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Operating Documents that Change in Real-time: Dynamic Documents and User Performance Support

Barbara K. Burian
NASA Ames Research Center

Lynne Martin
San Jose State University
NASA Ames Research Center

A Day in the Life of a Pilot

Nearing the end of the cruise portion of a flight, the airline captain began to prepare for the descent, approach, and landing. After weather and airport information were obtained through an automated radio broadcast and instructions were given by air traffic control, she began to look at the assigned arrival and approach procedures. First, she had to locate the arrival procedures to be used among six different ones for their destination airport. Once found, she then had to search through 23 lines of tiny text on the chart to find the arrival procedures to follow for their assigned runway. On this chart, she noted that for aircraft without a Global Positioning System (GPS), such as theirs, three other ground-based navigation aids had to be operational when flying that arrival. She asked her first officer to check the lengthy list of Notices to Airmen to confirm that the navigation aids they needed were in-service.

The wet runways and poor braking action reported by other pilots at the airport meant that the crew also needed to perform calculations to ensure their assigned runway would be long enough. To do this calculation the captain had to locate the Landing Distance table in a thick manual filled with other tables and checklists, and then find the section for her particular type of aircraft. In the table she located the subsection for the brake and flap settings they would be using along with their anticipated landing speed with “poor” braking action. This yielded a standard landing distance that she had to modify based upon the aircraft’s expected weight at landing, the wind speed and direction, temperature, and airport altitude. Finally, after all these calculations, she was able to determine that the assigned runway would be acceptable.

As she completed her review of the arrival, approach, and landing, she reminded herself and her first officer that when it came time to complete the landing checklist, they should remember *not* to arm the speedbrakes as they normally did as a part of that checklist. They had dispatched on that flight with the speedbrakes inoperative, using procedures in their minimum equipment list, and it could be quite dangerous to inadvertently try to use this equipment when it was not operating properly.

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This vignette describes typical actions required by pilots who complete thousands of flights every day. They include searching through multiple similar documents and lines of text to locate that which is pertinent, performing complicated calculations using tables and data acquired through multiple sources, and remembering not to perform typical actions even though checklists indicate that those actions should be taken. With the introduction of electronic operating documents, this snapshot of the current life of airline pilots has already begun to change. Indeed, electronic operating documents are now routinely used in a number of professional and industrial settings: nuclear and power plant control rooms (O'Hara, Higgins, & Stubler, 2000; Niwa, Hollnagel, & Green, 1996), ship and submarine bridges (Ronan, Routhier, & Ryan, 2000), airplane cockpits (Air Transport Association, 2002; Boorman & Hartel, 1997), airline operations centers, manufacturing and maintenance facilities (Seamster & Kanki, 2005), and more. Electronic operating documents which are *dynamic*, meaning they are altered in real-time based on specific circumstances that exist at the moment in which they are being used, bring even greater changes to the lives of professionals who work in these settings.

We begin this chapter with an introduction to operational documents and their formats and provide some examples from the world of airline operations. We then identify and examine a number of important issues with regard to the design, development, functionality, and use of dynamic operating documents. These issues are grouped into three main categories: operational considerations, cognitive and human performance considerations, and certification and approval considerations.

Electronic and Dynamic Operational Documents

What are operational documents? Generally speaking, an operational document is any printed or electronically presented textual, numerical or graphical information[1] relevant for performing actions or interpreting data and displays in operational settings. They include warnings, notes, lists, bulletins, checklists, procedures, performance tables, training and operations manuals, systems descriptions, charts and maps, system synoptic diagrams, alarm codes…and the list goes on. Some documents might contain just a single line of text, like a caution statement. Other documents, like an inspector's handbook, consist of volumes. Some information included in these documents, such as the location of pressure relief valves in a hydraulics system, will never change. Other information, such as the strength and direction of winds at an airport, can change almost as soon as it is determined.

Operational information and documents currently can be presented in four basic formats: paper, stand-alone electronic, integrated electronic, and dynamic electronic. A stand-alone electronic document is simply the electronic display of static information. It differs from a paper document only in the medium used for presentation. Integrated electronic documents are connected to at least one or, more commonly, a system of sensors. Sensor data is used to alter what or how information is displayed. It is sensor data that allows a particular document to be selected for display automatically or automatically indicate that a checklist step has been completed. A dynamic document, as described earlier, is one in which the actual content, specifications, directions, or instructions change in real-time. As with integrated electronic documents, dynamic documents rely upon data from an advanced system of sensors.

In addition to the four basic formats just described, there are also two subtypes within each of the three electronic operational document formats – those that do and do not allow or require the manual input of data by the operator for computation and use with other information (i.e., documents with or without an interactive feature). As is summarized in Table 1, the functionality, use, development, and maintenance of documents across these formats differ widely.

[Insert Table 1 approximately here]

Although some documents exist solely as one of the seven described in Table 1, it is not uncommon for a single electronic document to actually be composed of a combination of the six different electronic format types of information. For example, a procedure might contain some steps that are simply presented and do not change (stand-alone electronic, not interactive), some steps that require the entry of data that is combined with sensor information (integrated electronic, is interactive) and some steps whose content changes when certain conditions are sensed to exist (dynamic, not interactive).

Paper documents are still by far the most common but stand-alone and integrated electronic documents can be found in most operational settings. Integrated electronic documents are found less often though, as they require data from sensors, which may not be installed. Dynamic documents or information are the most rare. Although this chapter focuses on dynamic documents, some of what follows also pertains to integrated electronic documents as well. Our discussion will review types of documents which might be made dynamic and the benefits and limitations of dynamic and other types of electronic documents. Special attention will be given to some of the many challenges in developing dynamic documents with particular focus on human cognitive capabilities that must be considered during their design if they are to truly provide optimal user support. Some worthy topics pertaining to the mechanics of dynamic documentation (e.g., hyper-linking, eXtensible Mark-up Language [XML], and data tagging), different electronic document programming formats (pdf, doc, etc.), and display presentation issues (e.g., scrolling versus paging) are beyond the scope of this chapter and will not be addressed (for information on these and related topics see Civil Aviation Authority, 2005; Cosimini, 2002, and Hackos, 2002).

