually in simplified format to a set of controllers as a pilot trial of the procedure. This led to two changes in the scenarios. First, they were made more realistic, with aircraft types and status information etc., and the scenarios were mapped onto a hypothetical and simplified airspace map. Second, the main scenarios were presented in two contexts: a simple two aircraft setting, and a more realistic identical conflict scenario but with more surrounding aircraft, some of which 'blocked' certain resolutions from taking place. This 'progressive' strategy enabled the main solutions to be elicited at the first (simple) presentation, effectively defining the solution space referred to earlier. The second more detailed scenario would then be more helpful in eliciting factors, and seeing how the controllers would narrow down the solution space to get to a reasonable and safe/efficient resolution. Six scenarios were developed with these two formats, and there were two additional scenarios that contained multiple conflicts. These last two scenarios were complex and had a narrow solution space, and were aimed at looking at how controllers prioritised conflicts, and whether they approached multiple conflicts 'pairwise' or globally'. An example of one of the scenarios is shown in Figure 2.

The scenarios were shown to controllers in the same progressive sequence, moving from catch-up, to head-on, to narrow angle convergence (crossing), to a climb-through, a descend-through, and a right-angle crossing and climb-through, and then two complex scenarios with multiple aircraft in multiple conflicts.

Subjects

Since CORA is a pan-European project (i.e. aimed at supporting a number of European States), it was necessary to consider a number of different countries.

Therefore controllers from seven countries were interviewed individually and in groups, with the same standardised set of conflict scenarios. In two cases group sessions could not be carried out due to resource pressures during busy summer periods. The focus was on En Route (Area) Control, but in one case a group of Terminal Manoeuvring Area controllers (all of whom also had Area experience) were interviewed. For five of the countries the 'look ahead' time was 5-12 minutes, and for Shannon and Maastricht (which have some larger and longer sectors) the look ahead time was 8 – 14 minutes, depending on the scenario.

Table 1 shows the countries and centres visited during the study, the number of controllers that participated in the individual interviews (typically 90 minutes long) and the group interviews.

Table 1 – Participation in the study

Country	ACC	Individual interviews	Group interview
Area Control			
Italy	Rome[1]	6	Y (n=8)
Sweden	Malmo	6	N
UK	NERC	6	Y (n=3)
Portugal	Lisbon	6	Y (n=5)
France	Athis Mons	6	Y (n=4)
Ireland	Shannon	5	Y (n=5)
Holland	Maastricht	6	N
Terminal Manoeuvring Area (TMA) Control			
Sweden	Gothenburg (TMA)	4	Y (n=4)

Procedure

After having been briefed on the nature of the study, and being given an example of the scenarios, the controllers were asked to solve each scenario in sequence. The interviews were confidential, although number of years controlling experience was noted. There was no time pressure, except the controller's own constraints. The time to complete the scenarios was between 38 minutes and 2.5 hours. The group sessions typically lasted 2 hours.

The controller was asked how (s)he would resolve the scenario. The answer, due to the minimal amount of information in the scenario representation was often 'that depends…'. The controller would then ask questions or make assumptions, until he or she was happy enough to state the principal resolution he or she would propose. The interviewer would note the order of questions/assumptions and list these as 'factors' affecting the determination of the resolution advisory.

The controller interviewee was then probed for more than one solution, and these solutions were then placed in rank order. Typically there were around three potential solutions for each of the simple problem scenarios, less for the more complex ones.

[1] Participants in Rome were from four different Italian ACCs.

The last part of this particular interview approach was to ask the controller if there were any actions (*no-no's* already referred to) that should definitely not be executed. Such potential resolution advisories might appear reasonable to a non-controller and might even appear mathematically optimal, but would be seen as incorrect by a controller, and would be rejected immediately and could cause loss of trust in the tool.

Results

The (interim) results are presented in three sub-sections. The first concerns the rules that controllers appear to pay attention to. It must be said that there appeared to be less rules used than expected: the main controller aim is to separate aircraft, and to do this first safely, and then expeditiously. Many rules appear sacrificial as long as these two requirements are met.

The second section presents the strategies or principles mentioned by, or elicited from, the controllers during the interview process. These have been grouped loosely into a hierarchical arrangement from generic to specialised scenario-specific strategies.

