An Algorithm for Generating Data Accessibility Recommendations for Flight Deck Automatic Dependent Surveillance-Broadcast (ADS-B) Applications

Authors: Michael Zuschlag
Judith Bürki-Cohen
Divya C. Chandra

9 September 2014

DOT/FAA/TC-14/4

DOT-VNTSC-FAA-14-09

Prepared for:
NextGen
Human Factors Research and Engineering Division (ANG-C1)
U.S. Department of Transportation Federal Aviation Administration
800 Independence Avenue, SW Washington, DC 20591

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 the contents or use thereof.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE
9 September 2014

3. REPORT TYPE AND DATES COVERED
Final Report

4. TITLE AND SUBTITLE
An Algorithm for Generating Data Accessibility Recommendations for Flight Deck Automatic Dependent Surveillance-Broadcast (ADS-B) Applications

5. FUNDING NUMBERS
FA1BC3 KT824
FA16C3 LT824
FA16C3 MT824
FA16C8 MTE94

6. AUTHOR(S)
Michael Zuschlag, Judith Bürki-Cohen, and Divya C. Chandra

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Department of Transportation
John A. Volpe National Transportation Systems Center
Office of the Assistant Secretary for Research and Technology
Cambridge, MA 02142-1093

8. PERFORMING ORGANIZATION REPORT NUMBER
DOT/FAA/TC-14/4
DOT-VNTSC-FAA-14-09

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Department of Transportation Federal Aviation Administration
NextGen Human Factors Research and Engineering Division (ANG-C1)
Washington, D.C. 20591
Program Managers: Dr. Thomas McCloy and Ms. Colleen Donovan

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
This document is available to the public through the National Technical Information Service, Springfield, VA 22161.

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)
Automatic Dependent Surveillance-Broadcast (ADS-B) In technology supports the display of traffic data on Cockpit Displays of Traffic Information (CDTIs). The data are used by flightcrews to perform defined self-separation procedures, such as the in-trail procedure (ITP). Crews must have appropriate access to the data they need to perform the procedure. This report proposes an algorithm for determining whether data are satisfactorily accessible for each ADS-B task and procedure. Accessibility is defined as the effort of finding data on a visual display and looking directly at the data. The premise of the algorithm is that the more important the data for the procedure, the higher its recommended accessibility should be. The data's importance depends on a combination of their criticality and update rate, which are determined by expert judgment. The algorithm generates tables indicating recommended virtual locations for the data on the CDTI. Examples of algorithm inputs and output are provided. Additional work is required to validate the algorithm output. If the algorithm works as intended, it can be used to answer questions about how the data should be shown on the CDTI and where the CDTI can be installed on the flight deck.

14. SUBJECT TERM
CDTI, Automatic Dependent Surveillance-Broadcast, ADS-B, data accessibility, displays, traffic displays, flight deck displays, in-trail procedure, ITP

15. NUMBER OF PAGES
53

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	Unlimited

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18
298-102

This page left blank intentionally.

Preface and Acknowledgements

This technical report was prepared by the Aviation Human Factors Division in the Center for Safety Management and Human Factors at the John A. Volpe National Transportation Systems Center (Volpe Center). The Federal Aviation Administration NextGen Human Factors Research and Engineering Division (ANG-C1) funded this project. We thank the FAA program managers Dr. Thomas McCloy and Ms. Colleen Donovan for their assistance. This work was conducted in support of the Office of Aviation Safety (AVS).

The views expressed herein are those of the authors and do not necessarily reflect the views of the Volpe National Transportation Systems Center, the Office of the Assistant Secretary for Research and Technology, nor do they necessarily represent the views, policies, or guidance of the Federal Aviation Administration or the United States Department of Transportation.

SI* (MODERN METRIC) CONVERSION FACTORS				
APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
oz	ounces	28.35	grams	g
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa
APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
mL	milliliters	0.034	fluid ounces	fl oz
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
g	grams	0.035	ounces	oz
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	Kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

Table of Contents

List of Tables

List of Figures

Executive Summary

Automatic Dependent Surveillance-Broadcast (ADS-B) In technology supports the display of traffic data on Cockpit Displays of Traffic Information (CDTIs). These data can support new operational procedures that allow crews to self-separate from traffic, such as the in-trail procedure (ITP). Advisory Circular (AC) 20-172A, *Airworthiness Approval for ADS-B In Systems and Applications* requires the CDTI be evaluated for satisfactory accessibility. This report describes a proposed algorithm for determining "satisfactory accessibility" of the data that pilots use for ADS-B flight deck procedures. In this report, accessibility is defined as the effort of finding data on a visual display and looking directly at the data. Accessibility is determined by a combination of:

- *CDTI software design*, specifically the "virtual location" of the data, where the virtual locations are the traffic symbol and adjoining data tag, the data block, and locations that require pilot input to access (e.g., a press of a button).
- *CDTI installation*, specifically the physical location of the CDTI display on the flight deck, which could be in the forward, oblique, or lateral position.

The premise of the algorithm is that the more important the data for the procedure, the higher its recommended accessibility. The importance of the data depends on a combination of two factors:

- *Criticality*, which is how essential the data are for the task.
- *Update rate*, which is the frequency at which the pilot must be aware of changes in the data.

To use the algorithm, a team of subject matter experts on the ADS-B procedure first categorizes the criticality and update rate of each piece of data pilots use for the procedure. The algorithm assigns numeric values to categories of criticality and update rate and then arithmetically manipulates the values to determine the recommended virtual location for each piece of data, for a given CDTI physical location. These recommendations may be used to answer questions such as:

- Does a specific CDTI software design have data accessibility issues regardless of its physical installation location?
- Does a specific CDTI software design provide at least the minimum data accessibility to all attributes for a proposed installation location?
- In what physical locations could a specific CDTI be installed while still providing at least the minimum data accessibility to all attributes?
- What physical locations provide at least the minimum data accessibility to all attributes for a given ADS-B application, assuming a hypothetical "ideal" CDTI?

Additional work is necessary before the algorithm or its recommendations can be used in practice. This work includes:

- Validating that the algorithm produces correct recommendations.
- Integrating the use of the algorithm in the standards-production process, so that SMEs are convened to determine the input for the algorithm for each ADS-B application.
- Automating the computations of the algorithm to reduce the workload associated with turning input into algorithm output.
- Constructing a means of disseminating the algorithm output (base and contingency tables) for each application for use by government and industry (e.g., as an XML download).
- Automating and streamlining the evaluation process to reduce workload for evaluators.

Abbreviations and Symbols

a	Data Attribute
A	Accessibility
AC	Advisory Circular
ADS-B	Automatic Dependent Surveillance-Broadcast
AIRB	Basic Airborne Situation Awareness
ASAS	Aircraft Surveillance Applications System (ASAS)
ASSAP	Airborne Surveillance and Separation Assurance Processing
ATC	Air Traffic Control
AVS	FAA Office of Aviation Safety
C	Criticality
C_a	Criticality of attribute *a*
CDTI	Cockpit Display of Traffic Information
CDU	Control and Display Unit
DOT	Department of Transportation
EFB	Electronic Flight Bag
EVAcq	Enhanced Visual Acquisition
FAA	Federal Aviation Administration
FOV	Field of View
Fwd	Forward Physical Location
I	Importance
ID	Identifier
ITP	In-trail Procedure
Lat	Lateral Physical Location
NextGen	Next Generation Air Transportation System
Obl	Oblique Physical Location
OR	Operational Requirement
P	Physical Location
PFOV	Primary Field of View
R	Update Rate
R_a	Update Rate of attribute *a*
RTCA	Formerly, Radio Technical Commission for Aeronautics
RTCA DO-312	Safety Performance and Interoperability Requirements Document for the In-Trail Procedure in Oceanic Airspace (ATSA-ITP) Application
RTCA DO-317A	Minimum Operational Performance Standards for Aircraft Surveillance Applications System
SAE	Formerly, Society of Automotive Engineers
SME	Subject-Matter Expert
TCAS	Traffic Alert and Collision and Avoidance System
V	Virtual Location

V_{Pa}	Recommended virtual location for attribute *a* in physical location *P*
V'_{Pa}	Recommended contingency virtual location for raw source attribute *a* in physical location *P*
$V_{Pa}(\mathrm{i})$	Initial recommended virtual location for attribute *a* in physical location *P*
$V_{Pa}(\mathrm{r})$	Recommended virtual location adjusted for routine and non-routine attributes

1 Introduction and Motivation

Automatic Dependent Surveillance-Broadcast (ADS-B) In technology enables the display of traffic data on a Cockpit Display of Traffic Information (CDTI), which is the pilot interface portion of the Aircraft Surveillance Applications System (Federal Aviation Administration [FAA], 2012). This interface includes traffic display and all the controls that interact with such a display. At a minimum, CDTI includes a graphical plan-view (top down) traffic display. The CDTI can show traffic horizontal position, traffic altitude, and the direction in which the traffic is moving (its track). The ADS-B In processor installed on ownship receives these data from the ADS-B Out technology on other aircraft.

When used in combination with new flight deck and ground controller procedures and software, ADS-B data support operational procedures that allow crews to temporarily self-separate from traffic under carefully managed conditions, which can improve the efficiency and safety of flight operations. These ADS-B procedures require both ground and flight deck software applications. One example of an ADS-B procedure is the in-trail procedure (ITP). ITP allows an equipped aircraft in the oceanic environment to request and obtain a clearance to an altitude where the climb or descent involves passing one or two reference aircraft at distances below normal separation standards (RTCA, 2008).

This report focuses on flight deck software applications that support ADS-B procedures. Applicants who seek Federal Aviation Administration (FAA) approval to install ADS-B In flight deck equipment and software may use the means of compliance described in Advisory Circular (AC) 20-172A, *Airworthiness Approval for ADS-B In Systems and Applications* (FAA, 2012). One of the requirements in AC 20-172A (Section 3-2i) is to "[e]valuate the overall CDTI system installation for satisfactory accessibility and visibility under all lighting conditions." This report proposes an algorithm for determining "satisfactory accessibility" for a CDTI to support the evaluation described in AC 20-172A. While physical accessibility of the display and its controls is important to evaluate, accessibility of the *data* on each display is also a concern. In this report, accessibility is defined as the effort of finding data on a visual display and looking directly at the data. It is the effort necessary for a pilot in a normal seated position on the flight deck when looking forward along the flight path without disorienting or undue body movement:

Accessibility of ADS-B data is an issue because CDTIs can be located outside of the crew's primary field of view (PFOV), which is based on the optimum vertical and horizontal visual fields from the design eye (reference) point that can be viewed with eye rotation only using foveal or central vision.[1] Also, CDTI designers manage display clutter by showing data in different places on the screen, sometimes even requiring pilots to actively retrieve data, which further impacts data accessibility. In addition, CDTIs can support multiple ADS-B applications and the display may be configured differently depending on which application is being used (c.f. Estes, Penhallegon, and Stassen, 2010).

The proposed algorithm generates recommendations for the accessibility of each piece of data needed to fly each phase of the ADS-B procedure. Using the algorithm yields answers to practical questions such as:

- What CDTI data should be displayed in the plan view (either encoded in the traffic symbols or shown in a text data tag attached to the traffic symbol), as opposed to in the data block (e.g., on the edge of the CDTI for the selected target only)?

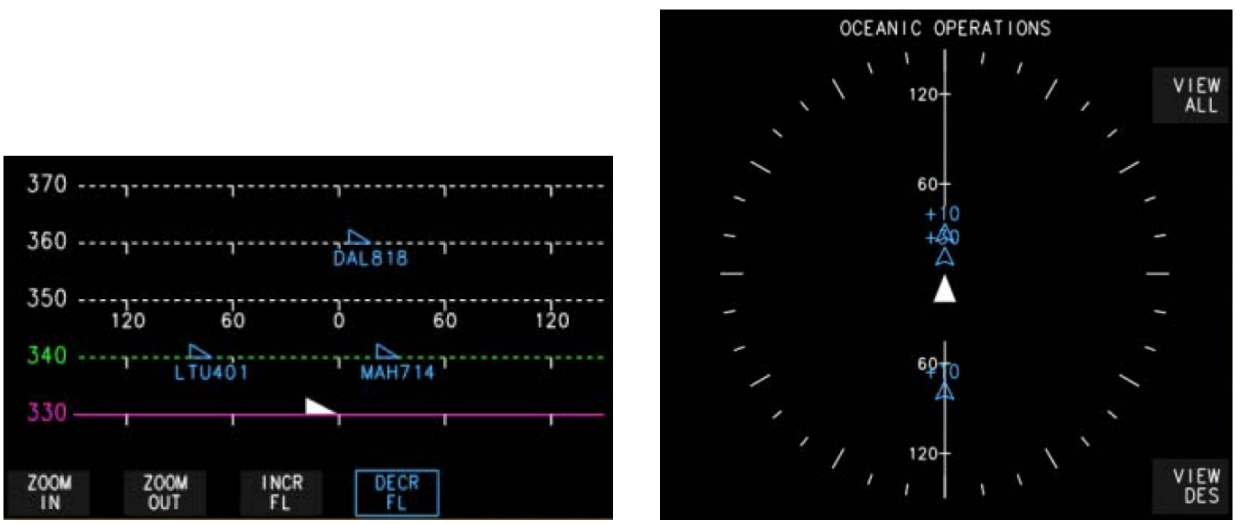
[1]With the normal line-of-sight established at 15 degrees below the horizontal plane, the values for the vertical (relative to normal line-of-sight forward of the aircraft) are +/-15 degrees optimum, with +40 degrees up and -20 degrees down maximum (FAA, 2007).

- When is it okay to require a button press or other pilot action for data access?

Government and RTCA standards committees face these types of questions when developing guidance for CDTI manufacturers. Subsequent to validating that the algorithm produces correct recommendations, the FAA, in coordination with industry and standards committees, could use the algorithm to generate recommendations for data accessibility and then evaluate conformance of a CDTI relative to those recommendations. CDTI manufacturers could use the recommendations to evaluate data accessibility for different display configurations during the design process. Standards committees could also use the algorithm to ensure that their documents have the appropriate level of specification.