To facilitate our discussion of dynamic operational documents, we will use examples from the world of airline operations; however, first we must revisit our definition of the word "document." Prior to the digital age, an operating document was information printed on paper. Clearly, an operations manual was a document whereas aircraft airspeed information displayed in the cockpit during flight was not. Documents contained static information; they could be revised (and reprinted) but otherwise, their content did not change. A significant limitation of paper documents is that information contained in some is not pertinent to the particular operation, or becomes obsolete very quickly due to variable external conditions, such as the weather at a destination airport. Dynamic operating documents, because they can change in real time, overcome these limitations. However, the demarcation is now much less clear between information in dynamic operating documents and other operational information, such as aircraft airspeed, which is also dynamic and is also derived through various sensors (Seinfeld, Herman,

& Lotterhos, 2002). Although we will continue to use it for the time being, we shall see that the term "document" may cease to be particularly accurate. In this discussion we will consider all operational information, regardless of its source, as existing on a continuum from that which is static and unchanging to that which is dynamic and able to change as contexts change. Current constraints on treating all dynamic information as having equivalent integrity regardless of its source, as we have done below, will be addressed in a later section on limitations in dynamic data.

Dynamic Information (and Documents) on Airline Flight Decks

As with most highly skilled professions, airline pilots use information from many sources during the course of a flight. Information related to flight parameters (e.g., airspeed, altitude), systems functioning (e.g., engine pressure ratio, cabin pressurization), active automation modes (e.g., flight level change, vertical speed), aircraft configuration (e.g. gear down, cargo door open), and weather radar, is derived largely through on-board sensor data and is displayed digitally or through the use of gauges or panel indicators located throughout the flight deck. Other information pertaining to navigation and flight management, such as the route and estimated time of arrival at destination, is displayed to the pilots through the flight management system (FMS) display units. The flight management computer derives this information using a combination of data entered by the pilots and data from on-board sensors and databases. Some information originates away from the flight deck and is transmitted to and from the pilots via radio voice communication or digital uplinks of textual data to the aircraft through the use of satellite or radio (i.e., data link). This includes information such as current airport weather conditions and air traffic control (ATC) clearances.

Operational information that traditionally existed as paper documents (some of which was carried on-board in pilot flight bags), such as aeronautical charts, airport information, operations manuals, the aircraft minimum equipment list and logbook, performance tables, and normal and emergency checklists, is accessed on the flight deck through onboard databases and manuals. This kind of information, when available in electronic form, is located either in an electronic flight bag (EFB; Gosling, 2002; Wade, 2002) or is displayed on one of the main forward multi-function displays.

An EFB is simply a type of electronic computing and display device, such as a laptop computer or personal digital assistant (Air Transport Association, 2002; Chandra, Yeh, Riley, & Mangold, 2003). There are three different classes of EFB hardware (Federal Aviation Administration [FAA], 2003a) and only the highest level, class 3, will accommodate integrated or dynamic electronic documents. This is because only class 3 EFBs are integrated with airplane databuses and thus allow documents stored on them to respond to sensor data from the aircraft. Therefore, class 3 EFBs are permanently installed aboard the aircraft and are subject to stringent approval and certification requirements (FAA, 2003a). EFB information is typically presented on its own displays which are usually positioned at an angle slightly off to the sides of the main forward flight-deck displays.

Some types of dynamic document information currently exist on airline flight decks. For example, sensors can detect low pressure in the right and center hydraulics systems and cause the "Right and Center Hydraulics Low Pressure" checklist to be automatically displayed. An electronic graphic depicting the hydraulics systems shows the right and center system lines in red, instead of the normal green, and graphically shows pump switches changing from ON to OFF as crews complete checklist steps directing them to complete those actions. Final actions from that checklist that need to be completed later during descent and approach are not presented but are appended to the Descent and Approach Checklist instead.

These are simple but powerful examples of the advantages of dynamic documents over static ones (see Table 2). A document, in this case the Descent and Approach Checklist, is lengthened to include steps that must be accomplished at that time to accommodate a non-normal situation. The electronic synoptic display provides immediate feedback to crews as they perform various actions which confirm that their commands are actually being carried out and also increases the likelihood of identifying an error should one be made.

[Insert Table 2 approximately here]

Returning to our "A Day in the Life of a Pilot" vignette at the beginning of the chapter we can see far greater future possibilities for dynamic operating documents on the flight deck. Current airport weather conditions and ATC instructions could be uplinked to the flightdeck causing the exact assigned arrival procedures (and only those procedures) to be automatically evaluated on-board for suitability; aircraft performance capabilities and equipage data (in our example, the lack of a GPS) would be compared against the performance requirements of the assigned arrival and electronic information confirming the operation of necessary external navigation aids. Suggested landing brake and flap settings could be determined automatically through computation of data from the uplinked weather information and on-board data and presented to the crew for confirmation. The required landing distance, instead of being computed through a complicated printed table and reference to external data, is computed automatically and in the blink of an eye, the assigned arrival and runway would be determined to be acceptable and the arrival procedure queued for display on the flight deck. At the same time, the routing of the arrival procedure would load into the flight management computer awaiting the pilots to press the "Execute" button. Finally, data in the electronic minimum equipment list would be referenced in constructing the approach and landing checklists, and the item "Set Speedbrakes" on the landing checklist would change to read "Do Not Arm Speedbrakes" since the crew dispatched with the speedbrakes inoperative. Thus, actions that once took many minutes to complete, required reference to multiple sources of information, and involved considerable cognitive demand in terms of attention, memory, and mental calculations are reduced to two or three simple and quickly executed steps with the potential for pilot error being significantly lessened.

