AD-A261 177

(2)

DOT/FAA/NA-92/2
DOT-VNTSC-FAA-92-14

Automation
Engineering Division
Washington, DC 20591

Controller Response to Conflict Resolution Advisory

RSPA/VNTSC

ATC HUMAN FACTORS PROGRAM

DTIC
S ELECTE D
FEB 1 1 1993
C

Kim M. Cardosi
Judith Bürki-Cohen
Pamela W. Boole
Jennifer Hourihan
Peter Mengert
Robert Disario

U. S. Department of Transportation
Research and Special Programs Administration
John A. Volpe
National Transportation Systems Center
Cambridge, MA 02142

DISTRIBUTION STATEMENT A
Approved for public release;
Distribution Unlimited

Final Report
December 1992

93-02563

BEST
AVAILABLE COPY

This document is available to the public
through the National Technical Information
Service, Springfield Virginia 22161

93 2 10 080

U.S. Department of Transportation
Federal Aviation Administration

NOTICE

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no liability for its contents or use thereof.

NOTICE

The United States Government does not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE
December 1992

3. REPORT TYPE AND DATES COVERED
Final Report - Jan. 1992 - Apr. 1992

4. TITLE AND SUBTITLE
Controller Response to Conflict Resolution Advisory

5. FUNDING NUMBERS
A2035/FA2L3

6. AUTHOR(S)
Kim M. Cardosi, Judith Bürki-Cohen*, Pamela W. Boole*, Jennifer Hourihan**, Peter Mengert, Robert DiSario

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Department of Transportation
Research and Special Programs Administration
John A. Volpe National Transportation Systems Center
Cambridge, MA 02142

8. PERFORMING ORGANIZATION REPORT NUMBER
DOT-VNTSC-FAA-92-14

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Department of Transportation
Federal Aviation Administration
Automation Engineering Division
800 Independence Avenue, NW
Washington, DC 20591

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
DOT/FAA/NA-92/2

11. SUPPLEMENTARY NOTES
* Dynatrend
**Brown University

12a. DISTRIBUTION/AVAILABILITY STATEMENT

This document is available to the public through the National Technical Information Service, Springfield, VA 22161

12b. DISTRIBUTION CODE
ANA-100

13. ABSTRACT (Maximum 200 words)

Conflict Resolution Advisory (CRA) is an automated software aid for air traffic control specialists at air route traffic control centers (ARTCCs). CRA calculates, validates, and displays to the en route controller a single resolution for predicted separation violations detected by the conflict alert (CA) function. This simulation study was conducted to determine controller-response time to a CRA message. This response time is the total time required for controllers to notice that the advisory is present, to read and comprehend the text message, and to decide that the resolution is acceptable. The mean time required to decide that a resolution was acceptable was 18 seconds (S.D. = 8.6). This result is compared to the response time of 13 seconds (S.D. = 6.2) observed with the CRA prototype and the implications of these results for estimating the delay between CRA onset and pilot response are discussed. Controllers' opinions regarding the CRA function are also reported.

14. SUBJECT TERMS
Controller-Response Time, Conflict Resolution Advisory

15. NUMBER OF PAGES
32

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unclassified

PREFACE

Conflict Resolution Advisory (CRA) software is intended to provide the air traffic control (ATC) specialist at air route traffic control centers (ARTCCs) with a suggested maneuver to prevent separation violations between aircraft. CRA calculates, validates, and displays a single resolution for potential separation violations predicted by the conflict alert (CA) function. For this purpose, it is critical to know the time required for the ATC specialist to process and transmit the maneuver and for the pilot to acknowledge it. The controller- response time, that is, the time required for a controller to notice, read, comprehend and evaluate the advisory, was determined in a previous simulation study using the prototype CRA software (DOT/FAA/NA-92/1). The transmission and pilot-response time was determined by analysis of actual voice tapes of ATC communications (DOT/FAA/RD-91/20). The purpose of this simulation was to validate the controller-response time found with the CRA prototype software using the enhanced CRA software (CRAE). Data were also collected on controller opinion on the CRA message format and on CRA in general.

This study was sponsored by the Federal Aviation Administration's (FAA's) Automation Engineering Division (ANA-100). We thank all the people who contributed to the development and conduct of this study, including: Larry Reeves of ANA-130 for his technical guidance and for providing the resources necessary to complete the study; John Moore of Martin Marietta for coordinating and guiding the efforts of the many key participants; James Valleley and his crew from the FAA Technical Center Television Facility for working double shifts to videotape the test sessions; Wayne Nowicki and Pat Lewis of ACN-110 for their support and the FAA headquarters and MiTech personnel who participated as observers.

There were numerous participants from Fort Worth ARTCC, without whom this study would not have been possible. We are particularly grateful to Charles Dukes for his constant supervision and expert technical support; the scenario developers Larry Foreman, Darrell Meachum, Pamela Shedden, and Mike McCully, who excelled in choreographing realistic traffic situations; the six tireless DYSIM operators Richard Conley, Alan Weaver, David McKillip, Robert Lee, Robert Pinder, and Kirk DeWeese; and, of course, the eight talented and patient test controllers.

Finally, we thank Ron Tornese of Mitre and Alan Yost for their technical guidance, and Jim Lavery and Harry D'Ascenzo of Computer Sciences Corporation for their assistance.