2 Model of CDTI Use and Terms

The proposed algorithm for generating the recommended accessibility of CDTI data is based on a model of how pilots use the CDTI to support an ADS-B procedure. In this model, each ADS-B procedure consists of pilot **tasks** that are completed either simultaneously or in sequence. For example, pilots perform four tasks in sequence to complete an ITP procedure: initiation, instruction, execution, and termination (RTCA, 2008, p. 59). Each task takes one to several minutes to complete. The tasks may be supported by different display modes of the CDTI. For example, the CDTI may show a profile view of similar-track traffic to help pilots select one or two reference aircraft during ITP initiation (see Figure 1a). For ITP execution, the CDTI may show a plan view to maintain awareness of the proximity of all traffic (Figure 1b).



(a) (b)

Figure 1. Profile view (a) and plan view (b) display modes for a CDTI supporting ITP. Images from Murdoch, Bussink, Chamberlain, Chartrand, Palmer, and Palmer (2008).

The model of CDTI use specifies that pilots complete each of the ADS-B procedure tasks through a control-loop (see Figure 2). Data about the aircraft and outside environment, such as ownship trajectory and traffic proximities, is sent to the CDTI and other flight deck displays (e.g., the navigation display) as needed. The data are processed and presented to the pilot, who perceives the data, interprets them, and executes a response. Pilot responses are transmitted through the flight deck controls, which in turn alter the aircraft or environmental state and associated data (e.g., changing ownship trajectory, which then affects the relative location of other traffic).[2]

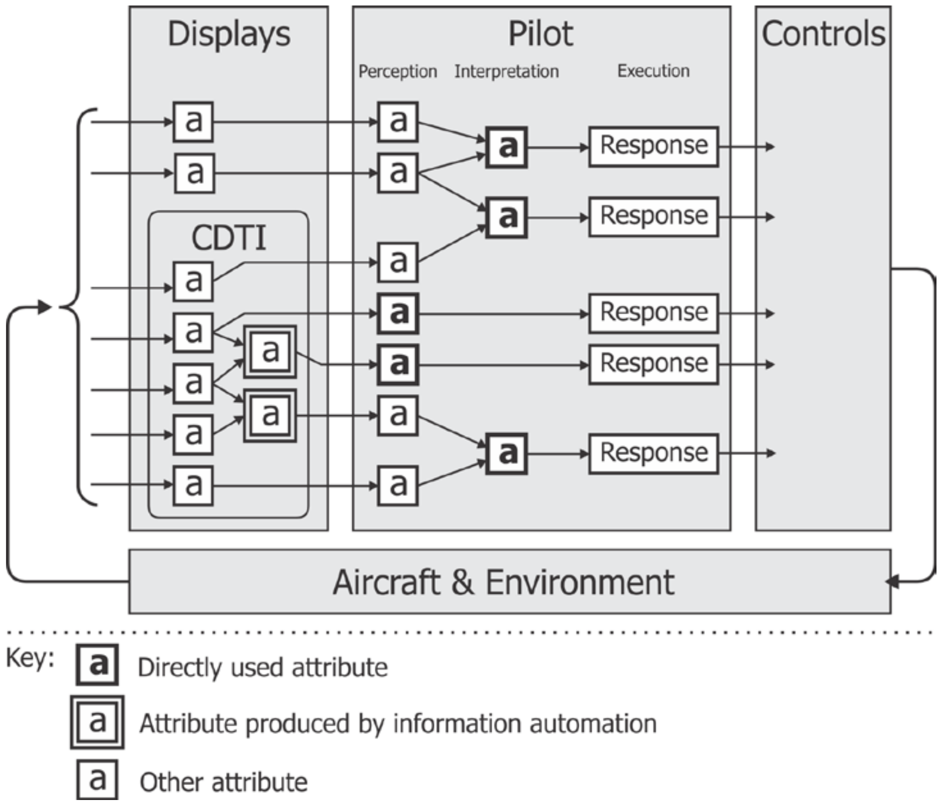


Figure 2. Control-loop model of a pilot using data from a CDTI to perform ADS-B tasks. Each attribute, or piece of data, is represented by *a*.

The pilot needs to access specific data in order to arrive at a response for each task within an ADS-B procedure. Some data are available on the CDTI, but some data may only be available from other locations, such as the vertical speed indicator.

Each piece of data available to the pilot is an **attribute** (*a* in Figure 2; see Table 1 for list of concepts in the model). An attribute is a variable that describes an aircraft or environment state whose values affect pilot perception or actions. Attributes may be represented on displays or they may only exist in the pilot's mind. That is, a pilot may read an attribute directly from a display, or create it by interpreting a display. Values that pilots enter into the CDTI (or other equipment), for the task, but do not access later, are not modeled. For example, parameters of a clearance from Air Traffic Control, such as what altitude to maintain, are not included in our model. We denote attributes using a bracket notation in this report (e.g., [range to target aircraft]).

Attributes have a particular **value**, which is the attribute's state at a given point in time. For example, [range to target aircraft] is an attribute with a quantitative value (e.g., 5.2 nm). However, attribute values do not have to be quantitative. They may be qualitative, such as a text value (e.g., "AAL212" for [flight id]), or they may be a categorical value representing a state (e.g., "not coupled" for the [coupled

[2] For simplicity, this conceptual model does not account for the role distribution and interactions among the flightcrew or between air traffic control (ATC) and flightcrew. However, the model could be expanded to include these roles and interactions.

status] attribute). In some cases, the value of an attribute is not explicitly displayed at all times. For example, the [alert status] attribute is displayed (or "true") only if it is in a "warning" or "caution" state. Pilots are to assume the non-alert state ("false") when there is no explicit display for [alert status].

In the model, attributes are classified as either **raw** or **derived**. Raw attributes are the attributes that are received directly from the Airborne Surveillance and Separation Assurance Processing (ASSAP) subsystem (RTCA, 2011). A derived attribute is an attribute constructed by the mental or automatic computation of one or more other attributes. For example, the [similar track status] attribute for a target aircraft is based on a comparison of the track attributes of the target and ownship. More specifically, if [ownship track] and [traffic track] values are less than 45 degrees apart in heading, then [similar track status] is "true" otherwise it is "false." The different attributes that go into constructing a derived attribute are **source** attributes. A source attribute may be raw or derived. That is, a derived attribute may be a function of a raw attribute or another derived attribute. A raw source attributes is an attribute that is both a raw attribute and a source attribute for a derived attribute.

A **derivation network** is a diagram that documents the relationships between derived and source attributes. For example, Figure 3 shows a simple derivation network for the derived attribute [similar track status], which has two source attributes that happen to be raw data attributes (i.e., they are available directly from ASSAP).

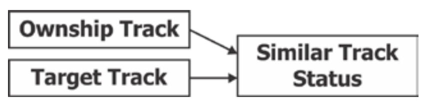


Figure 3. Example derivation network for [similar track status].

A derivation network can show derived attributes that are source attributes for other derived attributes, adding layers to the diagram. For example, a derived attribute such as [similar track status] could be a source attribute for another derived attribute. A derivation network for an entire task shows all the attributes needed to complete a task and their relationships to one another. Some attributes are more interdependent than others. In some cases, an attribute needed for the task may not be connected to other attributes needed for the task.

Sometimes a pilot mentally constructs a derived attribute from raw attributes shown on the CDTI, in which case the derived attribute only exists as a mental representation. Other times, the CDTI has **information automation** (Billings, 1997) that computes and displays derived attributes directly on the CDTI. For example, a CDTI with information automation could display the state of the [similar track status] attribute directly (yes/no), so that the pilot does not have to determine this state through a mental comparison of tracks. Even more advanced information automation can be a decision aid. For example, the automation could determine whether a particular maneuver is safe or not. The *a*'s with double borders in Figure 2 represent information automation.

Trustable information automation is present when the displayed derived attribute is one that the pilot can safely depend on; the pilot does not need to crosscheck the derived attribute against its source attributes. Thus information automation can reduce pilot workload to obtain data. The presence of trustable information automation is a property of the individual CDTI; information automation is not a property of the ADS-B procedure.

Finally, some attributes are defined as **directly used** attributes. These are attributes whose awareness leads directly to a pilot response in the procedure without any intermediary derived attributes. Directly used attributes include attributes at the far right of a derivation network and raw attributes that require no further information and derivation before pilot response. In Figure 2, directly used attributes are the *a*'s (shown in bold) that have an arrow pointing directly to a "response."

The pilot deliberately decides to access most of the data needed to complete a task when following the ADS-B procedure. For example, the pilot may access data when completing a checklist for the task or when the CDTI displays an annunciation. Such attributes are described as **routine** because accessing them is part of the documented procedure. In contrast, **non-routine** attributes are attributes that the pilot does not access routinely, but are nonetheless relevant to the task. For example, fault indications, warnings, cautions, and advisories are all non-routine attributes. As defined in Title 14 Code of Federal Regulations, §25.1322 (Flightcrew Alerting, 2011), warnings require immediate flightcrew awareness and immediate flightcrew response, cautions require immediate flightcrew awareness and subsequent flightcrew response, and advisories require flightcrew awareness and may require subsequent flightcrew response. Other non-routine attributes may require neither immediate pilot response nor awareness. Thus, alerts are non-routine attributes, but not all non-routine attributes are alerts.

In any case, all non-routine attributes should be "pushed" to the pilot. That is, assuming no aural signals for changes in the attributes, non-routine attributes must be visible to the pilot without requiring any pilot action, or else the pilot will not be aware of a change in the attribute. Particularly critical non-routine attributes, such as warnings and cautions, must be visible in the pilot's PFOV so that the pilot can detect them from a normal seated position on the flight deck when looking forward along the flight path without disorienting or undue body movement (FAA, 2010).

Table 1 summarizes the concepts in the model of CDTI use.

Table 1. Concepts in model of CDTI use.

Concept	Definition
Attribute	A variable that describes an aircraft or environment state whose values affect pilot perception or actions
Derivation network	A diagram that documents the relationships between derived and source attributes
Derived attribute	An attribute constructed by the mental or automatic computation of one or more other attributes
Directly used attribute	An attribute whose awareness leads directly to a pilot response in the procedure without any intermediary derived attributes
Information automation	The computation and display of a derived attribute directly on the CDTI
Non-routine attribute	An attribute that the pilot does not access routinely, but is nonetheless relevant to the task
Raw attribute	An attribute received directly from the Airborne Surveillance and Separation Assurance Processing (ASSAP) subsystem
Routine attribute	An attribute whose access is part of the documented procedure
Source attribute	An attribute that goes into constructing a derived attribute
Trustable attribute	A derived attribute that the pilot can safely depend on; the pilot does not need to crosscheck the derived attribute against its source attributes
Value	An attribute's state at a given point in time

3 Overview of Algorithm

The algorithm is derived from information access effort theory (Wickens, 1992). It elaborates on the protocol specified by Cardosi et al. (2011), who considered the accessibility of data for air traffic controllers. Wickens (1992) and Cardosi et al. (2011) postulate that the user should have easiest access to the most important data. The algorithm incorporates this premise.

The algorithm produces recommended levels of accessibility that correspond to the importance of each attribute in an ADS-B procedure's task. The algorithm requires subject matter experts (SMEs) to input characteristics of the directly used attributes for each task of the ADS-B procedure. A suitable set of SMEs may include representatives from the committee that developed the standards for the corresponding CDTI application and/or its associated ADS-B procedure. The algorithm can be run any time after the specifications for an ADS-B procedure are available.

Figure 4 illustrates the core of the algorithm for a single attribute. In order for the algorithm to match levels of accessibility with levels of importance for each attribute, it must first determine the importance of each attribute for each task of an ADS-B procedure.

Two inputs jointly determine the level of importance of an attribute:

- *Criticality* of the attribute (Cardosi et al., 2011)
- *Update rate* at which the pilot needs to be informed about changes in the value of the attribute (Wickens, 1992).

Each level of importance has a corresponding recommended level of accessibility. Consistent with Cardosi et al. (2011), accessibility is defined by the pilot's effort of finding data on a visual display and looking directly at the data. This effort depends on two factors:

- *Physical location* of the display on the flight deck relative to the pilot when seated in the normal position on the flight deck.
- *Virtual location* of the attribute, which is the location of the attribute within the virtual display space. The virtual display space includes all the different screen pages, including the "home" page and those which may need to be retrieved through one or more pilot actions.

Different attribute locations require different levels of effort to access. For example, an attribute immediately visible in front of a pilot is easier to access than an attribute that requires multiple pilot actions to retrieve.

After determining the recommended level of accessibility for an attribute from its importance, the algorithm then determines a recommended virtual location of the attribute for each physical location. The algorithm could just as easily do the opposite, i.e., determine the recommended physical location of the attribute for each virtual location, or even forgo decomposing the accessibility level by location. However, recommending a virtual location for each physical location of the display is expected to be more convenient for CDTI evaluations. (While virtual location is a characteristic of an attribute, physical location is typically a characteristic of an entire CDTI; thus it is more convenient to check that each attribute is in the recommended virtual location for a given CDTI physical location, than vice versa.)