There are many other possible ways in which dynamic operating documents might be employed on the flight deck. For example, numerous conditional branches are used in checklists for response to emergency and abnormal situations: IF *a*, THEN do steps *x*, *y*, and *z*; but IF *b*, THEN do steps *q*, *r*, *s*, and *t*. Integrated electronic and dynamic checklists, through their use of sensors, can determine which actions are pertinent and required for a particular set of circumstances and only these are presented, thereby eliminating the often confusing task of evaluating, selecting, and navigating through multiple conditional branches and even across multiple checklists (Burian, Barshi, & Dismukes, 2005; Niwa et al., 1996). Another example pertains to customizing procedures which would dynamically alter based on variables, such as wind speed and direction, aircraft weight, and the performance capabilities of specific aircraft equipage; flight management systems and avionics packages developed by different manufacturers vary in performance characteristics and these differences have crucial implications for how certain procedures are flown. As a final example, imagine the utility of an aircraft sensing its low and decreasing altitude and the fact that both its engines have been shut down, combining that with navigation data concerning its precise coordinates, and then automatically presenting only the most essential emergency checklist actions for flight crew completion. Here, the checklist adapts to the exact circumstances and needs of the situation as well as the workload of the pilots.

In the future, information from electronic operating documents, the FMS and data regarding flight parameters, systems functioning, autoflight modes, aircraft configuration, equipage, performance capabilities, on-board radar, external hazard detection, and external information uplinked to the aircraft could be combined and fully integrated to provide powerful support to the flight crew.

Benefits and Limitations of Dynamic Electronic Operational Documents

As illustrated above, there are many benefits to be had by the introduction of dynamic documents in operational settings (see Table 2). Workload can be substantially reduced, particularly with regard to combining information from a variety of sources to complete complex calculations, and sorting through reams of information to identify only that which is expected to be pertinent for the specific situation and operational procedure to be conducted. Decreased workload means that tasks become less vulnerable to interruptions minimizing the likelihood that procedural steps will get skipped (Dismukes, Berman, & Loukopoulos, 2007) and there is less demand placed on working[2] and prospective[3] memory. The likelihood of other types of human error, such as those related to habit capture[4], may also be reduced. Because dynamic documents are typically located and/or presented automatically based on data from sensors, it is significantly less likely that operators will access the wrong document or information. Dynamic documents will also tend to have fewer manual data entry requirements and could contain error checkers to help identify when manually entered data is incorrect. Thus, operational procedures can be simplified and streamlined resulting in great gains in accuracy and enhanced operator performance (Boorman, 2000).

Information from dynamic documents must be displayed however, and the design of clear, comprehensible displays, especially when document information is combined with other operational information, can be challenging. A poor design can actually increase operator workload and give rise to confusion and errors. Further, serious trouble can result if incorrect information is generated (e.g., there is a sensor failure), the wrong information is accessed or combined, or even if correct information is presented but at inappropriate times. Determining how to best combine and present information that accommodates situations or conditions that are highly unusual and unexpected is also extremely daunting and, in some cases, may never be fully achievable. Display "real estate" in many operational settings is also limited and it can be cumbersome to toggle among different displays when accomplishing concurrent tasks if separate displays are required (i.e., information from the multiple displays is not or cannot be combined). Indeed there are many challenges in designing dynamic document systems and the remainder of this chapter will be devoted to discussing some of them in more detail.

Issues in Designing and Developing Dynamic Operational Documents

Operational Considerations

Philosophy of Operations, Design, and Use. Whether explicitly stated or not, manufacturers design operating work stations, such as airplane cockpits, and documents and procedures in keeping with various philosophies (Boorman, 2000; Chandra et al., 2003). The answers to several questions help to clarify the philosophies that underlie the development, design, and use of dynamic operating documents. What kinds of roles should automation play relative to humans in the performance of different operational tasks? How much information should be made available or be presented to operators? How much control should humans have with regard to what dynamic information gets displayed, in what format, and when (i.e., is information automatically dynamically altered, manipulated, and combined or must users request that information and documents behave dynamically)? Is information automatically presented—"pushed"—or do operators have to request or "pull" it? Normal operational demands fluctuate over time and further vary as abnormal or emergency conditions arise. Over the course of these normal and non-normal operations there are many functions that dynamic operating documents might perform (e.g., to inform, complete a computation, support decision-making, accomplish or support completion of a task, etc.). For which purposes, tasks, or situations should dynamic information or documents be developed and why? Are there purposes, tasks, or situations for which the development and use of dynamic documents is not appropriate or is contraindicated?

These questions cut across many different areas: automation, workload and information management, communication, non-normal situation response, display design, and fundamental notions about how operations should be performed. Although dynamic operating documents can be quite beneficial, their development should be based upon a well-reasoned, consistent set of principles and stated philosophy rather than developed indiscriminately or haphazardly and driven mostly by serendipitous opportunity afforded by newly available technologies and sensors. Just because one *can* combine information and make a document dynamic does not mean that one *should*.

Advanced sensor technologies make it possible to "package" information for operator use in a variety of ways and developers must be clear at the outset about where on the "document-task demand" continuum their development efforts will be focused. At one end of the continuum, the "document" end, the traditional notion of what constitutes a document is the organizing feature. In other words, information is packaged and displayed as distinct and discrete documents. A dynamic checklist is located with other checklists and is recognizable as a single, coherent, and complete checklist. It is accessed or presented at the appropriate time, accomplished, and then put away. In contrast, at the "task demand" end of the continuum, documents cease to exist as identifiable units during operations. Instead, the information, actions, data, and directions that comprise traditional documents are broken apart (LeRoy, 2002; Ramu, Barnard, Payeur, & Larroque, 2004) and combined with other types of operational data. Entirely new compositions of data are presented to support the operator's task requirements at each moment. Thus, the specific task demands encountered are the feature that drives how information is organized and what is presented. Typically, not all dynamic documents will fall at the same place on the continuum within any single operational setting. Clearly, levels of automation, not to mention philosophy of automation-human roles, and the availability of various types of sensor data will drive some of the decisions about where on the document-task demand continuum the development of dynamic operational information will fall. For ease of reference, we will continue to use the term operational "document" to refer to any dynamically constructed and presented information regardless of where it technically falls on the continuum.