The third section shows the main factors that have been elicited from all the interviews (individual and group), and their relative importance according to how often they were mentioned during the scenarios.

Rules

The rules used by the controllers during the study have been grouped into two types – formal rules, and informal ones. These are shown below:

Formal Rules

- Semi-circular rule
- Letters of agreement
- Open Flight Information Region Constraints
- Quadrantal rule
- Proximity to edge of airways
- Separation against military airspace
- Speed regulations
- Rules of the air (pilot rules)
- Locking a/c on headings
- Minimum descent rates
- Co-ordination of vertical changes

Informal rules

- The 1 in 60 rule
- Landing a/c have priority
- Turbulence priorities
- Parallel headings
- Slower one behind
- Maintaining a/c on track
- Deal with head-on's first
- Vectoring first
- Vertical rate fixing
- Avoidance of head-on tracks
- Vectoring both a/c

There was much more variance of adherence to the informal rules, as one would expect. This variance seemed to be more to do with the local airspace and air traffic needs than with cultural training aspects for example.

A more general impact of the rules elicited, is that their variety highlights the need to tailor CORA or its algorithm to the local considerations and constraints in operation in an ACC. Even the ubiquitous semi-circular rule has a number of different interpretations, depending on the prevailing traffic flows in the ACC region.

Principles

Many principles were identified during the interviews. These were then grouped into five categories in terms of increasing specialisation. This was done to aid the integration of such principles into the algorithm or its constraints. The categories were as follows:

1. Generic & non-contextual (n=17)
2. Generic and contextual (n=38)
3. Country-based (n=4)
4. Airspace-based (n=8)
5. Scenario-based (n=42)

Examples of the principles are given in Table 2. The principles ranged from very high level strategies ('keep it simple') to more contextual scenario specific ones (e.g. 'don't rely on climb performance above FL200'). Many of the principles were only cited by an individual controller. This suggests that there is a high degree of individuality about these principles, or else that controllers do not tend to cite them as they are 'implicit' or 'tacit' knowledge rather than formal principles. It would be interesting to carry out a separate exercise to see how controller instructors view these principles, and to consider their suitability for use in training.

In general though, many of the principles support each other and do not conflict, and offer potentially useful ways of narrowing down the solution space in conflict resolution problem analysis.

Factors

A large number of factors which can influence conflict resolution choice were elicited during the interviews. However, unlike principles, there was more convergence on key factors, and there was a high preponderance of certain factors on certain scenarios. The main factors, in terms of information asked for, are shown in Figure 3. There were many other factors that were cited less often, but will be still of interest to the CORA algorithm, as they represent controller expertise. As an example, climbing a/c have inertia, and can over-shoot their intended level – such insight is relevant when levelling off a climbing aircraft one flight level below another, for example.

Some factors were less focused on the specific scenarios, but are interesting, e.g. 'trust in computers'. There were also a few citations of culturally-linked aspects, such as airline type, European and non-European a/c, etc., and whether the pilot was normally English-speaking etc. However, such factors were the exception rather than the norm.