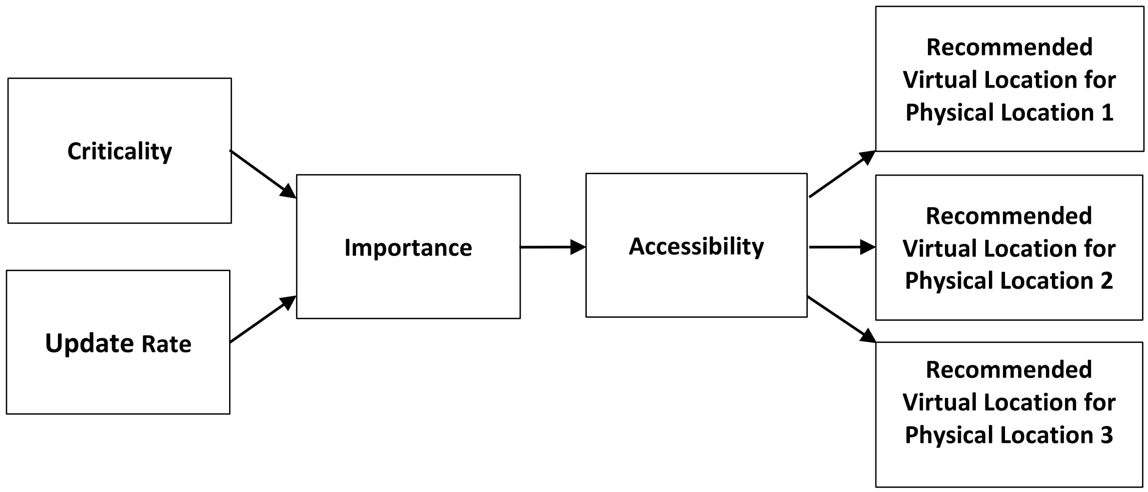


Figure 4. Core of the algorithm for a single attribute.

The algorithm requires the team of SMEs to provide a list of directly used attributes for each task of the ADS-B procedure under consideration, along with the following inputs for each attribute:

- Criticality level on a three-point scale, ranging from 1 (vital) to 3 (helpful).
- Update rate level on a four-point scale, ranging from 1 (continuous) to 4 (rare).
- Whether it is a routine or non-routine attribute.
- Whether it has a pre-specified required virtual location in guidance documents.
- Whether it is raw or derived.

The SMEs also need to document the derivation networks for this task, specifying the relations among the derived attributes and source attributes including raw attributes. The derivation networks are used later for evaluating CDTIs that may or may not have information automation. The derivation networks are not, however, an input for the algorithm that generates recommended virtual locations.

All inputs to the algorithm are characteristics of the CDTI application and its associated ADS-B procedure; the algorithm does not need any information about specific CDTI software design. The SMEs determine the inputs by reviewing industry standards and specifications for the application and associated procedure. These documents may include safety performance and interoperability requirements, minimum aviation system performance standards, minimum operational performance standards, best practice recommendations (e.g., from the Society of Automotive Engineers), and concepts of operation produced by government or industry agencies.

For a given ADS-B procedure, the SMEs identify the tasks, which the industry documents may specify, and list the documented attributes to be directly used by the pilots. This includes attributes that according to the documents must be displayed on the CDTI (or be made available to the pilot) and attributes the documents say will be used in the procedure. To complete the list of directly used attributes, the SMEs review all ADS-B raw attributes (RTCA, 2011) and judge whether any may be directly used in the task, perhaps to provide context or backup to attributes that the documents explicitly cite. For example, if the documents state that the procedure uses [traffic range], then the SMEs may infer that [display range/map scale] (RTCA, 2011) is also used to help interpret the apparent [traffic range] shown in the CDTI plan view.

If an attribute is not received directly from the ASSAP subsystem, then the SMEs construct a derivation network to identify any raw attributes that serve as source attributes. The algorithm concerns accessibility recommendations for CDTI attributes only; therefore, the SMEs need to list only attributes that are at least partially derived from raw CDTI attributes. The algorithm does not provide accessibility recommendations for attributes accessed from displays other than the CDTI.

SMEs decide if a directly used attribute is routine or non-routine by whether or not the ADS-B procedure for the CDTI application explicitly calls for the pilot to access that attribute. If the ADS-B procedure calls for the pilot to access the attribute, it is routine and likely to be included in training and/or procedure checklists, or prompted by visible changes in other attributes. Otherwise, the attribute is non-routine, and must be visible to the pilot without any action.

Finally, SMEs determine if a directly used attribute must be set to a pre-specified virtual location (e.g., the standards document for the application may stipulate that the attribute *shall* appear in the data tag).

For each attribute in the list, the algorithm uses the SME-assigned levels of criticality and update rate to determine the recommended virtual location for each physical location. The algorithm adjusts the recommended virtual locations to ensure the following two display characteristics:

- Non-routine attributes are visible to the pilot without requiring any pilot action.
- Pre-specified virtual locations override the virtual locations determined by attribute importance alone.

Furthermore, the algorithm sets up *contingency* recommended virtual locations to evaluate the accessibility of the raw source attributes of CDTIs that show derived attributes. This is how the algorithm accommodates CDTI data with information automation. The algorithm's contingency recommended virtual locations assume that if a CDTI displays a trustable derived attribute, then it is acceptable for the associated raw source attributes to be less accessible.

The algorithm needs to be executed once for each task of a procedure, but not for each CDTI under evaluation. Once the algorithm has generated recommended virtual locations for each task of a procedure, the algorithm does not need to be executed again unless the standards change for the procedure or associated application. For a given application, the same recommended virtual locations would be applied to all CDTI designs. Design-specific parameters, such as space available on the CDTI, are outside the scope of the algorithm (see Section 6).

To evaluate the conformance of an individual CDTI with the recommendations from the algorithm, an evaluator would compare, for each physical location, the recommended virtual location of each directly used attribute with the virtual location of each attribute as it is designed to appear in the individual CDTI. If the CDTI does not display a derived attribute, then the evaluator compares the recommended virtual location to the design virtual locations of the source attributes. If the virtual location in the CDTI design makes the desired attribute harder to access than the recommended virtual location generated by the algorithm, the CDTI does not conform to the accessibility recommendations for the given physical location, attribute, and task.

4 Formal Algorithm

4.1 Level Definitions

SMEs must assign numeric levels of criticality and update rate in order for the algorithm to determine attribute importance, and thus, its recommended accessibility. The algorithm's performance depends on easy-to-use definitions of each level of criticality and update rate. The algorithm translates the resulting recommended accessibility of the attribute into the recommended virtual location for each physical location. Thus, usable recommendations require well-defined levels of virtual and physical location. The criticality and update-rate levels are flight deck analogues of the categories of information defined by Cardosi et al. (2011). The intent is to define the criticality and update rate levels such that they represent approximately equal-sized intervals of importance.

4.1.1 Criticality Levels

Criticality, *C*, is a rating of how essential the attribute is for completing a specific task of an ADS-B procedure. *C* has three levels defined in Table 2.

Table 2. Levels of criticality (*C*).

Level	Label	Definitions and Examples of Criticality (*C*) Levels	Examples
1	Vital	Attributes related to the tasks of flight control, navigation (guidance), and essential power plant operation.	[Target airspeed] that the crew must maintain to ensure aircraft spacing.
2	Necessary	Attributes necessary for pilot responses in the ADS-B procedure task, including data the pilot must access to complete the task.	[Flight ID] of a reference aircraft for ITP, which must be communicated to the controller in order to initiate ITP.
3	Helpful	Attributes serving as a backup or context for interpreting necessary and vital data, including attributes used to derive necessary and vital attributes that the CDTI displays.	[Ownship directionality reference] (i.e., ownship “track” or “heading”), which provides context for ITP but is not directly used to complete the ADS-B procedure.

Level 1 (vital) is the highest level of criticality. It applies only to attributes related to the tasks of flight control, navigation, and essential power plant operation. This is in contrast to the other two levels, which are related to tasks intended to support, for example, traffic situation awareness. ADS-B applications intended to support basic situation awareness, including ITP and others listed in AC 20-172A (FAA, 2012), do not have any vital attributes by this definition.

4.1.2 Update Rate Levels

Update rate, *R*, is the frequency with which the pilot must be updated on the data to maintain sufficient awareness for the task. *R* has four levels, with 1 being the fastest update rate. The definitions of the update-rate levels for routine attributes are different than for non-routine attributes, as shown in Table 3 and Table 4.

Table 3. Levels of update rate (*R)* for routine attributes.

Level	Label	Definitions of Update Rate (*R)* Levels
1	Continuous	More than two updates per minute during the task, and the task duration is greater than 1 minute (> 2 updates/minute).
2	Multiple	Multiple updates during the task, up to twice per minute for tasks lasting longer than 1 minute (≤ 2 updates/minute).
3	Once	1.5 or fewer updates on average per task, but more than 0.5 updates on average per task (regardless of task duration).
4	Rare	0.5 or fewer updates on average per task, but more than 0 updates per task (regardless of task duration).

Table 4. Levels of update rate (*R)* for non-routine attributes.

Level	Label	Definitions of Update Rate (*R)* Levels
1	Immediate	Less than 30 seconds after the value of the attribute changes.
2	Near-term	Between 30 seconds and 2 minutes after the value of the attribute changes.
3	Far-term	More than two minutes after the value of the attribute changes.
4	Occasional	Usually no need for updates on changes to the value of the attribute.

For routine data attributes, the update rate generally equals the rate the pilot specifically checks for the data, because checklists and established procedures are designed to ensure pilots update themselves on relevant attributes as often as needed. However, this is not necessarily true of non-routine attributes, because, by definition, pilots do not look for non-routine attributes.

The update rate of an attribute is not equal to how often the values changes. Rather, update rate is equal to how quickly a pilot needs to become informed *if the attribute were to change* to certain values. Theoretically, an attribute could change several times per minute. However, if the pilot does not need to know about value changes for several minutes after they occur, then *R* is at level 3. In contrast, an attribute may change infrequently, but still have a short update rate. For example, non-routine attributes that are warnings or cautions have an *R* of 1, regardless of the frequency with which the [alert status] changes to “warning” or “caution.” Pilots need to be immediately updated if the [alert status] changes from “non-alert” to either a “warning” or “caution.”

4.1.3 Physical Location Levels

Physical location level, *P*, is the display position on the flight deck with respect to pilots’ field of view when looking forward from the normal seated position in the cockpit, assuming that the pilot has a clear unobstructed view of the display and the display is free of glare, reflections, or artifacts. The algorithm applies only to displays visible from a normal seated position on the flight deck when looking forward along the flight path, without requiring disorienting or undue body movement. There are three levels of physical location corresponding to three levels of accessibility. Table 5 provides the definitions of the three levels, where level 1 represents the easiest level of accessibility. A low numeric value for a level (e.g., 1 versus 3) represents low effort and thus easy access.

Table 5. Levels of physical location (*P*).

Level	Label	Definitions of Physical Location (*P*) Levels	Examples for Typical Cases
1	*Forward* (Fwd)	The attributes are displayed within +/– 15 degrees horizontally and +/– 15 degrees vertically of the pilot's line of sight.*	Navigation display, primary flight display, head-up display.
2	*Oblique* (Obl)	The attributes are displayed outside the forward physical location but at or within +/– 35 degrees horizontally, and +40 to -20 degrees vertically of the pilot's line of sight.*	Control and display unit (CDU), control-column mounted electronic flight bags (EFBs), auxiliary displays.
3	*Lateral* (Lat)	The attributes are displayed outside the oblique physical location but at or within +/– 60 degrees horizontally and +65 and -35 degrees vertically of the pilot's line of sight.*	EFBs mounted on either side of the flight deck or on kneeboards.

*The pilot's line of sight is a line extending from the design eye (reference) point forward along the flight path angled 15 degrees below the horizontal plane.

Figure 5 illustrates the physical location levels.

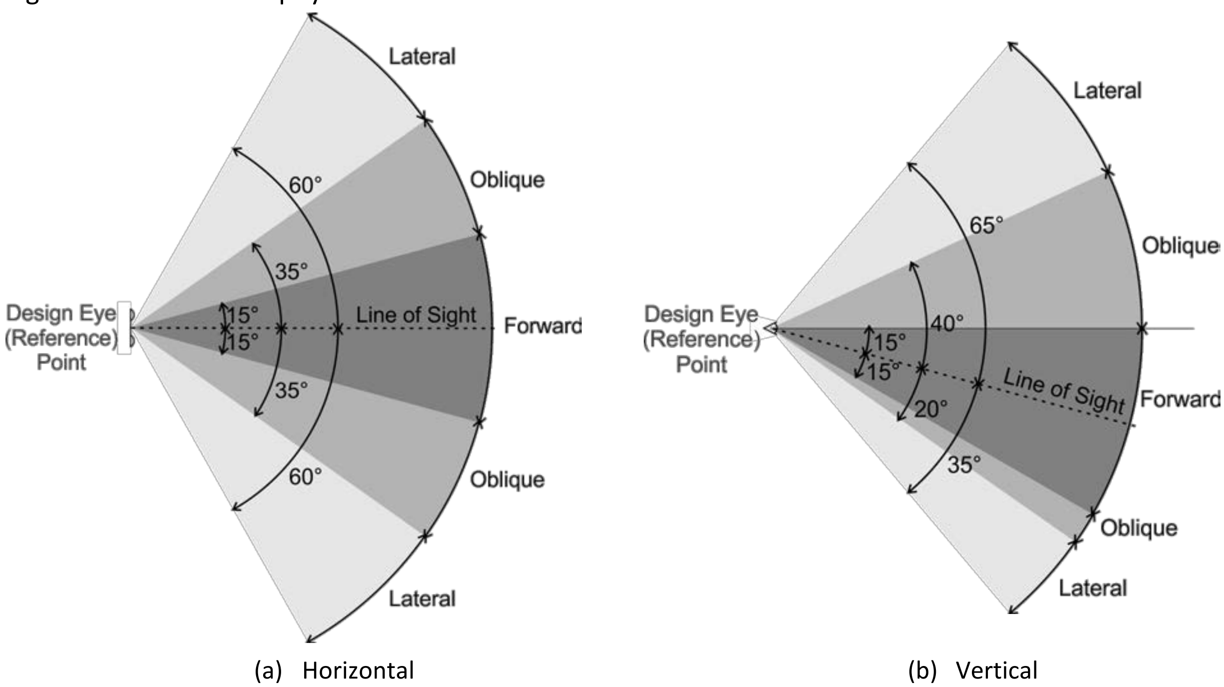


Figure 5. Physical location levels

The forward physical location corresponds to the "optimum primary field of view," and the oblique physical location corresponds to the "maximum primary field of view," as defined in AC 25-11A (FAA, 2007). The oblique physical location also corresponds to the angles where looking includes not only eye movement but also some head movement (Wagner, Birt, Snyder, and Duncanson, 1996; Wickens, 1992). The lateral physical location corresponds to the "secondary field of view" as defined by General Aviation

Manufacturers Association (GAMA) Publication No. 10 (GAMA, 2000). The algorithm does not apply to displays located greater than +/– 60 degrees horizontally or +65 and -35 degrees vertically.