Accession For
NTIS GRA&I ☑
DTIC TAB ☐
Unannounced ☐
Justification
By
Distribution/
Availability Codes
Dist | Avail and/or Special
A-1

DTIC QUALITY INSPECTED 3

METRIC / ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)
1 inch (in) = 2.5 centimeters (cm)
1 foot (ft) = 30 centimeters (cm)
1 yard (yd) = 0.9 meter (m)
1 mile (mi) = 1.6 kilometers (km)

AREA (APPROXIMATE)
1 square inch (sq in, in^2) = 6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2) = 0.09 square meter (m^2)
1 square yard (sq yd, yd^2) = 0.8 square meter (m^2)
1 square mile (sq mi, mi^2) = 2.6 square kilometers (km^2)
1 acre = 0.4 hectares (he) = 4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)
1 ounce (oz) = 28 grams (gr)
1 pound (lb) = .45 kilogram (kg)
1 short ton = 2,000 pounds (lb) = 0.9 tonne (t)

VOLUME (APPROXIMATE)
1 teaspoon (tsp) = 5 milliliters (ml)
1 tablespoon (tbsp) = 15 milliliters (ml)
1 fluid ounce (fl oz) = 30 milliliters (ml)
1 cup (c) = 0.24 liter (l)
1 pint (pt) = 0.47 liter (l)
1 quart (qt) = 0.96 liter (l)
1 gallon (gal) = 3.8 liters (l)
1 cubic foot (cu ft, ft^3) = 0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3) = 0.76 cubic meter (m^3)

TEMPERATURE (EXACT)
$[(x - 32)(5/9)]$ °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)
1 millimeter (mm) = 0.04 inch (in)
1 centimeter (cm) = 0.4 inch (in)
1 meter (m) = 3.3 feet (ft)
1 meter (m) = 1.1 yards (yd)
1 kilometer (km) = 0.6 mile (mi)

AREA (APPROXIMATE)
1 square centimeter (cm^2) = 0.16 square inch (sq in, in^2)
1 square meter (m^2) = 1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2) = 0.4 square mile (sq mi, mi^2)
1 hectare (he) = 10,000 square meters (m^2) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)
1 gram (gr) = 0.036 ounce (oz)
1 kilogram (kg) = 2.2 pounds (lb)
1 tonne (t) = 1,000 kilograms (kg) = 1.1 short tons

VOLUME (APPROXIMATE)
1 milliliter (ml) = 0.03 fluid ounce (fl oz)
1 liter (l) = 2.1 pints (pt)
1 liter (l) = 1.06 quarts (qt)
1 liter (l) = 0.26 gallon (gal)
1 cubic meter (m^3) = 36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3) = 1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)
$[(9/5)y + 32]$ °C = x °F

QUICK INCH-CENTIMETER LENGTH CONVERSION

INCHES	0	1	2	3	4	5	6	7	8	9	10

CENTIMETERS 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 | 25.40

QUICK FAHRENHEIT-CELSIUS TEMPERATURE CONVERSION

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

For more exact and/or other conversion factors, see NBS Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50. SD Catalog No. C13 10 286.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

Conflict Resolution Advisory (CRA) is an automated software aid for air traffic control specialists at air route traffic control centers (ARTCCs). CRA calculates, validates, and displays to the en route controller a single resolution for predicted separation violations detected by the conflict alert (CA) function. This simulation study was conducted to determine controller-response time to a CRA message. The response time is the total time required for controllers to notice that the advisory is present, to read and comprehend the text message, and to decide that the resolution is acceptable.

Eight full performance level air traffic controllers were presented with six different two-hour traffic scenarios ranging from moderately high to very high levels of traffic load and complexity. They were asked to read and evaluate the CRA messages as they appeared. Response time, defined as the lag between the onset of the CRA message and the beginning of the controller's speech indicating that the resolution was acceptable, was measured. This response time varied from 3 to 71 seconds with a mean response time of 17.7 (S.D. = 8.6). While the response time was relatively high, the error rate was only two percent.

Controller comments on the CRA function and message format were assessed with questionnaires and informal interviews. Generally, controllers were not satisfied with CRA. In its present form, they perceived it as unreliable and said that they would be reluctant to use it in actual operations. Five out of the eight controllers thought that the CRA message format was easy to understand. There was no consensus among the others as to how to improve it.

To calculate the delay that is to be expected between CRA onset and pilot response, the results of this study must be applied to the results of a previous study (DOT/FAA/RD-91/20) that examined the time required for message transmission and pilot response. The analysis of the combined data from these two studies suggests that 49 seconds should be considered as the upper limit on the time expected to elapse between CRA onset and the pilot's initial input into the aircraft's controls. However, such a long delay may be indicated only in situations similar to the ones tested in this study, such as extremely high workload and high incidence of CAs for which CRA was not able to offer a resolution. A previous study with the prototype CRA software (DOT/FAA/NA-92/1), with a slightly lower workload, and a higher proportion of CAs for which a resolution was presented, yielded a mean response time of 13 seconds (S.D. = 6.2) and a more realistic error rate; these data suggested an upper limit of 40 seconds for the delay parameter. Presumably, controllers in the present study assigned a lower priority to reading the CRA message than controllers in the first study and this, along with the lower error rate, resulted in higher response times.

1. INTRODUCTION

Conflict Resolution Advisory (CRA) software is intended to provide the air traffic control (ATC) specialist at air route traffic control centers (ARTCCs) with a suggested maneuver to prevent separation violations between aircraft. CRA calculates, validates, and displays a single resolution for potential separation violations predicted by the conflict alert (CA) function.