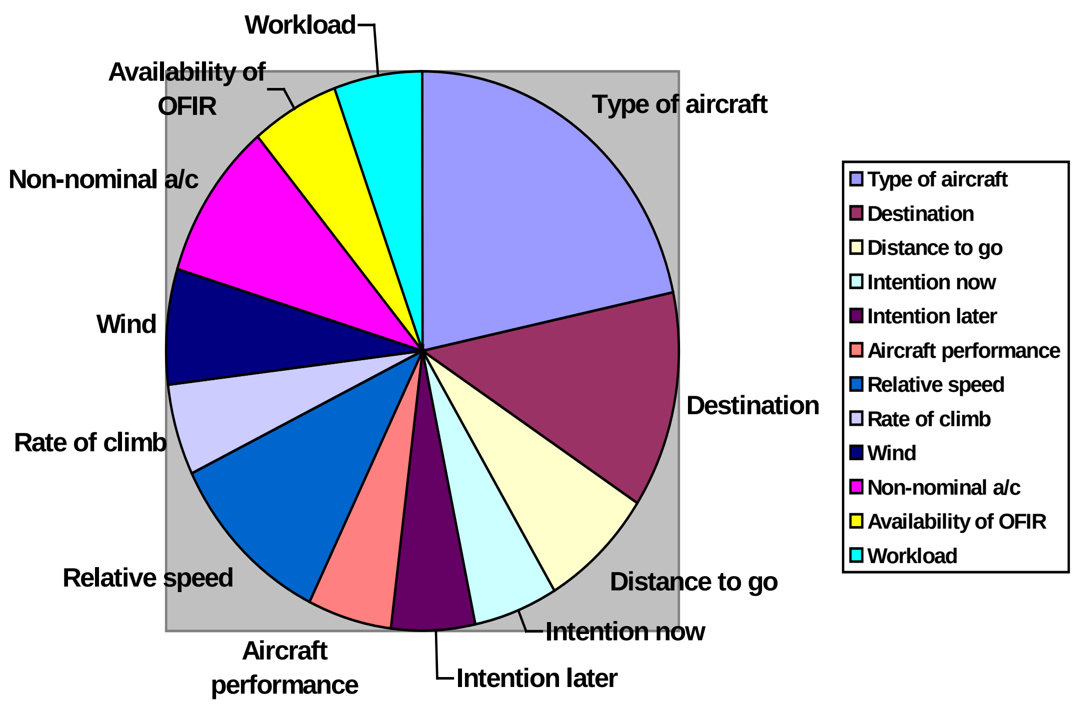
Conclusions

The study has successfully elicited rules, principles and factors that affect conflict resolution performance. This information will be used to inform the CORA algorithm, to lead to the development of a controller-centred approach to conflict resolution assistance.

There remain data to be analysed. In particular, the actual resolutions controllers used for each conflict in each scenario, and the degree of agreement for such solutions. Such information can help to determine optimum solutions and their ranking, so that controllers can be presented with the best solutions in ranked order. Additionally, there are the 'no-no's' to be analysed – these need to be accounted for by the CORA support environment.

One insight gained so far, is that practices in different locations do vary considerably, and it may be that CORA will need to be tailored to fit these non-homogeneous regions.

Figure 3 – Main factors – area representing number of citations



Lastly, the controllers were asked about the need for such a system as CORA. As usual, the controllers gave their honest opinions on the matter. All agreed though that it should remain an En Route control-based tool, and all also thought this was a challenging project area. Some were not convinced of the need for such a system, whereas others would like it sooner rather than later. Work is now continuing on developing the detailed requirements for a working CORA support environment, and in carrying out initial safety analysis of the proposed system.

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Table 2 – Extract of Principles & Strategies used by controllers

Category	Ref.	Principle	No. of controllers	Scenarios
Generic & Non-Contextual		**Simplicity**		
	GN1	Keep it [the resolution] simple	7	1a, 2b, 3b, 8
		Deciding who to move, and how	1	
	GN2	Penalise the one that needs something (leave alone the ones in steady state)	6	1b, 2a, 5a,
	GN3	Inconvenience least people	1	2a
	GN4	Minimise the penalty for a/c	3	1a, 2a, 3a
	GN5	Give them what you can	2	1a, 4b
	GN6	Change in line with a/c intentions	1	3a
		Workload management		
	GN7	Keep workload manageable	2	2a, 5b
		Safety		
	GN8	Make it safe first, before go further [with additional considerations etc.] [safety before convenience]	3	2b, 5b
	GN9	Need to have a fail-safe plan B	2	2a, 4b, 8
	GN10	The bottom line is safety	1	4b
	GN11	Things can deteriorate [Murphy's Law]	2	3b, 4a
		Understanding		
	GN12	Determine who is in the game	2	4b, 5b
	GN13	Reduce the complexity (eliminate problems)	2	7, 8
Category	Ref.	Principle	No. of controllers	Scenarios
Generic & Contextual		**Narrowing the problem & resolution space**		
	GC1	Check other a/c and rule them out (narrow down the problem space) – identify the conflict pair(s)	6	1b, 2b, 3b, 4b, 8
	GC2	Minimise the number of a/c to move	3	1b, 2a, 4b, 5b,
	GC3	Look for one key action that will resolve the situation	3	4b, 5b, 7
	GC4	Leave the over-fliers alone	1	5a
		Controlling the problem		
	GC6	Give initial (level) change early on and then fine-tune later	2	5a, 6a
	GC7	Solve easy conflicts first	1	8