Data Sources, Reliability, and Integrity. In most operational settings there are a large number of sources where data and information might originate for the construction of dynamic documents. Does the information come from databases, sensors, or algorithms? Does it come from sources within or near to the operational work station or is it sent or acquired from afar? How fresh or stale is the information? Is manual entry of some information required or is it generated automatically? Regardless of the source, the degree to which the data are accurate and reliable will be of paramount concern. When data from several sources are combined, bad data from one source affects all the others and renders all resulting dynamic operational information incorrect and untrustworthy. Obviously, it is absolutely essential that underlying algorithms or the manner in which information is combined and yields information is correct throughout all phases of the operation and under normal and non-normal operating conditions.

Operators may find it helpful for the sources of various types of dynamic operational information and the underlying assumptions or algorithms upon which they are based to be transparent (Chandra et al., 2003; National Transportation Safety Board [NTSB], 2007), in addition to having mechanisms whereby sensor errors can be identified and suspect information can be verified. However, operators should not be placed in the role of constantly having to cross-check or verify dynamic operational information; the current philosophy in the airline industry is for the automation to ensure that the information is correct or to not present it at all (Boorman, personal communication, February 19, 2009). When dynamic operational information is not correct or available, operators will need to have a back-up method for acquiring the information necessary for the performance of tasks. Currently, the minimal implementation of dynamic operating documents in most settings is due to the lack of necessary sensors or the complexity of testing and guaranteeing dynamic document reliability and integrity.

Information Integration and Presentation. The optimal ways to present dynamic operating documents to users, particularly when display space is limited, also poses challenges for developers. Many initial decisions regarding presentation will be driven by decisions made about where on the document-task demand continuum the development effort will be focused. From the development perspective, it is easier to keep documents as identifiable units and only select certain information within them for dynamic behavior. So too, operators are currently used to referring to multiple documents throughout an operational cycle, so maintaining documents as unified wholes requires the least amount of change in their behavior. This approach, however, does not harness the full potential of dynamic information in operational settings and does less to streamline procedures, minimize information gathering and consolidation activities, and reduce overall workload than development approaches closer to the middle or task demand end of the continuum.

Whatever development approach is used, it is essential that dynamic operational documents and information are compatible and consistent with other systems, information, displays, and technologies to be used by the operators (Chandra et al., 2003). Procedures should be developed for the integrated and coherent use of these multiple systems, displays, and technologies. If the same dynamic information is available in more than one display or through different technologies, developers must ensure that the information presented is the same, regardless of the display on which it is presented (Chandra et al., 2003). Additionally, it should be made clear to operators if back-up systems contain documents that are not dynamic. Procedures must also be in place for the use of these back-up document systems as well as the transition between the dynamic system normally used and the back-up, non-dynamic document system.

Optimal User Support. Dynamic operational documents, when well-designed, can greatly enhance operator performance. For this to occur, however, they must be designed with the human user's capabilities and limitations, particularly in the cognitive domain, first and foremost in mind. These considerations are so important that we devote an entire section to them later in this chapter.

Obviously, the organization of dynamic information and documents and modes of accessing them must support the user's operational needs throughout the operational cycle, during periods of high and low workload. Various types of tasks and work analyses that deconstruct operational (and cognitive) demands can be useful in guiding the development of dynamic systems (Boy, 1998; Diaper & Stanton, 2004; Seamster, Redding, & Kaempf, 1997; Vicente, 1999). Dynamic documents must support both operational tasks that are commonly performed as well as those that are rarely performed (Boorman, 2000) and thus, operational demand analyses must consider both normal and non-normal operations. During periods of high workload especially, dynamic operational documents should support and enhance user performance rather than serve as a distracter or increase workload demands (Chandra et al., 2003). Additionally, the right information should be presented or made available at the time it is needed. Alternate methods for locating operational information should be available to support users who desire information which cannot be anticipated by an automated dynamic operating document system. An extreme example of this would be during a non-normal event that has not manifested itself before. In this case, because the non-normal operating condition had not been previously predicted, the system will not be programmed to select the right documents or the right steps to address the problem. The default settings that the system falls back to should follow the basic guidelines above – to assist rather than hinder the user through the information it provided.

When manually input data are required, the type and format of the information needed must be clear to the operator. Additionally, operators should only be asked to enter and confirm the manually entered data once, even if this information is used by multiple operational systems and technologies (Chandra et al., 2003). Workload is not reduced if operators have to enter the same information in multiple locations or if they have to guess at what data are required or how it should be formatted for entry.

In most complex operational settings, it is rare for only one task to be completed at a time. Instead, multiple tasks are typically interwoven and accomplished concurrently (Loukopoulos, Dismukes, & Barshi, 2009). Developers will need to consider whether the same technologies, interfaces, or displays (e.g., EFB) will be required for accomplishing these multiple concurrent tasks and eliminate or at least minimize the amount of toggling among displays required. Indeed, one of the significant advantages of dynamic operating documents and information over other systems is the combination and integration of operational information that reduces the need to shift among displays and multiple sources of information. Further, it is essential that the behavior of dynamic operational document systems is consistent, predictable, and transparent to users. Some of the greatest confusions for pilots on the flight deck are caused by the unexpected behavior of automated systems (Sarter & Woods, 1995).