4.1.4 Virtual Location Levels

Virtual location, *V*, is the location of the data in the virtual space of the CDTI (Cardosi et al., 2011). There are four levels of virtual location corresponding to four levels of accessibility: level 1 (*principal*) is the easiest level of access, followed by levels 2 (*auxiliary*), 3 (*single-action access*), and 4 (*multiple-action access*). Analogous to physical location levels, a low numeric value for a level (e.g., 1 versus 4) represents low effort and thus easy access. Table 6 defines and provides examples for each level of *V*. Data tags (an example of level 1) are implemented with the traffic symbol to provide additional data such as altitude, vertical direct, and flight ID. Data tags are generally associated with all traffic symbols (RTCA, 2011). A data block is associated with a traffic symbol to provide even more detailed data on selected aircraft, such as ground speed, range, category, flight ID, and closure rate. Some applications use a data block to convey necessary data to the flightcrew. More than one data block may be displayed. Data block(s) should be displayed at a fixed location on the display unit (RTCA, 2011).

Single-action and multiple-action access levels (3 and 4) are defined by the average number of actions a pilot must perform to access the data. If, on average, the number of actions per task is greater than 1.5, *V* is level 4 (multiple-action). If on average the number of actions per task is between 0.5 and 1.5, *V* is level 3 (single-action). If the number of actions per task is on average less than 0.5 (i.e., input is not usually necessary), *V* is level 1 or 2, depending on where the attribute appears. So, if a pilot must manually select a CDTI display mode to show a certain attribute, but then leaves the display in that mode for more than two instances of accessing the attribute during the task, then *V* is 1 or 2, not 3. However, if the pilot must select the mode each time to access the attribute, then *V* is 3 or 4 (depending on the number of actions needed to select the mode), even if the attribute is accessed only once during the task. By defining *V* this way, the algorithm incorporates pilot inputs to the display to select a display mode designed to optimize the accessibility of the attributes for the particular task.

Table 6. Levels of virtual location *(V)*.

Level	Label	Definitions of Virtual Location (*V*) Levels	Examples
1	*Principal*	A region of the display intended to show attributes full time.	Plan-view traffic display of the CDTI, including both traffic symbology and data tags (RTCA, 2011).
2	*Auxiliary*	A region of the display intended to show variable attributes to supplement attributes in the principal region. These may be attributes for pilot-selected traffic, but otherwise the attributes appear automatically without pilot action. Attributes in auxiliary locations do not occlude attributes in the principal locations.	Data block for selected targets (RTCA, 2011).
3	*Single-action access*	Attributes that require a single pilot input, such as a button press, each time it is accessed. Attributes in the single-action virtual location may partially or fully occlude attributes in the auxiliary virtual location.	The display of map layers, changes to map range, changes of the selected target, access to other pages of data.
4	*Multiple-action access*	Attributes that requires more than one pilot input each time it is accessed.	Attributes in a multi-level menu.

4.2 Calculations, Constraints, and Contingencies

Given the SME-assigned levels of criticality and update rate, the algorithm computes the recommended virtual location for each physical location. Appendix A provides pseudo-code that summarizes these computations. This section provides a full conceptual description of the algorithm.

4.2.1 Calculating Importance

The importance *I* is determined by combining the numeric levels of the criticality *C* and update rate *R* as in Equation (1):

$$I = C + R - 1 \qquad (1)$$

Table 7 shows the importance levels that this function produces for every combination of *C* and *R*. With three levels for *C* and four levels for *R*, there are six levels of importance *I.* Subtracting 1 from the sum of *C* and *R* sets the highest level of importance to 1.

Table 7. Importance levels created by combining criticality and update rate.

	Criticality (*C*)		
Update Rate (*R*)	**1 Vital**	**2 Necessary**	**3 Helpful**
1 Continuous/Immediate	1	2	3
2 Multiple/Near-Term	2	3	4
3 Once/Far-Term	3	4	5
4 Rare/Occasional	4	5	6

By combining criticality and update rate in this way, level 1 importance implies that both the criticality is vital and the update rate is continuous. Conversely, level 6 importance implies that the criticality is merely helpful and the update rate is rare or occasional. There are multiple possible combinations of *C* and *R* for importance levels 2, 3, 4, and 5. For example, there are two ways to get level 2 of importance, either due to vital (level 1) criticality and multiple/near-term (level 2) update rate, or necessary (level 2) criticality and continuous/immediate (level 1) update rate. An essential assumption of this algorithm, which should be validated, is that different combinations of criticality and update rate resulting in the same calculated importance level are indeed approximately equally important.

4.2.2 Virtual Location Based on Importance

Six levels of importance require six corresponding levels of accessibility, which are produced by summing the effort to access the attribute, which depends on:

- The physical location of the display, which has three levels
- The virtual location of the attribute on the display, which has four levels.

The effort for accessing the physical location and virtual location is combined as in Equation (2) to yield the accessibility, *A*:

$$A = P + V - 1 \qquad (2)$$

Similar to the importance levels, most accessibility levels can be achieved by more than one combination of physical and virtual location, as shown in Table 8.

Table 8. Accessibility levels created by combining physical location and virtual location.

Virtual Location (V)	Physical Location (P)		
	1 Fwd	**2 Obl**	**3 Lat**
1 Principal	1	2	3
2 Auxiliary	2	3	4
3 Single-Action	3	4	5
4 Multiple-Action	4	5	6

Analogous with the importance levels, an essential assumption of this algorithm, which should be validated, is that different combinations of physical and virtual location that have the same accessibility level are approximately equally accessible. For example, if an attribute has a recommended accessibility level of 2, then an obliquely installed CDTI with the attribute on the plan-view conforms to the recommendation; just as a forward-installed CDTI with the attribute in the data block conforms to the recommendation. The algorithm also is constructed so that the recommended minimum accessibility level for an attribute is equal to its importance level I. For example, if an attribute has I equal to 2 then the recommended accessibility level also equals 2, so low values represent easy access and vice versa.

To provide output useful for a CDTI evaluation, the algorithm converts accessibility levels into recommended virtual locations for each physical location. Substituting I for A in Equation 2 and solving for V achieves this, as shown in Equation (3):

$$V_{Pa}(\mathrm{i}) = I - P + 1 \qquad (3)$$

V_{Pa} represents the recommended virtual location for attribute a on a display that is in physical location P. The notation V_{Pa}(i) indicates that Equation (3) provides the "initial" V_{Pa} in the sense that it depends only on the physical location and the attribute's importance (i.e., SME-assigned levels of criticality and update rate), and does not take into account other characteristics of the attribute, such as whether it is routine or non-routine.

Substituting Equation (1) for I yields:

$$V_{Pa}(\mathrm{i}) = C_a + R_a - P \qquad (4)$$

where C_a and R_a are the criticality and update rate for attribute a.

Levels of V_{Pa} that are zero or negative imply that there is no physical location that can provide recommended accessibility. If the result of Equation (4) is a number greater than 4, the level of V_{Pa} is assigned 4, the least accessible virtual location. The possible results of Equation (4) are in Table 9, which shows the six importance levels in rows. The table cells contain the levels for V_{Pa}. The indication "n/a" means V_{Pa} is zero or negative and there is no physical location that can provide recommended accessibility.

Table 9. Recommended virtual location as a function of importance and physical location.

Importance Level (*I*)	Physical Location (*P*)		
	1 Fwd	**2 Obl**	**3 Lat**
1	1 Principal	n/a	n/a
2	2 Auxiliary	1 Principal	n/a
3	3 Single-Action	2 Auxiliary	1 Principal
4	4 Multi-Action	3 Single-Action	2 Auxiliary
5	4 Multi-Action	4 Multi-Action	3 Single-Action
6	4 Multi-Action	4 Multi-Action	4 Multi-Action

While there are different ways of achieving a particular accessibility level, importance levels of 1, 2, or 3 constrain the physical and virtual locations. For all three levels, there are one or more virtual locations that cannot conform to the recommendations regardless of the physical location. For levels 1 and 2, there are one or more physical locations that cannot conform to the recommendations regardless of the virtual location. For example, to conform to the recommended accessibility for an attribute with an importance level of 2, the attribute can be in an auxiliary region of the forward display or the principal region of an oblique display. It can also be in the principal region of a forward display. Pilot actions must not be required to view the attribute, regardless of the display's physical location for an importance level of 2. An attribute continuously necessary for flight or navigation ($I = 1$) should be in the principal virtual location of a display located in the forward physical location. This recommendation is consistent with Advisory Circular (AC) 25-11A (FAA, 2007). In contrast to importance levels 1, 2, and 3, importance levels 4, 5, and 6 allow any physical location level and any virtual location level, although certain combinations of physical and virtual locations do not conform to the recommendations.

4.2.3 Tradeoff between Physical and Virtual Location

As indicated by Equation (2) and shown in Table 9, the algorithm implies a trade-off between physical location and virtual location. If an attribute is in an easy-to-access virtual location, such as in the principal region, the display can tolerate a less accessible physical location, such as a lateral position, while still yielding a moderate level of accessibility. Similarly, if an attribute is in an easy-to-access physical location, such as in the forward physical location, then the CDTI can tolerate a less accessible virtual location, such as requiring the pilot push a button to view the attribute, and still achieve the same moderate level of accessibility.

If a single physical display shows all the data for an ADS-B flight deck procedure, then the physical location of the display may be limited by the highest recommended accessibility level of any single piece of data used for the procedure. For example, if the attribute [closure rate] has an importance level of 2 for a task in the application (e.g., necessary for the task and needing continuous pilot update), then a CDTI installed in a lateral physical location on the flight deck does not conform to the recommendations. The lateral position has a *P* of 3, so even if [closure rate] is shown in the most accessible virtual location (the principal region, $V = 1$), the accessibility level according to Equation (2) is $3 + 1 – 1 = 3$, which does not satisfy the recommended accessibility of 2.

Furthermore, the virtual location that the manufacturer selects for certain data may limit where a CDTI could be installed in order to conform to the recommendations. For example, suppose the attribute [closure rate] has an importance level of 3 for a different task in the application, resulting in a minimum recommended accessibility level of 3. If the CDTI displays the [closure rate] in an auxiliary region ($V = 2$), then the display should not be installed in the lateral physical location (P = 3). The accessibility level for data in the auxiliary region of a laterally installed display is 2 + 3 – 1 = 4, which is less accessible than recommended. However, if the CDTI displays the [closure rate] in the principal region (V = 1), then it may be installed in the lateral physical location because the accessibility level is now 1 + 3 – 1 = 3, which conforms to the minimum recommended accessibility.

4.2.4 Constraints on Virtual Location for Non-routine Attributes

The V_{Pa} (i) depends only on the physical location of the display and the importance of the attribute, and can vary from 1 to 4. Non-routine attributes, however, are constrained to a smaller set of possible virtual locations. Because the pilot does not actively seek non-routine attributes, they need to be visible to the pilot without any pilot action. Therefore, non-routine attributes must have a virtual location of 1 or 2, regardless of their level of importance or the display's physical location. In other words, non-routine attributes may only appear in the top half of Table 8. This means that although the non-routine attribute can be shown on a display in any of the three physical locations, it must be in either the principal or auxiliary virtual location; that is, no pilot action beyond moving head or eyes should be required to access the non-routine attribute. According to the algorithm, warning- and caution- level alerts for vital attributes should have a visual annunciation (such as a master warning/caution light) in the forward (level 1) physical location if the CDTI display itself is not in the forward (level 1) physical location.

To formalize this constraint, let V_{Pa}(r) be the recommended virtual location adjusted for routine and non-routine attributes. For routine attributes, V_{Pa}(r) equals V_{Pa}(i). For non-routine attributes, if V_P(i) is 3 or 4, then the V_{Pa}(r) equals 2; otherwise, V_{Pa}(r) equals V_{Pa}(i).

Requiring that all non-routine attributes remain visible might lead to CDTIs with excessive clutter. However, a manufacturer can address such a requirement by turning multiple non-routine attributes into a single non-routine attribute prompting the pilot to seek them. Thus, if a particular CDTI design is not able to show certain non-routine attributes in the principal or auxiliary locations, it may instead create a derived attribute to show in the principal or auxiliary location. This "derived non-routine attribute" signals to pilot a change of source attributes, prompting the pilot to seek the attributes. To control clutter, the derived non-routine attribute could use a smaller visual image than the source attributes would use. (The derived attribute could also be an auditory signal, but auditory signals are outside the scope of this algorithm.)

4.2.5 Constraints on Virtual Location from Pre-specified Guidance

Guidance documents for a given application may pre-specify the virtual location of attributes used in a task. For example, an RTCA minimum operational performance standard may require that traffic symbols signal the suitability of traffic for a procedure. Because traffic symbols are in the principal virtual location, such a requirement pre-specifies that attribute [suitability of traffic for a procedure] appears in virtual location level 1. Because the algorithm provides only recommendations for levels of accessibility, the recommended virtual locations are equally constrained by recommendations ("should" statements) and requirements ("shall" statements) in the guidance documents.

To formalize this constraint in the algorithm, let V_{Pa} be the recommended virtual location that is adjusted for both the attribute's pre-specified virtual location from associated guidance documents and for its being non-routine. If the guidance document recommends or requires that an attribute be in a virtual location level that is more accessible than V_{Pa}(r), then V_{Pa} equals the recommended or required virtual location level. Otherwise V_{Pa} equals V_{Pa}(r).