As with any time-critical warning system, the algorithm must take into account the time required for the operator to use the system. The lag between the time that the CRA message appears on the controller's display and the time that the aircraft begins to maneuver will affect the number and type of potential resolutions. It is therefore critical to know the controller-response time, the transmission time and the pilot-response time. The transmission and pilot-response times, that is, the time from the beginning of the controller's message to the end of the pilot's correct acknowledgment, was determined by analysis of voice tapes of ATC communications (DOT/FAA/RD-91/20). Results of informal interviews and a small pilot study support the assumption that further delays between acknowledgment and aircraft maneuver are negligible.

This simulation examined the controller-response time, that is, the total time required for controllers to notice that the advisory is present, to read and comprehend the text message, and to decide that the resolution is acceptable. This decision process is required because the CRA software does not take into account all of the information available to the controller. The controller needs to ascertain that a resolution is valid, strategically acceptable, and does not turn the aircraft into restricted airspace, a thunderstorm cell or other hazard.

The controller-response time was determined in a previous simulation study using the prototype CRA software (DOT/FAA/NA-92/1). The purpose of this simulation was to validate the controller-response time found with the prototype software using the enhanced software (CRAE). Controllers were also asked to express their opinions on the CRA message format and on CRA in general.

2. *SIMULATION STUDY*

2.1 Method

This simulation study was conducted over a three-week period at the DYSIM laboratory facilities of the FAA Technical Center in Atlantic City, NJ.

CRA Display.

The CRA messages appeared on the CA tabular list. Figure 2-1 shows examples of CRA messages as they appeared to the test controllers. A single resolution was presented for each CA. For single-pair conflicts (Examples 1 and 2), the resolution was displayed directly below the CA list containing the aircraft identifications for the two aircraft in conflict. For multiple-pair conflicts (Example 3), the list of conflict pairs was first followed by a line consisting solely of the letter "M" for multiple conflict, and then by the recommended resolution.

For the resolution advisory, each aircraft involved in the conflict was displayed on one line, followed by the recommended maneuver. A maneuver consisted either of a horizontal maneuver, a vertical maneuver, or a "maintain" maneuver. A horizontal maneuver consisted of a right ("R") or a left ("L") turn followed by the number of degrees (Examples 1 and 3). A vertical maneuver consisted of a "descend" or "climb" expressed with the appropriate arrow (↑ or ↓) followed by the altitude in hundreds of feet (Example 2). If the aircraft was already climbing or descending, the vertical maneuver issued would be a "maintain". This was displayed as an "M" followed by the altitude in hundreds of feet (Example 2).

Sometimes, only one of the aircraft involved in the conflict was required to maneuver to resolve the conflict (Example 1). Other times, more than one aircraft involved in the conflict was required to maneuver. This was indicated by the letter "J" (for joint maneuver) preceding each resolution line (Examples 2 and 3).

For some conflicts, CRA was not able to provide a resolution. This was indicated by the message "NO-RES" below the CA tabular list, followed by the reason. "NO-RES AVAIL" was displayed when no resolution was available that passed the validation procedure of the CRA logic or when the conflict involved an uncontrolled aircraft below 18,000 ft with a nondiscrete beacon code or no flight plan (Example 4). "NO-RES IF" (for interfacility) was displayed when the conflict involved an aircraft that was under the control of another facility. "NO-RES SEP" was displayed when a separation violation had already occurred or when a resolution could not be computed before a separation violation would have occurred.

EXAMPLE 1: SINGLE PAIR CA, SINGLE HORIZONTAL CRA

```
CONFLICT ALERT
.AAL210  UAL202    01   04[1]
   AAL210
   UAL202[2]  R30[3]
```

EXAMPLE 2: SINGLE PAIR CA, JOINT VERTICAL CRA

```
CONFLICT ALERT
.AAL210  UAL202
  J AAL210       M270[4]
  J UAL202       ↑290
```

EXAMPLE 3: MULTIPLE-PAIR CA, JOINT HORIZONTAL CRA

```
CONFLICT ALERT
.AAL210  UAL202
.UAL202  DAL301
  M[5]
  J AAL210
  J UAL202  R30
  J DAL301  L30
```

EXAMPLE 4: NO RESOLUTION AVAILABLE

```
CONFLICT ALERT
.AAL210  UAL202
  NO-RES AVAIL
```

FIGURE 2-1. EXAMPLES OF CRA MESSAGES

---

[1] CA tabular list with intersector notation.

[2] AID for CRA aircraft.

[3] Position for display of horizontal maneuver - right or left turn in degrees.

[4] Vertical maneuver - climb, descend, or maintain.

[5] Designates multiple-pair conflict.

As a result of the previous simulation study using the CRA-prototype software (DOT/FAA/NA-92/1), the maximum display time for a resolution was 24 seconds. When a conflict persisted beyond 24 seconds, the resolution lines were replaced by the message "NO-RES TOUT" directly below the CA list indicating that the time for issuing the resolution had run out. This time-out message persisted until the conflict was resolved (but see Section 2.2).

If the conflict configuration changed after the first 12 seconds of displaying a resolution, any new or changed data in the CRA tabular list blinked and the list including the new data was displayed for 24 seconds. If the newly calculated CRA was inconsistent with the previous one, i.e., it required a change in type or direction of maneuver, or if no valid resolution could be determined, the message "NO-RES AVAIL" was displayed.

If there was more than one conflict configuration at any one point, the CA and CRA list of a configuration immediately followed the CA and CRA list of a previous configuration.

Subjects.
Eight full performance level (FPL) controllers were selected from a list of volunteers from the Ft. Worth ARTCC. The controllers were certified and current on the sectors that they worked during the test.