Cognitive and Human Performance Considerations

Situation Awareness and Maintaining Operator Understanding. Generally speaking, situation awareness, as applied to operational documents, can be thought of as an operator's perception of information, knowledge of the origin of that information, and understanding the meaning or implications that information has for operations both at the current moment but also in the near future (Endsley, 1995). It can be easy for operators to lose situation awareness in several different ways when documents are presented electronically, and particularly when they are dynamic. For example, when an electronic document is not presented automatically, cues may be necessary to remind the operator that a needed document is available so it can be manually accessed. Operators can also lose orientation or perspective (a particular problem when graphic images are presented on displays that cannot accommodate their complete size), or lose track of their progress when using electronically presented textual information. Readers are referred to Boorman (2000), Civil Aviation Authority (2005), Cosimini (2002), and Hackos (2002), for a more in-depth review of document presentation issues and various design solutions (e.g., paging versus scrolling, using color to indicate step completion, etc.).

The integration of information from multiple sources can also be rather disorienting, particularly for users who are used to dealing with separate distinct documents or sources of data. Experts' knowledge is cognitively represented in a well-tested schema, which is a mental representation used to structure and organize information (Bartlett, 1979). With practice, users adapt and refine their schema until they can utilize it for organizing and understanding every aspect of their work tasks, which leads to quick & efficient performance. Klein (1993) has emphasized the degree to which experts rely on well-honed schema to recognize and react to time-critical and stressful situations. So, changing a significant aspect of operators' routines, such as the source and format of the information they use, can force them to reorganize their cognitive schema. Additionally, when some of that information changes dynamically, as was illustrated in the revised "A Day in the Life of a Pilot" above, users can easily lose track of what calculations have been performed automatically, what information went into those calculations, and the original sources of that information (Berman, personal communication, March 23, 2009). Knowledge of these things becomes particularly important if an automated calculation is suspected of being incorrect. Therefore, developers must devise ways to ensure the transparency of not only the underlying philosophy, algorithms, and organization of dynamic documents, as discussed earlier, but also the information sources when data are integrated, combined, or used in automated calculations.

Memory Load and Workload. Despite their intended use as memory aids or memory replacements, static (i.e., non-dynamic) documents can place a heavy memory demands and workload on users. This is caused, in part, by users having to navigate within the documents to locate only that information that is pertinent at that time and simply remembering which documents to turn to if there are multiple tasks to complete. Assisting operators by integrating information from multiple sources, performing complicated computations, and presenting only that information which is needed are some of the great advantages of dynamic documents over all other formats.

A related advantage is that dynamic documents can present information at the exact time that it is needed, thereby reducing memory load and helping to minimize prospective memory failures, i.e., failing to remember to perform a task when its execution must be delayed until a later point in time. For example, in 1996, a Continental DC-9 landed gear up because the crew missed the "Hydraulics on High" item on the In-Range Checklist and then in the ensuing confusion, forgot to complete the Landing Checklist (NTSB, 1997). Had the In-Range Checklist automatically remained on the display until all items were completed and had the Landing Checklist automatically been presented, it is much less likely that the error chain would have occurred as it did.

Because of the advantages just described, almost by definition dynamic operating documents reduce user workload. It is possible however, to design a dynamic operating document system that actually increases a user's workload, such as when the interface for accessing documents is not intuitive and simple; when unnecessary, inaccurate, or incomplete information is presented; when users cannot easily locate documents, or information is not automatically presented or queued for presentation; or when the system requires that a great deal of data be manually input by the user. As stated earlier, workload is not reduced when users must manually input the same data in multiple places or must guess at the format in which the data must be entered. A user's workload will also not be lessened when only a small fraction of the possible information is made dynamic and users must still access and integrate information from multiple sources.

Information Overload. A question facing the designers of all documents is how much information to make available to potential users of a system beyond the items that require user input. An increasingly prevalent problem resulting from efficient microchip storage (where a small chip can contain terabytes of data) is that a physically small system can provide more data than a person can possibly assimilate. Given more information to sift through than can be organized cognitively, users can experience information overload (Edmunds & Morris, 2000), where they cannot pull out the relevant key items of information required to make a decision or to act. Hiltz and Turoff (1985) describe information overload arising first as a "problem" and then growing into a "constant challenge to be overcome," underlining that people can become drawn into information management to the detriment of the task at hand. Set against this is the benefit of making larger amounts of information available for those who might need it.

Thus, there are two issues that a dynamic document developer has to consider. First, archives and instructions need to be easily obtained without creating clutter in the main flow of activity. Second, if steps in a workflow are not necessary in a particular situation, should they be left in but marked as non-applicable in some way, such as graying out the text, or should they be deleted entirely (the hallmark of dynamic documents)? There are advantages but also costs to both approaches. As discussed earlier, deleting non-applicable information reduces the length of documents, decreases workload, and streamlines procedures. However, retaining but graying out non-applicable steps may assist a user in maintaining better situation awareness and, as noted above, reduce confusion if the user needs to refer to paper or non-dynamic electronic documents in the event that the dynamic operating document system is unavailable.

Interruptions, Distractions, Concurrent Task Management, and Operator Attention. As mentioned earlier, in most professional and industrial settings, operators must accomplish multiple tasks within the same time period. Quite often, steps comprising these multiple tasks are interwoven or interleaved requiring the operator to constantly shift focus among these multiple tasks, performing a few steps for one task before moving to a different task and then back again (Loukopoulos, Dismukes, & Barshi, 2009). The management of these multiple concurrent tasks is not an easy feat, however, and being interrupted or distracted during the performance of these tasks makes operators in all settings vulnerable to errors such as forgetting a step related to a task or getting fixated on one task and forgetting to shift attention and execute the others (Loukopoulos, et al., 2009). Because dynamic operating documents can streamline procedures, the amount of concurrent task management required is reduced as several tasks can be integrated into one. Also, as already discussed, by reducing operator workload and the amount of time required to execute tasks, dynamic operating documents also reduce the likelihood of operator error due to interruptions and distractions. Electronic tools, such as place-holders and moving highlighting or color changes upon task completion can help users combat those interruptions that do occur and avoid memory-related errors when using dynamic and other types of electronic documents.