SMEs determine pre-specified virtual locations in their review of industry standards and specifications for the application and associated procedure as part of preparing the input to the algorithm. Table 10 provides examples of language in a guidance document that would indicate pre-specified virtual location levels 1 and 2 for an attribute.

Table 10. RTCA language that implies minimum accessibility levels.

V	**Language**
1	The CDTI **symbology** shall/should include/provide/display/indicate [attribute] The CDTI **data tag** shall/should include/provide/display/indicate [attribute]
2	The CDTI shall/should include/provide/display/indicate [attribute] The CDTI **data block** shall/should include/provide/display/indicate [attribute]

4.2.6 Virtual-Location Contingencies for Information Automation

The algorithm represents information automation as derived attributes calculated from source attributes. If a CDTI does not display a trustable derived attribute at the recommended level of accessibility, then the pilot needs to access the source attributes in order to determine the derived attribute for the task. In that case, the source attributes are as important as the derived attribute and are recommended to have the same V_{Pa}'s as the derived attribute.

For example, consider the [similar track status] derived variable, a true-false attribute that is derived from [target track] measured in degrees (see Figure 3). If [similar track status] has a V_{Pa} of 2 for the oblique physical location (P = 2), we can describe this situation as V_{2a} is 2. If the CDTI does not display a trustable [similar track status], then source attribute [target track] has the same V_{2a} of 2 as the derived attribute [similar track status].

However, if a CDTI displays a trustable derived attribute at the recommended level of accessibility, then the source raw attributes serve only as a backup or context for interpreting the displayed derived attribute. That is, the raw source attributes have a criticality level of 3, or "helpful" (see Table 2). In other words, because the raw source attributes have relatively low criticality, the algorithm recommends relatively low accessibility for them. The presence of information automation can thus lower the recommended accessibility level for the raw source attributes.

Formally, let V'_{Pa} be the "contingency" recommended virtual location to be used to evaluate the raw source attributes of a displayed derived attribute *a.* To calculate V'_{Pa} of the source attributes for a trustable derived attribute, the algorithm substitutes 3 ("helpful") for C_a in Equation (4) yielding Equation (5).

$$V'_{Pa} = 3 + R_a - P \qquad (5)$$

The algorithm applies the same V'_{Pa} to all source attributes of a particular derived attribute *a.* The algorithm does not constrain the raw source attributes for being non-routine and pre-specified. Because the CDTI displays the derived attribute, these constraints only need to apply to the derived attribute.

As an example, if a CDTI calculates and displays a trustable [similar track status] of a selected target, then the algorithm calculates the source attribute virtual location V'_{Pa} for each P using a C of 3 ("helpful"). If [similar track status] has a criticality level (C) of 2, is a routine attribute, and does not have a pre-specified virtual location from guidance documents, then the recommended virtual location V'_{Pa} of the raw source attributes is exactly one level less accessible than the corresponding V_{Pa}. If V_{2a} (recommended virtual location for the oblique physical location) is 2, then V'_{2a} is 3. This means that if the CDTI shows a trustable [similar track status] in the datablock (virtual location level 2), then the algorithm allows for the access to [traffic track] to require one pilot action, as defined for virtual location level 3.

4.2.7 Algorithm Output

The algorithm generates two tables of virtual locations as output: a base table and a contingency table. The base table provides the V_{Pa} for each of the three physical location levels *P* and each directly used attribute *a* (be it raw or derived) of a task. That is, the table contains the recommended virtual locations for each directly used attribute in each of the physical locations. The contingency table recommends, for each physical location *P*, the virtual location V'_{Pa} of the raw source variables for each directly used derived attribute *a* of a task. That is, the table contains the recommended virtual locations for the raw source attributes of a derived attribute *a* when the CDTI displays *a*.

5 Examples

5.1 Single Attribute for the In-Trail Procedure

The following example provides a walk-though of the algorithm for a single attribute used in the execution phase of ITP as described in RCTA DO-312 (RTCA, 2008). For this example, we (the authors of this report) played the role of the SMEs and set the inputs to the algorithm ourselves, as an illustration of the method. When the algorithm is used to derive recommendations for actual use, its inputs should come from experts representing industry and government (e.g., an RTCA subcommittee). This walk-through is an illustration only, so the output should not be regarded as actual recommendations for ITP.

RTCA DO-312 states that, during the ITP execution phase (or task), if “the distance between the ITP and Reference Aircraft is reduced such that a significant reduction in safety or potential midair collision is possible, the ITP flightcrew shall follow regional contingency procedures” (A2.2.3.3, OR.13). This statement implies the ITP procedure considers an attribute we call [traffic unsafe range status], which may have the values “safe” (no potential for midair collision) or “unsafe” (potential for midair collision). The example in this section applies the algorithm to the attribute [traffic unsafe range status] as we interpret it being used for the ITP execution task.

5.1.1 Input Preparation

The attribute [traffic unsafe range status] is a derived attribute, not a raw attribute received directly from ASSAP. We, acting as SMEs, would construct the derivation network for [traffic unsafe range status]. From our reading of RTCA DO-312, we infer that [traffic unsafe range status] is derived from the raw CDTI attribute [traffic range] and an unspecified criterion range such that when [traffic range] falls below the criterion, the [traffic unsafe range status] changes from “safe” to “unsafe.” Figure 6 shows the derivation network for [unsafe traffic range status]. The implied range criterion is excluded from the derivation network because it is not ASSAP data. That is, while a specific CDTI may contain a range criterion, CDTIs are not required to show such data (RTCA, 2011).

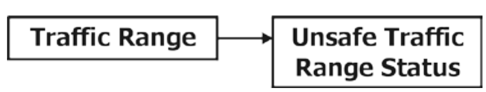


Figure 6. Derivation network for ITP execution.

To determine the recommended accessibility for [traffic unsafe range status], we need to set the criticality and update rate of the attribute, and also whether or not the attribute is routine and pre-specified. RTCA DO-312 says [unsafe traffic range status] is necessary for pilot responses in ITP (because it triggers regional contingency procedures). Thus the criticality level is at least 2 (necessary). However, given that [unsafe traffic range status] is a binary variable, it was apparent to us that this attribute by itself does not provide specific flight control or guidance information, thus excluding a criticality level of 1 (vital). Therefore, we set the criticality level as 2 (see Table 2).

RTCA DO-312 does not specify that the pilot check for [traffic unsafe range status] during the task as part of flightcrew performance. To the contrary, RTCA DO-312 explicitly says "ITP aircraft crew is not required to monitor the ITP Distance to the Reference Aircraft" (Section A2.2.3.1, p. 72). Thus, we regard [traffic unsafe range status] to be a non-routine attribute. RTCA DO-312 states that when [traffic unsafe range status] is "true," then "a significant reduction in safety or potential midair collision is possible." RTCA DO-312 does not state that "true" necessarily implies an *actual* reduction in safety or an *imminent* midair collision, only that such events are "possible." We interpreted the language in RTCA DO-312 to mean the pilot does not have to immediately respond to a change in [traffic unsafe range status] to "true," but safety is deteriorating fast enough that the pilot must respond within a minute or so in order to maintain safety. Thus, we concluded that the pilot needs to be updated of changes in [traffic unsafe range status] within a minute, and this corresponds to update rate level 2 for non-routine attributes (see Table 4).

Finally, we found no pre-specified virtual location for [traffic unsafe range status] in the guidance documents.

Table 11 shows the input the "SMEs" prepared for the algorithm. The dash for pre-specified indicates no pre-specified virtual location level.

Table 11. Illustrative input for [traffic unsafe range status].

Attribute	**Derived?**	***C***	***R***	**Routine?**	**Pre-specified**
Traffic unsafe range status	Yes	2	2	No	-

5.1.2 Algorithm Processing

Table 12 illustrates how the algorithm processes [traffic unsafe range status] to determine the base table of virtual locations.

Table 12. Algorithm processing of [traffic unsafe range status] for base table.

Attribute	***C***	***R***	**Routine?**	**Pre-specified**		V_{Pa}		
						Fwd 1	**Obl 2**	**Lat 3**
Traffic unsafe range status	2	2	No	-	Initial (i)	3	2	1
					Routine (r)	2	2	1
					V_{Pa}	2	2	1

In the first row, the algorithm uses Equation (4) to calculate V_{Pa}(i), the initial virtual location for [traffic unsafe range status] at each of the three physical locations. For example, V_{Pa}(i) for the forward physical location (V_{1a}(i)) is 2 + 2 – 1 = 3, while , V_{Pa}(i) for the oblique physical position (V_{2a}(i)) is 2 + 2 – 2 = 2. In the second row, the algorithm computes V_{Pa}(r), taking into account the input that [traffic unsafe range status] is non-routine. This constrains V_{Pa}(r) to level 2 or better. This changes V_{1a}(r) from 3 to 2. The remaining V_{Pa}(r)'s are unchanged from V_{Pa}(i). Finally, in the last row, the algorithm constrains V_{Pa} by the pre-specified virtual location. There is no pre-specified virtual location, so the final V_{Pa} equals V_{Pa}(r).

To conclude, based on our straw-man "SME" inputs, the algorithm recommends that CDTIs that are installed in the forward or oblique physical locations should display [traffic unsafe range status] in the auxiliary virtual location (or better). The algorithm recommends that CDTIs installed in the lateral physical location should display [traffic unsafe range status] in the primary physical location.

The attribute [traffic unsafe range status] is a derived variable, so the algorithm calculates the recommended virtual locations for the contingency table by applying Equation (5). Table 13 illustrates the algorithm's processing.

Table 13. Algorithm processing of [traffic unsafe range status] for contingency table.

		Raw Source Attribute V'_{Pa}		
Derived Attribute	***R***	**Fwd 1**	**Obl 2**	**Lat 3**
Traffic unsafe range status	2	4	3	2

Table 13 shows the recommended virtual locations for the raw source attributes of [traffic unsafe range status] if the CDTI displays [traffic unsafe range status]. The same three V'_{Pa} apply to all raw source attributes of [traffic unsafe range status]. In this case, [traffic unsafe range status] has only one raw source attribute: [traffic range], so Table 13 is the recommended virtual locations for [traffic range] if the CDTI displays [traffic unsafe range status]. Comparing Table 13 and Table 12 for [traffic unsafe range status] shows that, for each physical location, [traffic range] may require more effort to access than [traffic unsafe range status], consistent with the raw source attributes being less important that displayed derived attributes.

To conclude, based on our straw-man SMEs' inputs, if the CDTI displays [traffic unsafe range status], then the algorithm recommends that [traffic range] be shown in virtual location level 4 for a forward installation, level 3 for an oblique installation, and level 2 for a lateral installation. In reality, [traffic range] is apparent from the plan view of the CDTI (RTCA, 2011). Therefore the designed virtual location is more accessible than this straw-man recommendation and CDTIs will conform to the recommendation.

5.2 In-Trail Procedure Execution Task

Here, as an illustration, we apply the algorithm to the execution task of the ITP flight deck procedure. Appendix B contains a demonstration of the algorithm on all phases of the ITP procedure. As above in Section 5.1, RTCA DO-312 (2008) serves as the guidance document for ITP. We again served as straw-man SMEs determining the inputs to the algorithm. The results are merely illustrative and should not be regarded as actual recommendations for ITP.

5.2.1 List of Attributes

The first step is to identify all the data attributes that are used for the task, including both raw and derived attributes, and both explicit and implied attributes. Our interpretation of RTCA DO-312 is that the execution task of ITP uses:

- [Traffic unsafe range status]

- [Traffic selected status]

The former is used because RTCA DO-312 discusses avoiding potential midair collisions during execution (as detailed in Section 5.1). The latter is used because pilots need to be updated on changes in which traffic is selected for the ITP during the execution task.

We then reviewed all raw attributes provided by ASSAP (RTCA, 2011), and selected additional attributes we regarded as relevant to ITP execution:

- [Display range/map scale]
- [Altitude band]
- [Non-default display criteria]

We believed these raw attributes all provide context for maintaining awareness of the potential for a midair collision.

5.2.2 Input Preparation

Having identified five attributes directly used for the execution task of ITP, we next assigned the input settings for these attributes:

- The attribute [unsafe traffic range status] is the only derived attribute used for the execution task.
- We assigned a criticality level of 2 (“necessary”) for [traffic unsafe range status] and [traffic selected status]. In our interpretation of RTCA DO-312, both are necessary for pilots to complete the execution task, but neither one concerns flight control, navigation (guidance), or essential power plant operation.
- We assigned a criticality level of 3 (“helpful”) to the remaining three attributes. All these attributes provide context for interpreting other attributes.
- We assigned an update rate of 2 (“multiple”/“near term”) to [traffic unsafe range status] and [traffic selected status]. In our interpretation of RTCA DO-312, pilots would not have to be continuously or immediately updated on changes in these attributes, but they would need to be updated within about a minute on any change.
- We assigned an update rate of 3 to the remaining three attributes. We believed the pilot would only have to check on these attributes once during the task to verify their settings.
- In our interpretation, only [traffic unsafe range status] is a non-routine attribute.
- In our interpretation, RTCA DO-312 does not provide pre-specified virtual locations for any of attributes we listed.

Table 14 shows our settings.

Table 14. Illustrative input for ITP execution task.

Attribute	Derived?	*C*	*R*	Routine?	Pre-specified
Traffic unsafe range status	Yes	2	2	No	-
Traffic selected status	No	2	2	Yes	-
Display range/map scale	No	3	3	Yes	-
Altitude band	No	3	3	Yes	-
Non-default display criteria	No	3	3	Yes	-

5.2.3 Algorithm Output

Table 15 shows the base table generated by the algorithm. For brevity, the table does not show the intermediary values for V_{Pa}(i) and V_{Pa}(r).