Airspace.
The simulated airspace consisted of three contiguous test sectors. Two of these sectors were high altitude sectors (Dallas High and Ardmore High) and the third was a low altitude sector (Frisco Low). These sectors were supported by a controller on a "ghost" sector; the ghost sector initiated and received aircraft from the three test sectors.

Scenarios.
Six different scenarios, each approximately 1 1/2 to 2 hours in duration, were developed based on the actual traffic from the sectors chosen for the simulation. To ensure the occurrence of conflicts, the scenarios were constructed to range from moderately high to very high workload (in terms of number of aircraft and traffic complexity). The scenarios contained emergencies and other unusual conditions (e.g., aircraft with no radio) and one of the scenarios contained significant weather conditions. Simulated aircraft were operated by experienced DYSIM pilots. The scenario developers worked with the DYSIM pilots and were able to make immediate adjustments to the traffic loads, as necessary.

Data Collection and Procedure.
The simulation took place over the course of three weeks. During each week, the six scenarios were run over three days. On each day, two different scenarios were run between 6:00 p.m. and midnight. Data from approximately 68 hours of simulation were collected.

Controllers were instructed to work as they normally would in that sector, following standard operating procedures. Each controller worked alone as there were no D-side (radar associate) controllers. Before the first test session, the controllers were briefed on the functions and limitations of the CRA function and were given a description of the display.

For each CA, the controllers were asked to key the microphone and state whether it was a nuisance alert (when separation was already assured or the conflict pair was not in their airspace), an alert involving VFR aircraft (i.e., an uncontrolled aircraft with no discrete beacon code or no flight plan filed flying under Visual Flight Rules), or a true CA. For a true CA, they were asked to read the callsigns of the conflicting aircraft and the CRA message. If a CRA maneuver was present, the controllers were asked to evaluate it, that is, to key the microphone and state whether or not the resolution was acceptable. They were explicitly told that they did not have to use a resolution even if they judged it to be acceptable.

For the analysis of the controller-response time, controllers' comments (including all communications with the DYSIM pilots and other controllers), the CA/CRA tabular list as it appeared to the controllers on the Plan View Display (PVD), and the PVD time were recorded on videotape.

To assess controllers' subjective impressions regarding the realism and the complexity of the traffic as well as the workload involved in controlling it, controllers filled out questionnaires after each test session. Controllers' overall opinions regarding the realism of the equipment and the communications were collected with a post-simulation questionnaire. The same questionnaire also asked controllers' opinions regarding the CRA message format and CRA in general.

2.2 Results

CRA Display.

Resolution Maneuvers. There were 1,411 instances of CA during the approximately 68 hours of simulation. Table 2-1 shows the distribution of resolutions by type of maneuver.

Forty-three percent (604) of the advisories contained a maneuver. Over 85% (521) of these were single maneuvers, and fewer than 15% (83) were joint maneuvers requiring more than one aircraft to take action. Of the single maneuvers, close to half (237) consisted of a "maintain", the rest were almost equally distributed among vertical and horizontal maneuvers. Of the 150 vertical maneuvers, most (147) were descents, only three consisted of a climb. Of the 134 horizontal maneuvers, 82 were left turns and 52 were right turns.

For 53% (746) of the CAs, no resolution could be advised. In the vast majority (545) of these cases no resolution was available because a VFR aircraft (275 cases) was involved or because the CRA function was not able to calculate a valid resolution.

In four percent of the CAs, a malfunction occurred resulting either in the aircraft identifications (AIDs) appearing alone or in "NO-RES TOUT" appearing as the initial CRA message.

TABLE 2-1. RESOLUTIONS BY TYPE OF MANEUVER

Maneuver Type		Number		Percentage of Total
Single Maneuvers		521		37
Maintain	237		17	
Descent	147		10	
Climb	3		.2	
Left Turn	82		6	
Right Turn	52		4	
Joint Maneuvers		83		6
No Resolution Advisory		746		53
NO-RES AVAIL	545		39	
NO-RES IF	45		3	
NO-RES SEP	156		11	
Display Malfunction		61		4
NO-RES TOUT	33		2	
AIDs only	28		2	

Display Clutter. One of the concerns about the CRA display was that it may add too many lines to the tabular list and be too cluttered to read when there was more than one conflict. In order to examine this issue, the number of lines of text that appeared on the CRA display for each new conflict were counted. For one conflict involving two aircraft, three lines of text (including the CA list) would appear if a resolution was displayed, and two lines of text (CA list and "NO-RES") would appear if a resolution was not presented (see Figure 2-1). As can be seen in Figure 2-2, the tabular list was blank when 64% of the CRA messages appeared (as indicated by 900 instances of an initial display of fewer than four lines). In 511 (36%) of the conflicts, however, there were already four or more lines of text on the tabular list when the CRA message indicating a new conflict appeared.