There are some demands on a user's mental resources that cannot be minimized by making documents dynamic – the amount of attention an operator should pay to any given document is one of these. However, the functionality available for dynamic documents can help users not only focus their attention where they need to but also reduce the amount of time spent looking at irrelevant documents. If the system offers the correct document for a task, users do not spend time and mental resources looking for what they need. For this to happen, the dynamic system has to sense aspects of the situation that allow it to select the correct document. This logic is relatively straightforward if one document must follow another but in less defined situations where there are many possible options, the logic guiding document presentation is far more complex and is correspondingly more difficult to validate (Boorman, 2000).

Thus, how and when to present electronic documents and information are not easy decisions for developers. It is important to provide or make available the information necessary to support efficient operator performance throughout all phases of the operational cycle under both normal and non-normal operating conditions but not in a manner that is in itself distracting or takes the operator's attention from other more critical tasks. A great deal of testing and validation of dynamic and electronic operating document systems is required to ensure that all of these criteria are met.

Limitations in Dynamic Data and Indicating Degrees of Uncertainty. Integrated electronic and dynamic documents are often developed in response to a number of the common errors that operators make when using paper-based documents (see for example Boorman, 2000). However, as should be obvious by now, the development of a sound, reliable, and accurate dynamic operating document system poses many challenges and designers must take care that they do not introduce new error modes as they try to reduce the likelihood of old error modes common with less technically advanced document formats (Boorman, 2000).

Another development issue, particularly related to dynamic operating documents used in aviation and similar fields, pertains to the fact that information from various sources has different levels of fidelity and is certified or approved according to different standards (see below). Thus, there is the potential that some information may not be as accurate as other information with which it is integrated. In aviation, document developers believe that in a paper-based world, when users turn from one document to another, they should be aware that the content of the documents they are using may have different levels of accuracy, especially if the sources from which they were drawn have different certification or approval requirements (Boorman, personal communication, February 19, 2009). However, users of complex systems tend to trust automation they are familiar with (Lee & See, 2004; Parasuraman & Riley, 1997) even if it makes occasional errors. So, indicating the trustworthiness of dynamic information to users is important. A design challenge for the developer of dynamic operating documents then, is to communicate these confidence levels to users without distracting them. In other words, when using a system, the user should be aware that, although all the documents available dynamically function in the same way (i.e., they have the same "look and feel"), they should not be viewed with the same level of confidence. Two approaches to address this would be to allow users to drill down to access information's confidence levels or to display an indicator of the level of uncertainty to remind operators that the information may not be completely reliable or accurate. A third approach is to simply decide that information from sources which have lower levels of integrity will not be integrated or combined with that from sources of higher integrity.

Training New Skills. Training operators to use dynamic documents should be easier than training them to use paper-based documents because much of the knowledge about where to find information and manipulating it will be performed by the automation. This eases the users' mental loads—memory and reasoning—thus reducing the number of skills that need to be trained. However, training will have to expand in other areas. One addition to the curriculum will be explanations of how the dynamic operating document system works, sources from which the information is drawn, and how it is integrated or combined. One key aspect of this training will be to make users aware of how much, and when, information varies in reliability, accuracy, and fidelity, when information of varying levels of integrity have been combined, and educate users about the implications these variations have for how the information, and the dynamic operating document system as a whole, are to be used.

Certification and Approval Considerations

Certification for any product confirms that it meets certain performance and quality requirements. Performance criteria may include efficiency or a product's suitability for its intended use. In the case of safety-critical systems like some dynamic documents, certification may include the degree to which safety criteria are met and testing results are robust. Certification is usually achieved through an assessment by an agent or organization outside of the design and production company – in the field of aviation in the United States this organization is the Federal Aviation Administration (FAA). Thus, certification demonstrates that a third, disinterested party considers that the product meets certain specified criteria.

An electronic document can be seen as having two parts, the database of information that is displayed to the user and the software that drives the look and functionality of the system, giving the data its dynamic capabilities. The database of information must be correct and the software driving the system must function appropriately and be designed with the human operator in mind for users to obtain the information they require at the appropriate time. Users are most concerned with the contents of the documents they are using (and the functionality makes it more or less easy to access the information desired). Although both parts of an electronic document are important to a certifier, in aviation certifiers typically place a greater emphasis on ensuring appropriate software functioning because that software must link to other aircraft systems in order to allow the electronic documents to behave dynamically.

Database Approval. The information in a set of documents, the database, needs to be checked for its accuracy when it is initially developed and at any later point after editing, in addition to when the equipment is certified. It is possible that, post-certification some or all of this information may change based on new findings or circumstances. For example, if an element in a system is redesigned, the procedures for using that element may change too, and the procedure-related information for this element will need to be updated in the documentation. (This is the "information maintenance process" described in Table 1.) Therefore, the certification process needs to allow for the resubmission and approval of changes to the information in documents (of all formats) on at least a semi-regular basis.

In aviation within the United States, the database for electronic documents is classified as operational information and requires only FAA regulatory approval (rather than full certification) under Federal Aviation Regulations Part 121 (see Advisory Circular [AC] 120-64). Information included in electronic databases has to adhere to the same approval criteria as information in paper manuals (see Federal Aviation Regulation 121.133) because the information in both media is the same. Hence, airlines are able to make updates and changes to electronic document databases when they need to just as they would do in a paper manual, as described in Table 1. Provision for the use of electronic database information for electronic checklist systems is outlined in AC120-64, and includes criteria for training and retraining flight crews in its use.

Software Certification: The functionality of electronic document systems should not change as regularly as their content, if at all. Certification needs to verify that document functions – access of documents for display, links, sensor inputs, software-driven reformatting, automatic computations, etc. – are predictable, consistent, accurate, and operate as intended. Currently the software, or functionality, of electronic checklists and documentation developed in aviation under U.S. jurisdiction, is certified as "avionics software" according to AC 20-145 and the Radio Technical Commission for Aeronautics document 178B (RTCA DO-178B). DO-178B states that the software for aviation electronic documents of any kind will be held to the same criteria and treated in the same way with respect to certification as the flight management system or any other computer-driven system on the aircraft. Thus, aviation electronic software must be certified (rather than just approved) under Federal Aviation Regulation Part 25, subpart F.