Table 15. Illustrative base table for ITP execution task.

Attribute	Derived?	*C*	*R*	Routine?	Pre-specified	V_{Pa}		
						Fwd 1	Obl 2	Lat 3
Traffic unsafe range status	Yes	2	2	No	-	2	2	1
Traffic selected status	No	2	2	Yes	-	3	2	1
Display range/map scale	No	3	3	Yes	-	4	4	3
Altitude band	No	3	3	Yes	-	4	4	3
Non-default display criteria	No	3	3	Yes	-	4	4	3

The algorithm computes the recommended virtual locations for [traffic unsafe range status] as detailed in Section 5, constraining its virtual location to level 2 or better because [traffic unsafe range status] is a non-routine attribute. The remaining attributes are routine, and no attributes have pre-specified virtual locations. Thus, the recommended virtual locations for the remaining attributes are simply the sum of criticality *C* and update rate *R* minus the physical location *P*, as defined in Equation (4). For [display range/map scale], [altitude band], and [non-default display criteria], Equation (4) yields 5 for the forward physical location. However, the least accessible virtual location level is 4, so the output is 4.

Table 16 shows the contingency table generated by the algorithm. The attribute [traffic unsafe range status] is the only derived attribute, so the contents of Table 16 are identical to Table 13 from the earlier example of a contingency table with [traffic unsafe range status].

Table 16. Illustrative contingency table for ITP execution task.

Derived Attribute	*R*	Raw Source Attribute V'_{Pa} Fwd 1	Obl 2	Lat 3
Traffic unsafe range status	2	4	3	2

6 Limitations and Assumptions

Output from the algorithm is intended to ensure that data on a CDTI are appropriately accessible (see Section 1), where we defined accessibility as the amount of effort of finding data on a visual display and looking directly at the data. The algorithm can be applied to any CDTI, regardless of its level of information automation (see Section 4.2.6). The algorithm also makes allowances for different types of attributes, including routine and non-routine attributes, and it considers established specifications related to the display of data on a CDTI. However, the algorithm has limitations and assumptions that impact its potential validity and applicability.

One key assumption of the algorithm is that each level of importance corresponds to the same level of accessibility. For example, we intend that an attribute with level 3 importance should have level 3 accessibility to match the pilot's needs. These levels are broadly defined, so we expect that this assumption is true in general. However, the validity of the algorithm's output depends on this assumption being consistent with reality.

A limitation of the algorithm is our definition of accessibility. Merely finding the data on the screen and looking directly at the data does not guarantee that the data are used effectively for the task. The pilot must perform additional cognitive steps to make use of the data. For example, the pilot must notice the presence of the data attribute, read its value, and interpret its meaning and relevance to his or her current goals. Some of the factors that may affect the use of the data, but are outside the scope of the algorithm, include:

- Text selection, symbol design, and rendering (e.g., legibility, recognizability, and distinctiveness).
- The visual form of the attribute (e.g., use of text versus graphics, use of highlighting, size, or stroke intensity to add emphasis).
- Decision aids and related automation designed to reduce the pilot workload.
- Visual clutter (e.g., a particular CDTI design may not have enough space in the principal virtual location to display all the attributes recommended by the algorithm without clutter).
- Auditory display of traffic data.

A full evaluation of the ability to use data on the CDTI would assess the CDTI on all these factors in addition to the accessibility of the data as we have defined it.

The algorithm also does not consider the internal consistency of the layout of the CDTI or the relationships between attributes. In other words, the algorithm does not take into account whether related attributes are visually well organized. The algorithm treats each attribute independently. Therefore, results of the algorithm should be reviewed to check whether the accessibility of one piece of data is somehow affected by the accessibility of another piece of data. For example, two pieces of data may need to be displayed together for a better overall representation of the situation.

Another limitation of the algorithm is that it considers only the data on the CDTI. ADS-B procedures generally require pilots to *integrate* data from more than one flight deck display, but we do not analyze any other displays (e.g., the navigation display or the vertical speed indicator). Evaluation of such other displays used in an ADS-B procedure requires a separate analysis, which may be based on the principles of the algorithm (e.g., that continuously used flight control and navigation data should be in the forward physical location).

Finally, the validity of the algorithm depends on the definitions of the levels of criticality, update rate, virtual location, and physical location. Our intent is to define the levels such that they represent equal-sized intervals (i.e., an interval scale) in the underlying constructs of importance and accessibility. That is, each level of the variable is supposed to be approximately equally distant from any other adjacent level (e.g., the difference between criticality level 1 and 2 is the same as the difference between criticality level 2 and 3). Furthermore, different variables use the same size intervals (e.g., the difference between criticality level 2 and 3 is the same as the difference between update rate level 2 and 3). If the levels represent equal-sized intervals, then it is valid to add and subtract level numbers and compare the results. Having equal-sized intervals means, for example, that an attribute with criticality level 2 and update rate 3 is as important as an attribute with criticality level 3 and update rate 2.

7 Using the Algorithm Output to Evaluate a CDTI

After SMEs have used the algorithm to generate accessibility recommendations for an ADS-B, a government or industry evaluator may use the recommendations to evaluate CDTI software designs and installations. Evaluating a CDTI's conformance to the recommendations of the algorithm requires three inputs:

- The base and contingency tables of recommended virtual locations generated by the algorithm for all CDTIs.
- The derivation networks created by SMEs as part of preparing input for the algorithm.
- The actual virtual location of each attribute in the CDTI design to be evaluated.

Figure 7 illustrates the basic process for evaluating the accessibility of a single attribute shown on a given CDTI design for a specific task of a specific ADS-B procedure.

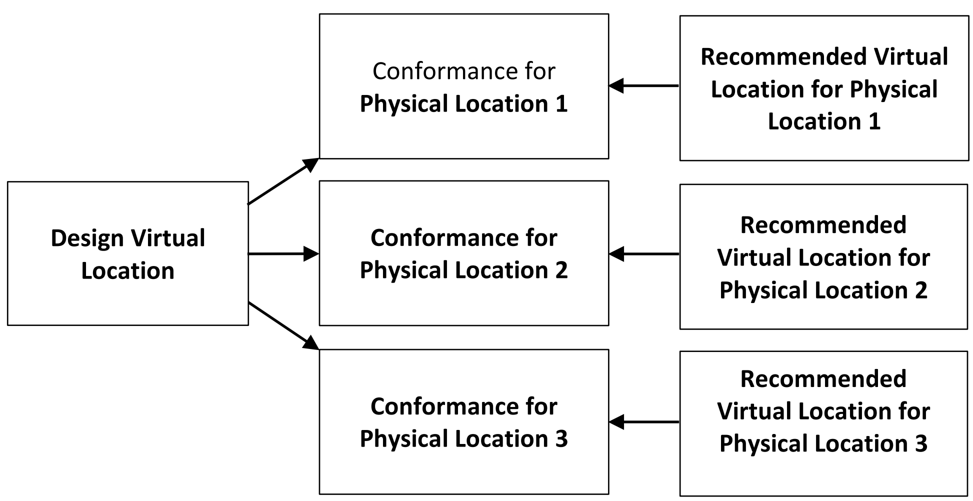


Figure 7. Comparing the algorithm's recommended virtual location for an attribute with designed locations to evaluate CDTI conformance.

Because the CDTI may have multiple display modes, the attribute could be shown in different places depending upon the task. The evaluator therefore first has to identify where each attribute will be shown on the CDTI during each task, using the display modes as intended by the manufacturer to optimize the CDTI for the task. The evaluator's classification of the design virtual location level should include the pilot actions necessary to set the display mode, using the task "average" number of actions as described in Section 4.1.4.

For each task of each ADS-B procedure, the evaluator compares, for each attribute and each physical location, the design's virtual location to the recommended virtual location. If the design's virtual location is harder to access than the recommended virtual location, the CDTI does not conform to the accessibility recommendations for the given physical location, attribute, and task. It is of course always acceptable for an attribute to be displayed at a more accessible level than recommended by the algorithm.

For example, consider evaluating a CDTI for the execution task of ITP using the illustrative base (Table 15) and contingency (Table 16) tables in Section 5.2 above. Assume the CDTI displays [unsafe traffic range status] in the data block (i.e., virtual location level 2) when the CDTI is used for the execution task. According to the illustrative base table, the recommended virtual location level is 2 for CDTIs installed in the forward and oblique field of view, and 1 for CDTIs installed in the lateral field of view. Thus, the CDTI design conforms to the recommendations for [unsafe traffic range status] if the CDTI is installed in the forward and oblique physical locations, but not if the CDTI is installed in the lateral location.

The evaluator considers information automation in the evaluation by identifying the trustable derived attributes that the CDTI displays and determining their virtual locations. If the CDTI displays a trustable derived attribute, then the evaluator:

- Compares the design virtual location of the attribute with the recommended virtual location for each physical location in the base table, as described above for [unsafe traffic range status].
- Uses the derived attribute's derivation network to identify the raw source attributes of the derived attribute. For example, [unsafe traffic range status] has one raw source attribute, [traffic range] (see Figure 6).
- Determines the design virtual location of each raw source attribute on the CDTI under evaluation. For example, assume [traffic range] is visible on the CDTI plan view (virtual location level 1) during the execution task of ITP.
- Compares the design virtual location of the raw source attribute with the recommended virtual location for derived attribute in each physical location in the *contingency* table. For example, Table 16 recommends virtual location levels 4, 3, and 2 for [unsafe traffic range status] on CDTIs shown in the forward, oblique, and lateral physical positions respectively. Thus, having [traffic range] on the CDTI plan view conforms to the recommendations of the algorithm for all physical locations.

If the CDTI does not display a derived attribute, or does not display the derived attribute at the recommended level of accessibility, then the evaluator:

- Uses the derived attribute's derivation network to identify the source attributes of the derived attribute. For example, [traffic range] is a source attribute for [unsafe traffic range status].
- Determines the design virtual location of each source attribute on the CDTI under evaluation.
- Compares the design virtual location of the source attribute with the recommended virtual location for derived attribute in each physical location in the *base* table. For example, Table 15 recommends virtual location levels 2, 2, and 1 for [unsafe traffic range status] on CDTIs shown in

the forward, oblique, and lateral physical positions respectively. Thus, by having [traffic range] on the CDTI plan view, the CDTI conforms to the recommendations of the algorithm for all physical locations. This is true even if the CDTI does not display [unsafe traffic range status] in the recommended virtual locations (or does not display [unsafe traffic range status] at all).

All the data attributes on the CDTI should conform to the algorithm's recommendations. If one or two attributes do not conform to the recommendations, a minor redesign should be recommended to improve the accessibility of those specific attributes. The rationale behind this suggestion is that the algorithm's recommendations were carefully designed to be easy to meet. For example, by our definition of the criticality levels, an ADS-B application supporting only situation awareness has no vital attributes. In fact, guidance from RTCA DO-317A (see Section 7.3) will often exceed the recommendations of the algorithm. So if the manufacturer complied with RTCA DO-317A, many attributes will automatically conform to the algorithm's recommendations.

Ultimately, approval of a CDTI design depends on the full context of its use. Context could mitigate non-conformance of an attribute. For example, if a CDTI design shows a non-routine attribute at virtual location level 3, contrary to constraints in Section 4.2.4, a manufacturer could compensate by including an auditory display to signal a change in the attribute value. As another example, attributes from other more accessible flight deck displays could be used to derive a CDTI attribute that does not conform to the recommendations for a particular design and installation.

7.1 Addressing Specific Evaluation Questions

The results of the evaluation show whether or not each attribute of a particular CDTI design installed in a specified physical location meets the recommended accessibility, as determined by the algorithm, for each task of a CDTI application. Section 1 mentions that the algorithm's output can address specific evaluation questions such as:

- What CDTI data should be displayed in the plan view (either encoded in the traffic symbology or shown in a text data tag attached to the traffic symbol), as opposed to in the data block (e.g., on the edge of the CDTI for the selected target only)?
- When is it okay to require a button press or other pilot action for data access?

These are questions about the specific data attributes that the algorithm answers through the base and contingency tables.

The algorithm output can also address broader design and evaluation questions such as:

- Does a specific CDTI software design have data accessibility issues regardless of its physical installation location?
- Does a specific CDTI software design provide at least the minimum data accessibility to all attributes for a proposed installation location?
- In what physical locations could a specific CDTI be installed while still providing at least the minimum data accessibility to all attributes?
- What physical locations provide at least the minimum data accessibility to all attributes for a given ADS-B application, assuming a hypothetical "ideal" CDTI?

These broader questions are addressed next.

7.1.1 Accessibility Issues Regardless of Installation Location

The algorithm output may be used to indicate whether some attributes in a CDTI may have accessibility issues regardless of the display's physical installation location. This process may be used to flag issues before considering installation. It is accomplished by comparing each attribute's design virtual location to the recommended virtual location for the forward physical location.

Because the forward physical location is the most accessible physical location, any attribute whose virtual location is less accessible than recommended even for the forward physical location will also be less accessible than recommended for any other physical location. For example, if [traffic unsafe range status] has V_{1a} = 2 (auxiliary region), as shown in Table 15, then any CDTI that requires a pilot action (virtual location level 3) to display [traffic unsafe range status] and [traffic range] will not conform to the algorithm's recommendations for ITP regardless of where the CDTI may be installed.

7.1.2 Accessibility for a Proposed Installation Location

The algorithm output may be used to indicate if there may be accessibility issues with any attribute given a proposed installation for the CDTI. This is accomplished by comparing each attribute's design virtual location to the recommended virtual location for the proposed physical location for the CDTI installation. If the CDTI displays an attribute at a virtual location level that is less accessible than the algorithm's recommendations, then, in order to conform to the algorithm's recommendations for the proposed physical location, the CDTI design must be modified to put the attribute in a more accessible virtual location.

For example, if a manufacturer proposes installing the CDTI in the lateral physical location, then [traffic unsafe range status] or [traffic range] must be displayed in the principal virtual location for the execution task in order to conform to the straw-man recommendations in Table 15.