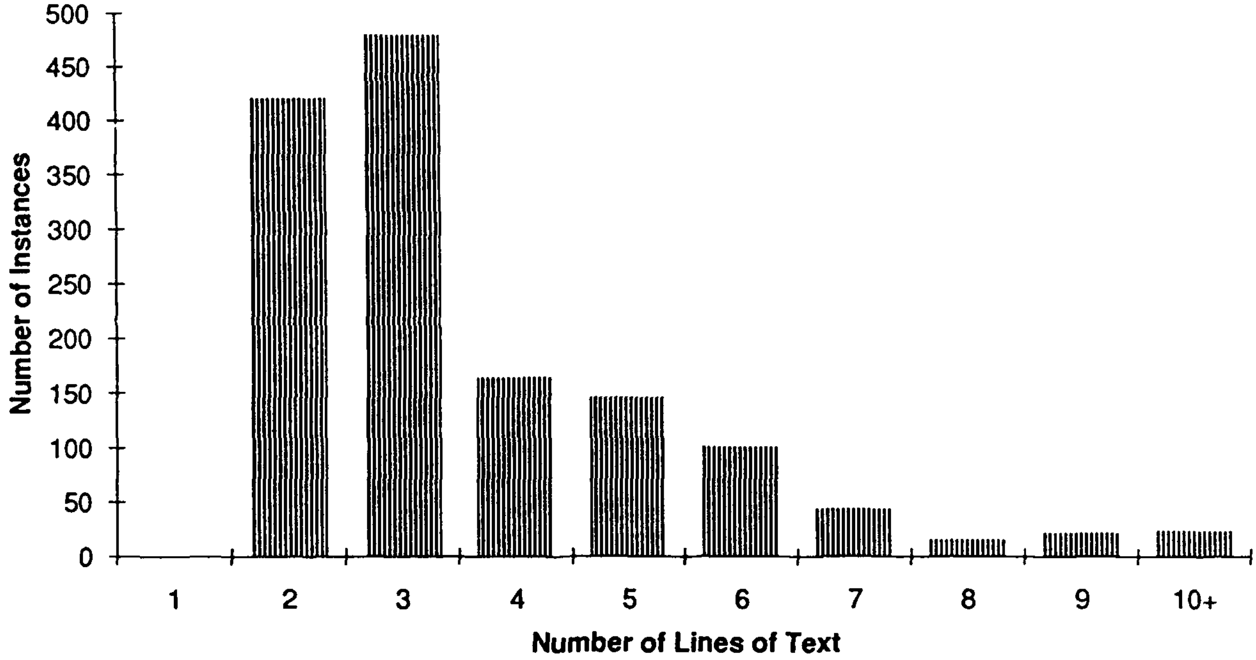

FIGURE 2-2. NUMBER OF LINES OF TEXT IN INITIAL CRA DISPLAY

All CRA messages disappeared upon conflict resolution (as CA disappeared) or, after 24 seconds, changed to "NO-RES TOUT". "NO-RES TOUT", which was supposed to disappear after conflict resolution, persisted for a minimum of 10 seconds and a maximum of 43 minutes. On average, it disappeared after 68 seconds (S.D. = 147 seconds). The long maximum is assumed to be due to a display malfunction. In nine percent of the CAs, a malfunction caused the time-out message to disappear, and reappear several seconds later.

Controller Response.

Table 2-2 categorizes the eight controllers' responses to the 1,411 alerts. CRA messages generated as a result of a nuisance CA or when all of the conflict aircraft were not in voice communication with the test controller (i.e., under track control only) were not evaluated by the controllers. An additional 479 CAs/CRAs were either not noticed or not commented on by controllers. In 396 instances of CA, the controller said that CRA did not offer a resolution (i.e., he or she read "No Res" into the tape). There were 258 instances of CRA where the resolution was evaluated by controllers as either acceptable or unacceptable.

TABLE 2-2. CONTROLLER RESPONSES TO CA/CRA

Controller Response	Frequency
Resolution Acceptable	193
Nuisance Alert	76
No Comment on CA/CRA	479
Aircraft Under Track Control Only	130
No Resolution Available	396
Resolution Unacceptable	65
Other	72
Total	1,411

Acceptable Resolutions. In 14% (193) of the total CAs (75% of the 258 CRA messages that were evaluated by the controllers), the resolution was considered acceptable. Twenty-one of these resolutions were not explicitly evaluated by the test controllers but were considered acceptable because the controller issued the same maneuver just prior to the CRA display onset, or immediately after the CRA message appeared (but without any indication that the controller read the resolution). In 16 instances, a malfunction caused a delay in the CRA display so that the resolution appeared seconds after the onset of the CA. The remaining 156 instances in which the resolutions were explicitly evaluated and the CRA display worked properly were analyzed for controller-response time.

The time between the onset of the CRA message and the onset of controller speech indicating an acceptable resolution was measured. For example, if the controller's response was, "CRA wants to turn United 123 right thirty degrees . . . yeah, that will work," the end of the response time was measured as the beginning of the "yeah." This response time varied from 3 to 71 seconds (see Table 2-3) with an average of 18 seconds. Table 2-4 shows the response times at several percentiles.

TABLE 2-3. CONTROLLER-RESPONSE TIME (IN SECONDS)

Minimum	3.00
Maximum	71.00
Mean	17.74
Standard Deviation	8.65

Total Number of Observations = 156

TABLE 2-4. CONTROLLER RESPONSE-TIME (PERCENTILES)

5th	9.0
10th	10.0
50th	16.0
90th	27.0
95th	30.0

The variability among controllers in terms of response times was small. The mean response time for individual controllers ranged from 14.6 to 20.7 seconds.

Nuisance Alerts. Only five percent of the CA instances were classified by the controllers as nuisance alerts. The resolutions to these nuisance CAs were not evaluated by the controllers.

No Comment. In 479 (34%) of the 1,411 instances of CA the controller did not comment on the CA or CRA message. Most (371) of these instances were due to the controller not mentioning that a CA was occurring. The remaining of these instances (108) were due to the controller noting that there was a CRA message but not saying whether or not the resolution was acceptable. An example of such a controller's response is "CRA says to turn American 123 right 30 degrees, but I'd rather climb him ...".