Prior to certification, software developers will run multiple tests to work out as many system bugs as possible and system checking will be continuous throughout development starting even before any code has been written. There are multiple methods for testing software, ranging from running the system and assessing it based purely on its output, to testing function points, which are derived from user requirements (Albrecht, 1979). However, developing software is an iterative and evolving process. A software developer starts with an analysis of a dynamic document's requirements, and then testing begins with the first program and with each evolution of the dynamic functions until each meets pre-specified exit criteria (Pan, 1999). In the development of some equipment, such as the designing and building of a new aircraft, systems are incrementally constructed and tested. At appropriate points, dynamic documents are integrated into their host systems and tested in-situ. The certification process for the entire aircraft begins when all of these various systems have been integrated and tested together.

The focus of the certification process for some equipment and systems, such as aircraft or air traffic control and processing plant operating stations, is primarily on safety rather than a variety of other factors such as efficiency, weight, or other factors that are of concern to the designer. To meet certification requirements, the designer has to specify all the intended functions of the system and how it will be used and then specify all possible hazards or failures – instances where a system might not operate as intended – and give an account of the effects these failures could have (i.e. a Failure Modes and Effects Analysis, FMEA). For example, what possible effects could there be if a checklist gives a flight crew the wrong guidance? If this results in the aircraft gear being left down rather than retracted during flight, then the outcome would be reduced fuel efficiency and possible damage to the gear. However, if the incorrect guidance results in the gear being retracted when it should be left down, then the outcome could be a wheels-up landing, which has many safety implications and could constitute a far greater hazard. The design team works to remove the possibility of these hazards or failures arising. For certification in aviation, the third party regulator (e.g., the FAA) has to concur with all the hazard categories developed and analyses performed by the design team and to agree that functionality of all systems meet their intended objectives.

In aviation, the steps that precede and form the certification process of electronic document software are time consuming, but essentially consist of studying and testing that the system performs its stated functions as specified and ensuring that the listed hazards are avoided or create only the errors specified (and agreed upon) in prior analyses. It is accepted that there are extremely rare, as-yet unseen, events for which a system may not function as desired but that it is impossible to predict these events. A system will pass certification scrutiny if it is demonstrated to function safely during all possible known events.

The rules governing the approval or certification of electronic documentation systems in other industries (e.g., process control, maritime, nuclear, etc.) will likely differ in some respects from those described above and developers of such systems will need to become intimately familiar with the rules that apply to their industry. An illustration of the approval and certification process in the aviation industry is described below to give novice developers of electronic documentation systems a more complete picture of the kinds of steps that might be required.

Electronic Document System Approval & Certification: An Illustration. In aviation, because safety is a critical consideration, the process of system checking and certification begins at the outset of design. The FAA, as the aviation regulatory body, certifies aircraft, and all their systems, in a four phase process. These phases are 1) formal application, 2) design assessment, 3) performance assessment, and 4) administration to issue the final certificates, i.e., Part 25 Certification and Part 121 Approval (FAA, 2008). For the formal application, aircraft designers have to submit all the manuals that will accompany the aircraft. This means that any dynamic document content that involves, or is involved in, aircraft procedures has to be scoped and developed prior to the first FAA certification phase. However, aircraft manufacturers begin to design and test electronic documents long before this, as other aircraft systems are being designed.

To take a specific example, the Boeing Company began work to design the electronic checklists (ECL) for their B777 aircraft more than four years before the airplane was certified. Developers created the checklists in three phases prior to certification and a fourth phase that followed certification. In the first development and review phase the preliminary ECL system and database were scoped. The second, validation, phase had two stages. The first stage began with paper and pencil evaluations of checklist procedures and ramped up to testing using simple simulators. The findings from this stage were used to inform the next stage of validation and also to develop relevant portions of the aircraft's Flight Crew Operations Manual and flight crew training[5]. At this point, Boeing developers had the electronic checklist materials they needed to begin their application to the FAA for certification. The second validation stage repeatedly tested the checklists in simulators with increasing fidelity and culminated in flight tests in the first B777 aircraft itself. The ultimate test for an aircraft display system was (and is) a diversion to airport not originally intended as a destination, as might be needed during an emergency. This scenario maximizes the demands on the display functions. After the FAA certified the aircraft (and the checklists) Boeing designers worked with their customers to ensure that they understood how permissible modifications could be made to the checklist database.

Treating dynamic documents as two parts makes their ongoing revision possible. Boeing releases content updates approximately twice a year, and each airline customizes the generic checklists they receive from Boeing to fit their own policies and procedures, but these must also meet the instructions and requirements in AC120-64.

Conclusion

In the future, designers will be able to take advantage of advances in software and integrated system design to convert paper documents, not only to an electronic facsimile, but also to interactive dynamic documents that collect and manipulate data to present real-time information to the user. Thus, user workload with respect to document manipulation will be minimized. In the aviation world, advances in this direction are already being made with electronic flight bags, integrated navigational maps, and electronic checklists, to name a few. While stand-alone electronic documents reduce the "paper mountain," integrated electronic documents make the operator's task easier by using sensor data to facilitate progression through and use of the documents. Dynamic documents go one or two steps further – they integrate information from a wide variety of sources and manipulate these data, taking advantage of the ability to pare information presented down to just that which has expected relevance at that time, thereby providing more timely and better support to the system users.

End Notes

[1] For the purposes of this chapter, the terms "data" and "information" are used interchangeably.

[2] Working Memory is that part of human memory where information is held and manipulated. It is working memory that allows humans to analyze, plan, and perform mental calculations. The maintenance of information in working memory typically requires some type of rehearsal.

[3] Prospective Memory is remembering to perform a task at a later point in time when it is appropriate to do so.

[4] A Habit Capture error is the completion of a habitual task when, because of changes in circumstances, it is not appropriate to perform it.