7.1.3 Acceptable Installation Locations for a Specific CDTI

The algorithm output may be used to identify the installation locations that could present accessibility issues for a specific CDTI. This is accomplished by comparing each attribute's design virtual location against the recommended virtual location, for all physical locations. If the design virtual locations of all attributes conform to the recommended virtual locations of a physical location, then a CDTI installed in that physical location conforms to the recommendations of the algorithm. If the design virtual location of any attribute does not conform to the recommended virtual location of a physical location, then a CDTI installed in that physical location will not conform to the recommendations of the algorithm.

For example, suppose a CDTI design displays attributes as shown in Table 17, and the CDTI does not display [unsafe traffic range status]. In this CDTI, the virtual locations for all attributes conform to the illustrative recommended virtual locations in Table 15 for the forward and oblique physical locations. Thus, the CDTI will conform to the algorithms recommendations if installed in the forward or oblique physical location. However, the [altitude band] design virtual location is less accessible than Table 15 recommends for the lateral physical location (i.e., level 4 instead of level 3). So to conform to the recommendations, the CDTI cannot be installed in the lateral location. If the manufacturer wishes to install it in the lateral location, then the manufacturer would need to improve the virtual location of the [altitude band] to level 3 in order to conform to Table 15's recommendations.

Table 17. Virtual locations of attributes for a hypothetical CDTI.

Attribute Name	Design Virtual Location	
	Level	Name
Traffic Range	1	Principal
Traffic Selected State	1	Principal
Display Range/Map Scale	2	Auxiliary
Altitude Band	4	Multi-action
Non-default Display Criteria	2	Auxiliary

This use of the algorithm output assumes the CDTI is the sole source for the data used in the application. However, a particular flight deck may split-off or duplicate some data on another display installed in a location that is easier to access (e.g., primary flight display or navigation display).

7.1.4 Acceptable Installation Locations for a Given Application

Prior to any design or review of a specific CDTI, the algorithm output may be used to determine, for a given ADS-B task, what physical installation locations may present data accessibility issues. Accessibility below the recommended level is indicated by an impossible value for V_{Pa} for the physical location in the accessibility table.

For example, the illustrative recommendations in Table 15 indicate that theoretically a CDTI for ITP execution may be installed in any physical location, although each physical location constrains the recommended virtual location of each attribute. However, suppose a different ADS-B application required pilots to continuously monitor [traffic range]. This would give [traffic range] an R_a of 1, which, combined with a C_a of 2, produces a V_{Pa} of 0 for the lateral physical location (P = 3), according to Equation (4) (i.e., 2 + 1 – 3 = 0). Zero is an impossible level, since V_{Pa} must be between 1 and 4. Such an output means the algorithm recommends that the CDTI should not be installed in the lateral position for the application (unless a separate display in the oblique or forward physical location shows [traffic range]).

7.2 Display Modes

The algorithm generates accessibility recommendations for a given task of an ADS-B procedure. Thus, a given attribute’s virtual location may conform to the recommendations for one procedure application or task but not to the recommendations for another procedure or task. A manufacturer may choose to incorporate display modes into the CDTI that alter the virtual locations for some attributes in order to conform to recommendations for each application and task for which the CDTI is designed. For example, a manufacturer may choose to put [traffic application capability] at virtual location level 3 for one application and virtual location level 2 for another application for which [traffic application capability] has greater importance. The pilot is expected to switch among the display modes depending on the application she or he needs to use. Pilot effort related to manually switching display modes is represented by the evaluator’s identification of the design virtual location levels, which account for pilot actions in accessibility (see Section 4.1.4).

Display modes may be an effective strategy to manage display clutter as long as the pilot performs the tasks serially, rather than in parallel. This applies regardless of whether the tasks are from the same procedure or from different procedures. For serial tasks, the pilot can switch from the mode for one task to the mode for the other after completing the first task. However, for parallel tasks, a pilot may have to repeatedly switch between modes, thus reducing the accessibility of the attributes by in effect putting the attributes in virtual location level 3 or 4. This can result in the virtual locations requiring more effort to access than recommended.

Thus, we expect some CDTIs to remain in a single display mode for simultaneous tasks, and each attribute will have the same design virtual location for both tasks. When two tasks are performed in parallel, the attribute must be in the more accessible virtual location recommended for either of the two tasks in order for the CDTI design to conform to the algorithm's recommendations.

7.3 Implications of the Enhanced Visual Acquisition and Airborne Situation Awareness Applications on Algorithm Use

Simultaneous procedures or tasks may be rare, and thus may not represent a serious challenge for CDTI designers or evaluators. However, two applications, enhanced visual acquisition (EVAcq) and airborne situation awareness (AIRB), can be regarded as continuous for an entire flight (FAA, 2012; RTCA, 2011). If regarded as such, the recommended virtual locations for EVAcq information need to be met at all times while in flight.

RTCA DO-317A does not provide a detailed description of an AIRB or an EVAcq procedure that could be used to assign criticality and update rates for attributes. However, RTCA DO-317A does pre-specify the virtual location of many attributes, including those used in EVAcq and AIRB. For example, Section 2.3.1.2 of RTCA DO-317A states that a CDTI shall display the following traffic information graphically (e.g., in the traffic symbol), or as part of the data tag or data block:

- Horizontal position
- Directionality
- Altitude
- Air/ground status
- Vertical direction indicator
- Application capability

This requirement suggests that each of these attributes must be in virtual location level 1 or 2.

Given the algorithm's handling of pre-specified attributes (see Section 4.2.5), a CDTI will conform to the algorithm's recommendations for AIRB and EVAcq if the attributes are in a virtual location that is at least as accessible as specified in RTCA DO-317A.

For example, suppose V_{Pa} for [altitude band] for the ITP execution task is as shown in the illustrative Table 15. A CDTI with the [altitude band] in virtual location level 3 conforms to Table 15 for all physical locations. However, RTCA DO-317A specifies that "the CDTI shall display… altitude band." (2.3.1.2). If one applies the RTCA implied minimum accessibility levels listed in Table 10, this means [altitude band] should always be in the principal or auxiliary region of the CDTI regardless of the physical location of the display or application currently in use.

8 Conclusions and Next Steps

This paper proposes an algorithm for determining recommended accessibility of the data that pilots use for ADS-B procedures. The algorithm takes into account the CDTI software design, including information automation and physical installation. It formalizes the analysis of procedures to determine the importance of the data. However, additional steps are necessary to ensure that the algorithm is useful in practice for designing and evaluating CDTIs:

- Validate that the algorithm produces correct recommendations from correct inputs.
- Integrate the use of the algorithm in the standards-production process, so that SMEs are convened to determine the input for the algorithm for each ADS-B application.
- Automate the computations of the algorithm to reduce the workload associated with turning input into algorithm output.
- Construct a means of disseminating the algorithm output (base and contingency tables) for each application for use by government and industry (e.g., as an XML download).
- Automate and streamline the evaluation process (e.g., build a computer program to loop through the tasks, attributes, and physical locations, comparing of design virtual location values against recommended virtual location values) to reduce workload for evaluators.

The immediate next step is validation of the algorithm. This could be accomplished by having SMEs from government and industry review the algorithm and its logic, and test that correct inputs yield sensible recommendations. For example, the SMEs could determine the correct inputs for ITP and judge the resulting recommendations. The algorithm may also be validated by assessing the impacts of deviating from the recommendations through human-in-the-loop experiments. If the SMEs judge the resulting recommendations to be invalid or if deviations have no experimentally verified impacts, then the model's assumptions should be traced and verified to identify where the logic could be improved.

This paper provides a foundation for the long-term goal to integrate an algorithm that generates recommendations for data accessibility into a process of evaluating CDTIs. With further work, this can evolve into a consistent, accurate, and effective means of determining accessibility recommendations, ensuring access to each data item is consistent with its importance.

9 References

Billings, C. E. (1997). *Aviation automation: The search for a human-centered approach (Human Factors in Transportation).* Mahwah, NJ: Lawrence Erlbaum Associates Publishers.

Wagner, D., Birt, J. A., Snyder, M., and Duncanson, J. P. (1996) *Human Factors Design Guide* (DOT/FAA/CT-96/1). Atlantic City, NJ: FAA Technical Center.

Cardosi, K. M., Willems, B., Albert, H., Anderson, G., Carter, R., Chen, J.M., Della Rocco, P.S., Donohoe, C., Felbinger, R., and Murphy, E.D. (2011). *Protocol for information display* (DOT/FAA/TC-TN-10/00). Washington, DC: Federal Aviation Administration.

Estes, S., Penhallegon, W., and Stassen, P.H. (2010) A multi-purpose cockpit display of traffic information. *Proceedings of the International Conference on Human-Computer Interaction in Aeronautics (HCI-Aero 2010).* 3-5 November, Cape Canaveral, FL.

Federal Aviation Administration (2007) *Electronic Flight Deck Displays* (AC 25-11A). Washington, DC: Author.

Federal Aviation Administration (2010) *Flight Crew Alerting* (AC 25.1322-1). Washington, DC: Author.

Federal Aviation Administration (2012). *Airworthiness Approval for ADS-B in Systems and Applications* (AC 20-172A). Washington, DC: Author.

Flightcrew Alerting, Title 14 Code of Federal Regulations, Part 25, §25.1322. (2011).

General Aviation Manufacturers Association (2000). *Recommended practices and guidelines for Part 23 cockpit/flight deck design* (Publication No. 10). Washington, DC: Author.

Murdoch, J.L., Bussink, F. J. L., Chamberlain, J. P., Chartrand, R. C., Palmer, M. T., and Palmer, S. O. (2008). *Enhanced oceanic operations human-in-the-loop in-trail procedure validation simulation study* (NASA/TP-2008-215313). Hampton, VA: National Aeronautics and Space Administration, Langley Research Center.

RTCA (2008). *Safety, performance and interoperability requirements document for the in-trail procedure in oceanic airspace (ATSA-ITP) application* (DO-312). Washington, DC: Author.

RTCA (2011). *Minimum operational performance standards (MOPS) for aircraft surveillance applications system (ASAS).* (DO-317A). Washington, DC: Author.

Wickens, C. D. (1992). *Computational Models of Human Performance*. Aviation Research Laboratory, University of Illinois at Urbana-Champaign. Technical Report ARL-92-4/NASA A^3I-92-1.

Appendix A: Algorithm Summary in Pseudo-Code

The algorithm is summarized in the following pseudo-code. First, SMEs prepare input for the algorithm:

```
For each application
    For each task
        Identify and list all directly used attributes used for the task
        For each directly used attribute a
            Identify if a is derived or raw
            If a is a derived attribute
                Draw derivation network (for later use in the CDTI evaluation)
            Set values for C_a and R_a from guidance documents and judgment
            Identify if a is non-routine
            Identify any pre-specified virtual locations for a from guidance documents
```

Then, the algorithm processes the SME input to write the base and contingency tables for each task:

```
For each application
    For each task
        Read attribute list, including each attribute's characteristics set by SMEs
        For each directly used attribute a
            For each of the P levels
                Calculate V_Pa(i) from C_a and R_a with Equation (4)
                If attribute is non-routine then
                    If V_Pa(i) represents lower access than Level 2 then
                        Set V_Pa(r) = 2
                    Else
                        Set V_Pa(r) = V_Pa(i)
                If pre-specified virtual location of a represents higher access than
                    V_Pa(r) then
                        Set V_Pa = pre-specified virtual location
                Else
                    Set V_Pa = V_Pa(r)
                Write V_Pa to base table
        For each directly used derived attribute a
            For each of the P levels
                Calculate V´_Pa with Equation (5)
                Write the V´_Pa to contingency table
```

Appendix B: In-Trail Procedure Example

The in-trail procedure (ITP) is an application where a flightcrew in oceanic airspace may change altitude passing vertically by one or two reference aircraft at distances below normal separation standards. The flightcrew uses ADS-B data on the CDTI to determine if the traffic is at a range, track, and relative speed that allow a safe altitude change past the traffic. Flightcrews must request an ITP clearance from the air-traffic controller, who may allow it after following air traffic control (ATC) procedures (RTCA 2008).

As in the previous ITP examples in Section 5, we (the authors of this report), played the role of SMEs and set the inputs to the algorithm. The results are merely illustrative and should not be regarded as actual recommendations for ITP. We analyzed RTCA (2008) DO-312 to assess information needs for ITP, with particular emphasis on the material in Annex A (Operational Services and Environment Definition). RTCA DO-312 Annex A defines four tasks ("phases") of ITP (p. 59). These tasks are:

- *Initiation*. The crew prepares to perform the ITP, identifying reference traffic in the procedure and transmitting the ITP request to ATC.
- *Instruction*. The ITP clearance is issued by ATC and re-evaluated by the flightcrew. The crew confirms whether conditions still permit execution of the procedure.
- *Execution*. The crew conducts the ITP maneuver while maintaining the rate of climb/descent as cleared.
- *Termination*. The procedure terminates when the ITP crew achieves the requested Flight Level or an abnormal event results in premature termination of the ITP maneuver.

The Termination task does not require the use of CDTI data, so it is not addressed in our algorithm.

ITP Initiation Task

List of Attributes

Our interpretation of RTCA DO-312 yielded the derived attributes listed in Table 18. In addition, our review of all raw attributes provided by ASSAP (RTCA, 2011) found that the attributes in Table 19 were directly used in the task. Definitions and description of each attribute are in the corresponding sections of DO-317A given in Table 19.

Table 18. Derived attributes for the ITP initiation task.