Advisories for Aircraft Under Track Control Only. Nine percent of the CAs involved aircraft that were not in voice communication with the test controller. Resolutions that were presented to the test controller, but were intended for aircraft under track control only (and not in voice communication with the test controller) were not evaluated by the controllers.

No Resolution Available. For 396 (28%) of the CAs, the controllers stated that CRA did not generate a resolution. The majority (275) of these cases involved VFR aircraft.

Unacceptable Resolutions. In four percent (65) of the total CAs (25% of the evaluated CRAs), the resolution was considered unacceptable. This does not include the instances in which the CRA resolution given to the controller involved maneuvers for aircraft not in voice communication with the test controller. The controllers' reasons for judging the resolutions to be unacceptable varied. In most cases, the controllers thought that the stated resolutions would either not be of sufficient magnitude (as in the case of a turn) to resolve the conflict, or would cause a conflict with a neighboring aircraft. Very few of the resolutions were judged to be unacceptable for reasons other than traffic avoidance (e.g., due to weather or restricted airspace). However, since the controllers were not required to state the reasons why each resolution was unacceptable, a meaningful statistical breakdown of these reasons is not possible.

Other. In five percent of the total CAs, the CRA message disappeared or changed to "NO-RES TOUT" (time out) before the controller could read it. Fewer than one percent could not be read because the tabular list was too cluttered.

Controller-Response Errors.
There were only five instances (two percent of the 258 CRAs that were evaluated) in which the controller read information that was different than what appeared on the tabular list. In three cases, the controller misread (or misspoke) the aircraft call sign and in one case, the controller reported the wrong maneuver. In the fifth case, the maneuver was assigned to the wrong aircraft; for example, in a conflict between UAL 123 and AAL 456, the controller read "Right 40 for AAL 456" when the resolution was "Right 40 for UAL 123".

This two-percent error rate is substantially lower than what would be expected for such a task; it is also lower than the 24 errors (16% of the 125 CRAs that were evaluated, excluding four errors where no resolution was reported when one appeared) observed in the previous study (DOT/FAA/NA-92/1). There are two probable reasons for this difference. First, changes in the display made some of the errors less likely. For example, in the previous display an "R" meant both that the resolution involved only one maneuver (as opposed to a joint maneuver) and a right turn, depending on the location of the "R". This ambiguity was removed from the display of the enhanced software. Second, controller-response time was substantially longer for the second test than for the first test. Despite other possible reasons for this longer response time, fewer errors would be expected because of the well-established speed/accuracy trade-off in such tasks.

Post-Run Questionnaires.
Controllers rated the realism of the traffic situations after each session on a scale of 1 to 5. A score of 1 was equivalent to "very unrealistic", 3 was "moderately realistic" and 5 was "very realistic". The arithmetic mean (average) of the 48 scores collapsed across scenarios and sectors was 3.9 with a standard deviation (S.D.) of .98. Scores ranged from 1 (one single response) to 5.

Workload was measured by having controllers rate the volume and the complexity of traffic. Traffic estimates ranged from 70% to 150% of the traffic volume normally seen in the sectors simulated, with a mean of 111% (S.D. = 19.52). Traffic complexity ratings ranged from 1 (very low complexity) to 5 (very high complexity), with a mean of 4.1 (S.D. = .74).

3. POST-TEST QUESTIONNAIRE RESULTS

After the simulation, controllers were given a questionnaire asking them to rate the overall realism of the communications, the communications equipment, and the displays and controls. Furthermore, they were given the opportunity to make suggestions regarding the format and content of the CRA messages and to express their opinions on CRA in general.

3.1 Controller Comments on Realism of Simulation

With the anchors "very unrealistic", "moderately realistic", and "very realistic" for the ratings of 1, 3, and 5, respectively, the eight controllers gave both the communications and the communications equipment a mean rating of 3.75, each with a standard deviation (S.D.) of .83. The displays and controls were given a realism rating of 4.25 (S.D. = .66).

3.2 Controller Comments on CRA

Comments on CRA Message Format and Content. Five of the eight controllers thought that the format of the CRA messages was easily understood. Three controllers thought that it was hard to understand.

Only one of the controllers remembered having observed a blinking update to a CRA message. Six of the controllers approved of the blinking update presentation in principle, with R- and D-side capability to suppress blinking. Two controllers did not express an opinion.

All controllers (with the exception of one who didn't answer the question) approved of the fact that "NO-RES TOUT" was presented steady state rather than blinking. Two controllers thought that all CRA messages should change to "NO-RES TOUT" after 24 seconds, just as they observed in the test. Three controllers, however, would have liked the message to disappear instead, one of them suggesting that the line remain blank. One controller, for the "NO-RES" messages, would have liked to be able to read why no resolution was available until the end of the CA. Another would have preferred to also keep the advisories, marked "TOUT". A third suggested that the advisory be reevaluated and a newly calculated resolution (new or old) be displayed again for 24 seconds.

Two controllers indicated that the "NO-RES SEP" message should appear only when separation between aircraft had already been broken. Two others thought the message should only appear when the CRA function was not able to calculate a resolution that ensured separation. One controller would have liked the "NO-RES SEP" message to appear in both cases. Two controllers suggested a blank line below the CA in either case. One controller did not express a preference.

For conflicts involving an uncontrolled aircraft with no discrete beacon code or no flight plan, none of the controllers liked the "NO-RES AVAIL" message displayed during the simulation. Instead, four controllers would have preferred no message at all, three controllers suggested a blank space appear under the CA list, and one controller would have preferred the message "NO-RES VFR".