Table 2 - continued – Extract of Principles & Strategies used by controllers – *continued*

Category	Ref.	Principle	No. of controllers	Scenarios
		Controlling the resolution		
	GC10	Prefer resolutions which require less co-ordination	2	4a, 3a
	GC11	Decide the priority of communication	1	7
	GC12	Hand-off traffic in a way that is acceptable to next sector	2	1a
	GC15	Lock a/c on headings when using vectors	1	4a
		Lateral dimension		
	GC19	Minimise additional track miles flown	1	4a
Generic & Contextual		**Vertical dimension**		
	GC21	Continuous climb and descent profiles are preferable	3	4a, 2b
	GC22	When complex, use vertical separation	2	7, 2b
		Speed dimension		
	GC25	Speed solutions – at cruising altitude their speed envelope is small, e.g. 10 – 20 kts, therefore cannot change much	1	3b
	GC26	If using the OFIR, use a very simple solution	1	4b
	GC27	Level changes can introduce extra conflicts	1	1b
	GC28	Leave the over-fliers alone	1	5a
		Emergencies		
	GC30	With an emergency, keep it simple and safe	1	6b
	GC31	Handle the emergency first – everyone else can wait	4	6b
		Pairwise approach		
	GC34	Solve conflicts in pairs	3	2a, 7, 8
	GC35	Solve pairwise, but if many pairs, plan B's will not work. Therefore need a plan C	1	2a
		Global approach		
	GC36	Aim for a more global solution – not penalising anyone	1	5b
	GC37	Will not go down to the minimum of 5nm – need more than this to be safe	1	1b
	GC38	Not simply pairwise – consider the priorities of the pairwise solutions, and the impact of each resolution on the remaining pairs	1	8

Table 2 continued – Extract of Principles and Strategies Used by Controllers

Category	Ref.	Principle	No. of controllers	Scenarios
Scenario-based		**Crossing conflicts**		
	S1	Turn slower a/c behind (in order to minimise extra distance flown)	1	3a
	S2	Stabilise until after crossing points	1	5b
		Converging/Head-on		
	S3	When there are few a/c, a temporary ODL is acceptable	1	3a
	S4	Ask the pilot whether (s)he prefers a level change or a vector	2	1b, 3b
	S5	Normally if vectoring, vector both a/c	1	3b
	S6	In turbulence, not always good to have level solutions, since they may not maintain their levels	1	7
	S8	Solve the head-on first	1	8
	S9	Turn faster one direct to route so leaves sector before slower one on same route	1	1b
	S10	Safe if locked on headings	1	2b
	S11	Sometimes not changing levels on a/c means you don't have to worry about them	1	4b
	S12	Give a short-cut which can end the conflict	1	4a
	S13	Better to put a/c behind than trying to go through the middle	1	3b

Biographies

Barry Kirwan obtained his Bsc in Psychology from Southampton University in 1981, then a masters in Ergonomics at Birmingham University in 1982. He worked in offshore and nuclear power industries for the next 4 years, before heading a Human Factors Unit at British Nuclear Fuels for five years. He then lectured at University of Birmingham in Human Factors and Human Reliability and finished his PhD, before moving to become Head of Human Factors in NATS, the UK's main Air Traffic Service provider. In 2000 he moved to work as a consultant with Eurocontrol, first in Brussels and now with the EEC in Bretigny.

Mary Flynn has a Bsc in Psychology from Open University (1998) and a post graduate Diploma in Management, Open University (1999). She has 13 years experience in a wide range of functions in private sector service industries (banking, brewing, distribution). She worked for one of Europe's leading business schools, INSEAD as Course Manager: Operations Management, Project Management and Quality for four years. Mary joined EUROCONTROL in 1992 and worked in Human Resources, responsible for Training and Recruitment at Experimental Centre, Bretigny. In this role she gained experience in applied psychology and occupational psychology. She has been Project Manager for the Conflict Resolution Assistant – Level 2 (CORA 2) project since May 2000.

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FIGURE 2 – EXAMPLE OF SCENARIO (2B)