Attribute	Description	Values	RTCA DO-312 Section
Traffic ownship geometry	Relative position of ownship and reference aircraft.	Leading: Ownship in front of reference aircraft. Following: Ownship behind reference aircraft.	A.2.2.1.4
ITP distance status	Adequacy of range to reference aircraft.	Adequate: Range is adequate given closure rate. Inadequate: Range is inadequate (too low) given closure rate.	A.2.2.1.5 OR.1
Similar track status	Whether ownship and reference aircraft are on similar tracks for the ITP clearance.	Similar: Tracks for ownship and reference aircraft are within 45 degrees. Different: Tracks for ownship and reference aircraft are more than 45 degrees apart.	A.2.2.1.5 OR.1
Traffic intermediate altitude status	Traffic vertical position relative to ownship and desired ownship altitude.	Irrelevant: Traffic is not between ownship and desired altitude. Acceptable: Traffic is in an acceptable position between ownship and desired altitude given required vertical separation. Unacceptable: Traffic is in an unacceptable position between ownship and desired altitude given required vertical separation.	A.2.2.1.5 OR.1
Reference aircraft status	Whether aircraft qualifies as reference aircraft for ITP	ITP Qualified: aircraft may be used as reference aircraft for ITP. ITP Not Allowed: ITP may not be performed. ITP Unnecessary: Flight level change may be performed without the ITP application.	A.2.2.1.5 OR.1

Table 19. Raw attributes for the ITP initiation task.

Attribute	Relevant RTCA DO-317A Sections
Traffic selected state	§2.3.2.4.3 §2.3.4.2.3
Traffic flight ID	§2.2.2.1.1.2 §2.3.4.2.2 §2.3.5.7
Display range/map scale	§2.3.1.2 §2.3.5.12
Altitude band	§2.3.1.2
Non-default traffic display criteria	§2.3.1.1.1
Ownship directionality reference	§2.3.1.2
Ownship application status	§2.2.2.1.5.3

Derivation Networks

Figure 8 shows the derivation networks we created for the derived attributes used in the instruction task. The only directly used derived attributes are [traffic-ownship geometry] and [reference aircraft status]. Variables not shown on the CDTI are excluded from the derivation networks (see Sections 3 and 5.1.1).

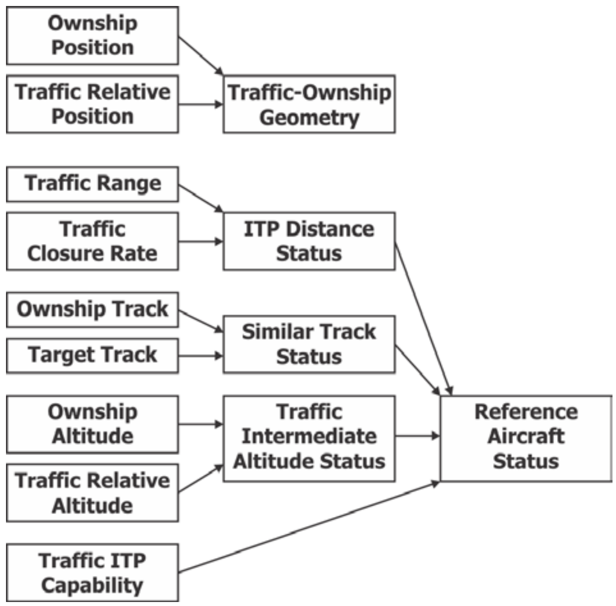


Figure 8. Two derivation networks for the ITP initiation task.

Base Table for ITP Initiation Task

Table 20 lists the criticality and update rate levels assigned to the directly used attributes. The table includes the two directly used derived attributes ([traffic-ownship geometry] and [reference aircraft status]) plus all eight directly used raw attributes listed in Table 19. We judged all attributes to be routine and did not find pre-specified virtual locations for any of the attributes. The columns under V_{Pa} in Table 20 are the output of the algorithm for each attribute. That is, the right three columns are the recommended virtual location levels for each physical location. In evaluating a CDTI, if the CDTI does not display a derived attribute, then the recommended virtual locations apply to its source attributes as shown in Figure 8. The algorithm calculates the recommended virtual location levels by using Equation (4). For Table 20, and all base and contingency tables, we corrected the results of Equation (5) to keep the virtual locations within the allowable values of 1 through 4. Because all attributes were routine and none were pre-specified, the algorithm did not apply any constraints to the results of Equation (4).

Table 20. Illustrative base table for the ITP initiation task.

Attribute	Derived?	*C*	*R*	Routine?	Pre-specified	V_{Pa}		
						Fwd 1	Obl 2	Lat 3
Traffic ownship geometry	Yes	2	3	Yes	-	4	3	2
Reference aircraft status	Yes	2	2	Yes	-	3	2	1
Traffic selected state	No	2	2	Yes	-	3	2	1
Traffic flight ID	No	2	2	Yes	-	3	2	1
Display range/map scale	No	2	3	Yes	-	4	3	2
Altitude band	No	2	3	Yes	-	4	3	2
Non-default traffic display criteria	No	3	3	Yes	-	4	4	3
Ownship directionality reference	No	3	3	Yes	-	4	4	3
Ownship application status	No	2	2	Yes	-	3	2	1

Contingency Table for ITP Initiation Task

Table 21 is the contingency table for the derived attributes used in the task. That is, the right three columns are the recommended virtual location levels of each raw source attribute of the corresponding derived attribute, as shown in Figure 8. In evaluating a CDTI, these recommended virtual locations apply to the raw source attributes only if the CDTI displays the corresponding derived attribute. The algorithm calculates the virtual location levels by using Equation (5), $V'_{Pa} = 3 + R_a - P$.

Table 21. Illustrative contingency table for the ITP initiation task.

Derived Attribute	*R*	Raw source attribute V'_{Pa}		
		Fwd 1	Obl 2	Lat 3
Traffic ownship geometry	3	4	4	3
Reference aircraft status	2	4	3	2

ITP Instruction Task

List of Attributes

We interpret RTCA DO-312 as the instruction task involving the derived attributes listed in Table 22. In addition, our review of all raw attributes provided by ASSAP (RTCA, 2011) found that the attributes in Table 23 were directly used in the task. Definitions and description of each attribute are in the corresponding sections of DO-317A given in Table 23.

Table 22. Derived attributes for the ITP instruction task.

Attribute	Description	Values	RTCA DO-312 Section
ITP distance status	Adequacy of range to reference aircraft.	Adequate: Range is adequate given closure rate. Inadequate: Range is inadequate (too low) given closure rate.	A.2.2.2.3 OR.6
Similar track status	Whether ownship and reference aircraft are on similar tracks for the ITP clearance.	Similar: Tracks for ownship and reference aircraft are within 45 degrees. Different: Tracks for ownship and reference aircraft are more than 45 degrees apart.	A.2.2.2.3 OR.6
Reference aircraft status	Whether aircraft qualifies as reference aircraft for ITP	ITP Qualified: aircraft may be used as reference aircraft for ITP. ITP Not Allowed: ITP may not be performed. ITP Unnecessary: Flight level change may be performed without the ITP application.	A.2.2.2.3 OR.6

Table 23 Raw attributes for the ITP instruction task.

Attribute	Relevant RTCA DO-317A Sections
Traffic selected state	§2.3.2.4.3 §2.3.4.2.3
Traffic flight ID	§2.2.2.1.1.2 §2.3.4.2.2 §2.3.5.7
Display range/map scale	§2.3.1.2 §2.3.5.12
Altitude band	§2.3.1.2
Non-default traffic display criteria	§2.3.1.1.1
Ownship application status	§2.2.2.1.5.3

Derivation Networks

Figure 9 shows the derivation network we created for the derived attributes used in the instruction task. The only directly used derived attribute is [reference aircraft status]. The derived attributes [ITP distance status] and [similar track status] are source attributes for [reference aircraft status]. Thus, a single network comprises all derived attributes. Variables not shown on the CDTI are excluded from derivation networks (see Sections 3 and 5.1.1).

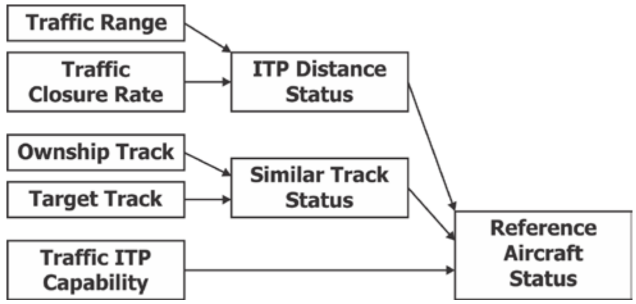


Figure 9. Derivation network for the ITP instruction task.

Base Table for ITP Instruction Task

Table 24 lists the criticality and update rate levels we assigned to the directly used attributes. We judged all attributes to be routine and did not find pre-specified virtual locations for any of the attributes. The columns under V_{Pa} in Table 24 are the output of the algorithm for each attribute. That is, the right three columns are the recommended virtual location levels for each physical location. In evaluating a CDTI, if the CDTI does not display a derived attribute, then the recommended virtual locations apply to its source attributes as shown in Figure 9. The algorithm calculates the recommended virtual location levels by using Equation (4). Because all attributes were routine and none were pre-specified, the algorithm did not apply any constraints to the results of Equation (4).

Table 24. Illustrative base table for the ITP instruction task.

Attribute	Derived?	*C*	*R*	Routine?	Pre-specified	V_{Pa}		
						Fwd 1	Obl 2	Lat 3
Reference aircraft status	Yes	2	3	Yes	-	4	3	2
Traffic selected state	No	2	2	Yes	-	3	2	1
Traffic flight ID	No	2	3	Yes	-	4	3	2
Display range/map scale	No	2	3	Yes	-	4	3	2
Altitude band	No	2	3	Yes	-	4	3	2
Non-default traffic display criteria	No	3	3	Yes	-	4	4	3
Ownship application status	No	2	3	Yes	-	4	3	2

Contingency Table for ITP Instruction Task

Table 25 is the contingency table for the derived attributes used in the ITP instruction task. That is, the right three columns are the recommended virtual location levels of each raw source attribute of the corresponding derived attribute, as shown in Figure 9. In evaluating a CDTI, these recommended virtual locations apply to the raw source attributes only if the CDTI displays the corresponding derived attribute. The algorithm calculates the virtual location levels by using Equation (5), $V'_{Pa} = 3 + R_a - P$.

Table 25. Illustrative contingency table for the ITP instruction task.

Derived Attribute	*R*	Raw source attribute V'_{Pa}		
		Fwd 1	**Obl 2**	**Lat 3**
Reference aircraft status	3	4	4	3

ITP Execution Task

See Section 5.2 for additional details of the inputs and the algorithm's process.

List of Attributes

Our interpretation of RTCA DO-312 is that the execution task involves a single derived attributes shown in Table 26. In addition, our review of all raw attributes provided by ASSAP (RTCA, 2011) found that the attributes in Table 27 were directly used in the task. Definitions and description of each attribute are in the corresponding sections of DO-317A given Table 27.

Table 26. Derived attributes for the ITP execution task.

Attribute	Description	Values	RTCA DO-312 Section
Unsafe Traffic Range Status	Whether traffic range is insufficient for safety	Sufficient: Safety is not affected. Insufficient: Safety is significantly compromised.	A.2.2.3.3 OR.13

Table 27. Raw attributes for the ITP execution task.

Attribute	Relevant RTCA DO-317A Sections
Traffic selected state	§2.3.2.4.3 §2.3.4.2.3
Display range/map scale	§2.3.1.2 §2.3.5.12
Altitude band	§2.3.1.2
Non-default traffic display criteria	§2.3.1.1.1

Derivation Networks

Figure 10 shows the derivation network we created for the derived attribute used in the execution task. Variables not shown on the CDTI are excluded from the derivation networks (see Sections 3 and 5.1.1).

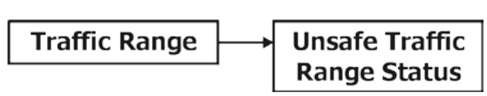


Figure 10. Derivation network for the ITP execution task.

Base Table for ITP Execution Task

Table 28 lists the criticality and update rate levels we assigned to the directly used attributes. In our judgment, only the [unsafe traffic range status] was non-routine. We did not find pre-specified virtual locations for any of the attributes. The columns under V_{Pa} in Table 28 are the output of the algorithm for each attribute. That is, the right three columns are the recommended virtual location levels for each physical location. In evaluating a CDTI, if the CDTI does not display a derived attribute, then the recommended virtual locations apply to its source attributes as shown in Figure 10. The algorithm calculates the recommended virtual location levels by using Equation (4). Because [unsafe traffic range status] is non-routine, the algorithm followed the process described in 4.2.4 (page 16) and constrained the recommended virtual location level to 2 for the forward physical position.

Table 28. Illustrative base table for the ITP execution task.

Attribute	**Derived?**	***C***	***R***	**Routine?**	**Pre-specified**	***V_{Pa}*** Fwd 1	Obl 2	Lat 3
Traffic unsafe range status	Yes	2	2	No	-	2	2	1
Traffic selected status	No	2	2	Yes	-	3	2	1
Display range/map scale	No	3	3	Yes	-	4	4	3
Altitude band	No	3	3	Yes	-	4	4	3
Non-default display criteria	No	3	3	Yes	-	4	4	3

Contingency Table for ITP Execution Task

Table 29 is the contingency table for the derived attributes used in the task. That is, the right three columns are the recommended virtual location levels of each raw source attribute of the corresponding derived attribute, as shown in Figure 10. In evaluating a CDTI, these recommended virtual locations apply to the raw source attributes only if the CDTI displays the corresponding derived attribute. The algorithm calculates the virtual location levels by using Equation (5).

Table 29. Illustrative contingency table for the ITP execution task.

Derived Attribute	***R***	**Raw source attribute V'_{Pa}** Fwd 1	Obl 2	Lat 3
Traffic unsafe range status	2	4	3	2

U.S. Department of Transportation
John A. Volpe National Transportation Systems Center
55 Broadway
Cambridge, MA 02142-1093

(617) 494-2000
www.volpe.dot.gov

DOT/FAA/TC-14/4

DOT-VNTSC-FAA-14-09