Overall, there was concern that the CRA lists were too long and cluttered and that 24 seconds was not enough time to evaluate a resolution, especially when there were several conflicts present at the same time.

Comments on CRA in General. To the question "How will CRA be used by controllers?", six controllers replied that they would not use it as presented because it was not sufficiently reliable. One controller mentioned that he would never use it, because he would not want to take his eyes off the aircraft in conflict to read the CRA list during a CA. Only one controller mentioned that he would use CRA occasionally, but only as a back-up aid. One controller added that even if CRA supplied reliable resolutions, it would be useful only after extensive controller training in reading and evaluating CRA maneuvers.

Controllers also mentioned that CRA may be counter-productive for two reasons. First, evaluating the CRA message in a moment of crisis consumes valuable mental resources and time that would be better spent on thinking of a resolution. Second, discrepancies between the displayed resolution and the one controllers thought of independently might undermine controllers' confidence in their own resolutions.

One last concern mentioned by the controllers was that continuous use of CRA may weaken controllers' problem-solving and planning skills. If controllers learn to rely on automated systems providing them with resolutions in critical situations, what will they do if the system fails?

4. SUMMARY AND CONCLUSIONS

4.1 Calculation of the Delay Parameter

The purpose of this study was to provide data for the computation of the delay parameter to be used in the CRA algorithm. This delay parameter would provide the expected time lapse between the onset of the CRA message and the pilot's input into the aircraft's controls. An estimate of this delay must take into account several factors. These factors include the controller's response time, the time required for successful transmission of a controller's message to the pilot, and the pilot's response time. The results of this study showed that an average of 18 seconds is required for a controller to read the CRA message and decide that it is usable.

To determine pilot-response time, a study was conducted using voice tapes from ARTCCs (DOT/FAA/RD-91/20, August 1991). Pilot-response time was combined with transmission time and measured from the beginning of the controller's transmission of a maneuver required for traffic avoidance to the end of the pilot's correct acknowledgement. The data from that study are summarized in Table 4-1 and Table 4-2. Personal communications with experts (such as the National Resource Specialist in Flight Management) and an informal pilot study supported our assumption that by the end of the verbal acknowledgement, the pilot will initiate an input into the controls (whether or not the pilot communicating is also the pilot flying).

TABLE 4-1. PILOT-RESPONSE TIME (IN SECONDS)

Minimum	4.00
Maximum	40.00
Mean	10.85
Standard Deviation	5.91

Total Number of Observations = 80

TABLE 4-2. PILOT-RESPONSE TIME (PERCENTILES)

5th	5.0
10th	6.0
50th	9.0
90th	17.0
95th	22.5

One way of estimating the CRA delay parameter is to add the mean or 90th percentile pilot-response time to the mean or 90th percentile controller-response time. However, a more appropriate statistical analysis considers all possible pairings of these two data sets and calculates the percentiles for the sum of the response times over all pairings. This method provides the best estimates available for the combined percentiles, assuming that the pilot and controller-response times are independent. Table 4-3 presents these percentiles with the upper and lower confidence limits and the mean with the 90th and 95th percent confidence limits. As can be seen in the table, we are 95% confident that the mean of this total time is greater than 26.72 and less than 30.46, and that the 95th percentile is less than or equal to 54 seconds.

TABLE 4-3. COMBINED CONTROLLER/PILOT-RESPONSE TIMES (IN SECONDS)

	Percentiles			
	5th	10th	90th	95th
Point Estimates (in seconds)	16.5	18	41	49
Confidence Limits:				
Lower .05	15.5	17	--	--
Lower .10	16	17	--	--
Upper .10	--	--	43	53
Upper .05	--	--	45	54

Mean Total Response Time = 28.59
95% Confidence Limits = (26.72, 30.46)
90% Confidence Limits = (27.02, 30.16)

These data suggest that, under the conditions tested, the upper limit on the time expected to elapse between the onset of the CRA display and the time the pilot makes an input into the aircraft's controls should be 49 seconds. However, there are other factors that need to be taken into account when assigning a value to the delay parameter.

First, the findings of the simulation study of the CRA prototype software (DOT/FAA/NA-92/1) should weigh heavily in determining the delay parameter. On the basis of this earlier study, a delay parameter of 40 seconds was recommended. (Reasons for the difference between the results of the two studies are discussed in the next section.) Second, although neither study was large enough to study response times as a function of level of workload, it is reasonable to assume that relatively long response times would be most prevalent under extremely high workload conditions. By design, the workload conditions used in the study were much more representative of "worst-case" than of normal conditions. (A more realistic simulation of controller workload would have resulted in a simulation study that was prohibitively long and expensive.) Third, increasing the delay parameter would result in an even higher percentage of situations in which the CRA function could not offer a resolution to the controller.

4.2 Comparison of Results of the Two Simulation Studies

The controller-response times observed in the present study were considerably longer than the ones observed in the simulation study of the prototype CRA software (DOT/FAA/NA-92/1). The previous simulation study was conducted in two parts. Part I (Week 1) examined how controllers use the CRA display and Part II (Week 2) examined the time required for a controller to read and evaluate the CRA text message. The results of Week 2 indicated that an average of 13 seconds (S.D. = 6.2) should be expected for the controller to read the CRA message and decide that it is usable. Ninety-five percent of the controllers' vocal responses were initiated within 26 seconds. In the present study, the mean controller-response time was 18 seconds, and the response time at the 95th percentile was 30 seconds.

There are many possible reasons for the higher response times found for this simulation study compared to the previous study. First, although the ratio of acceptable to unacceptable resolutions was very similar in the two studies (approximately 3:1), controllers found that no resolution was available much more frequently in this simulation than in the first study. This was, in part, due to the greater number of VFR aircraft in the present simulation, and in part to the longer delay parameter for the controller/pilot- response time assumed by the CRA algorithm as a result of the previous study (40 seconds instead of 24 seconds). In Part II of the first simulation, controllers found no resolution available for 11% (38) of all CAs (358). In the present study, controllers indicated that no resolution was available for 28% (396) of all CAs (1,411). Such a low payoff further lessens the controllers' inclination to take their eyes off of the conflict to look at the tabular list. Also, because a blank line in the prototype software was replaced by the text line "NO-RES AVAIL" in the enhanced software (in instances in which no satisfactory resolution could be calculated), and because there was a higher number of these instances in the second study than in the first study, the CRA display was more cluttered in the second study. (See also the discussion of display clutter in section 2.2.)

Second, it is likely that higher workload levels contributed to the higher response times found in the second study. Controllers estimated traffic load and traffic complexity only slightly higher in the second study--traffic load, estimated in percents of the traffic normally found in the same sector, ranged from 70% to 150% with an average of 111% compared to 60% to 150% with an average of 105% in Part II of the first study, and traffic complexity was rated an average of 4.1 (on a scale of 1 to 5) compared to 3.4 for the first study. However, there is some evidence that suggests that workload was higher in the present study than in the previous study. Specifically, with approximately 20 CAs per hour in the second study, as compared to approximately 10 CAs per hour in the first study, the number of CAs encountered by the controllers in the second simulation was dramatically higher. Although the number of CAs may have been slightly underreported in the first study because the total number of CAs was tallied by observers during the experiment rather than analyzed on videotape, the difference is still indicative of a higher level of workload in the second study.

It is likely that, given the extremely high workload situations and the fact that CRA generated a resolution for less than half of the CAs, evaluation of the CRA message was far lower on the controllers' lists of priorities than controlling traffic and maintaining proper separation. This conclusion is supported by the fact that the percentage of CRA messages in which the controller did not address the CA/CRA is higher in the second study (371 instances or 26% of all CA/CRAs) than it was in the first study (45 instances or 13% of all CA/CRAs). Additional support comes from the similarity of response times of the present study to the response times in Part I (Week 1) of the previous study. In Part I of the test of the CRA prototype, use of the CRA display was optional. Response times were measured for the instances in which the controller looked at and issued the CRA resolution. Out of 300 CAs, there were only 14 such instances, with an average of 18 seconds and a standard deviation of 10.4 seconds. While this procedure had the advantage of realism, it had to be discontinued because it generated too few data points for a valid parameter study; only the second part of the simulation was considered for determining the response times. Nevertheless, the fact that the average response time in Part I of the earlier study was identical to the one found in the present study suggests that the controllers in this study, despite instructions to the contrary, used the CRA display much like the controllers in Part I of the previous study did--they reviewed the CRA messages as time permitted without an intention to use the resolutions.

One last factor that may have contributed to the long response times in the present study is the unrealistically low error rate of approximately two percent. The 16% error rate found in the first study is much more in line with what would be expected for the performance of such a complex task. These data seem to show the same speed-accuracy trade-off found with many similar tasks.

In conclusion, the response times found in both the present and the earlier studies should be considered indicative of what would be expected in conditions that are similar to the ones tested. An average controller-response time of 18 seconds could be expected in a situation similar to the one of the present study: extremely high workload situations, a significant proportion of situations in which no resolution is available (in this case caused, in part, by the relatively high proportion of VFR traffic), and, consequently, a relatively low priority assigned by controllers to read the text message. A slightly shorter response time, such as the average of 13 seconds found in Part II of the first study, could be expected with slightly lower workload and a higher proportion of CAs in which a resolution is presented. Changes in other key factors, such as display characteristics, perceived reliability of CRA, etc., would also be expected to affect controller-response time.

As to how controllers would use an automated aid such as CRA, Part I of the simulation study using the prototype CRA software showed that the controllers' initial response to CRA was to resolve an impending conflict and then, if there was time, examine the CRA message. This response would be expected from controllers who have never used CRA. Experience with such a system would be expected to change the way controllers use it. If the system performs flawlessly, then controllers will trust it and will not hesitate to use the advisories, particularly when a CA was not anticipated or the controller does not already have an avoidance maneuver planned. This trust in the system would result in a relatively short response time. However, if the system generated maneuvers that the controllers find unacceptable, then the controllers would be reluctant to use it, and would probably only read the display out of curiosity or when caught off-guard by a CA. It is worth considering that, if the controller blindly issues a computer generated solution (whether out of inexperience, high workload, panic, fatigue, or a combination of these factors), the outcome of the situation will depend upon the reliability of the conflict resolution system. Also, the effects of long-term use of such a system on controller problem-solving and planning skills have not yet been systematically studied.

REFERENCES

Cardosi, K.M., Boole, P.W. (1991). Analysis of Pilot Response Time to Time-Critical Air Traffic Control Calls. Washington, DC: DOT/FAA/RD-91/20.

Cardosi, K.M., Warner, M., Boole, P.W., Mengert, P., DiSario, R. (1992). Controller Response to Conflict Resolution Advisory Prototype. Washington, DC: DOT/FAA/NA-92/1.