[5] FAA Certification also has to consider the user. The certification process has to include an implementation plan and this has to include a plan for pilot training to proficiency.

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Table 1: Operational Document Formats

Basic Format Type and Sub-type	Example	Functionality	Operator Use	Development
Paper	A table printed on paper located in the performance table chapter of an operating handbook	Static information exists on paper and is organized according to some predetermined scheme (e.g., single sheet, several page bulletins, chapter in a manual, etc.)	Operators must remember that a paper document with required information exists, and must manually locate the document and desired information at the required time of use	Information is generated, organized, and printed on paper according to predetermined organizational scheme. Document is then distributed for use
Stand-Alone Electronic - Without Interactive Feature	A description of the procedure to be followed when changing a tire on aircraft main-gear is in the equipment care and maintenance section of a file saved on a laptop computer	Static information is available for electronic display and is organized according to some predetermined scheme.	Operators must remember that an electronic document with required information exists, must manually locate the document at the required time, and must cause it to be electronically displayed Some search or hyperlink feature may be available to assist in locating the desired document or information.	Information is generated, organized, and saved for later presentation on an electronic display according to a predetermined organizational scheme. Document is then distributed for use
Stand-Alone Electronic - With Interactive Feature	Fuel load, weight of baggage, and number of passengers is entered into a computer, which then calculates aircraft weight and balance information and determines where an aircraft falls within its center of gravity	Data is manually entered into a computer that uses it to calculate some value and generate other information related to it. This information may or may not be compared against or combined with other information and is then displayed electronically	Operators must remember that an electronic document exists, must manually locate the document, cause it to be electronically displayed, obtain and manually insert required data in the proper fields at the time of use. Some search or hyperlink feature may be available to	Information is generated, organized, and saved for later presentation on an electronic display according to a predetermined organizational scheme. Fields for operator data entry are determined and programming allows for manipulation of data, presentation, and use with other static information. Saved program including information file, data entry fields and data computation is then distributed for use

	envelope.		assist in locating the desired document or information	
Integrated Electronic - Without Interactive Feature	An electrical bus relay fails and the procedures for handing the failure are automatically displayed for reference	Static information is available for electronic display and is organized according to some predetermined scheme Sensor information identifies the user's need for static information and it is displayed or queued automatically.	An electronic document is automatically displayed or queued for display and the operator must attend to the display or notice that a document has been queued and then cause it to be displayed	Information is generated, organized, and saved for later presentation on an electronic display according to a predetermined organizational scheme. Data file is then distributed for use A system of sensors within the operational environment is connected to the electronic information system so that specified sensor values will cause certain electronic information to be accessed and presented automatically
Integrated Electronic - With Interactive Feature	While completing a "Motor Failed" procedure, a message is displayed asking if the operator wishes to attempt to restart the motor. The operator selects the "yes" option and all the procedural steps required to restart the motor are then displayed for completion.	Static information is available for electronic display and is organized according to some predetermined scheme Sensor information identifies the user's need for this static information Data is manually entered into a computer, which uses it to calculate values and generate related info. This information may be compared against static or sensor information and is then automatically displayed or queued for display	Operator must obtain and manually insert required data in the proper fields at the proper time. An electronic document is automatically displayed or queued for display and the operator must attend to the display or notice that a document has been queued and then cause it to be displayed	Information is generated, organized, and saved for later presentation on an electronic display according to a predetermined organizational scheme. Fields for operator data entry are determined and programming for manipulation of data, presentation, and use with other information, including that which comes from a system of sensors. Saved program including information file, data entry fields and data computation is then distributed for use A system of sensors within the operational environment is connected to the electronic information system so that specified sensor values will cause certain electronic information to be accessed and presented automatically.
Dynamic Electronic – Without	Aircraft readiness for pushback data is combined with its	Real-time data from multiple sources (sensors, up-linked or down-loaded	An electronic document is automatically displayed or queued for display and the	Information is generated, organized, and saved for later presentation on an electronic display according to a predetermined organizational

Interactive Feature	flight priority to determine when and what order aircraft will be given clearances to pushback on a ramp. Schedules for pushback carts are altered accordingly and presented to the dispatcher with a scheduled time.	data) are used in combination with each other and with static data to yield other information which is then electronically displayed	operator must attend to the display or notice that a document has been queued and then cause it to be displayed	scheme. Programming for manipulation of data, presentation, and use with other information, including that which comes from a system of sensors, uplinked and down-linked data, is also saved. Program file is then distributed for use A system of sensors within the operational environment is connected to the electronic information system so that specified sensor values will cause certain electronic information to be accessed and presented automatically
Dynamic Electronic With Interactive Feature	A pilot enters that an aircraft thrust reverser is not to be used into the system. This information is combined with assigned runway and weather information, uplinked to the aircraft from air traffic control and compared with stored aircraft performance and limitations data. Displayed landing procedures are altered to for equipment limitations and environmental conditions.	Real-time data from multiple sources (sensors, up-linked or down-loaded data, data input from operators) are used in combination with each other and with static data to yield other information which is then electronically displayed	Operator must obtain and manually insert required data in the proper fields at the proper time. An electronic document is automatically displayed or queued for display and the operator must attend to the display or notice that a document has been queued and then cause it to be displayed	Information is generated, organized, and saved for later combination with other data and/or presentation on an electronic display according to a predetermined organizational scheme. Fields for operator data entry are determined and programming for manipulation of data, presentation, and use with other information, including that which comes from a system of sensors, uplinked and down-linked data, is also saved. Determinations of how various operational documents will be altered in real-time based on these data are made and saved to the program which is then distributed for use. A system of sensors within the operational environment is connected to the electronic information system so that specified sensor values will cause certain electronic information to be accessed and presented automatically
Maintenance for all these document systems will consist of updates to their content. Updates and revisions must be performed manually and the revised electronic information must be saved and distributed. In the case of electronic documents, previous versions must be located and overwritten or deleted, for paper documents, previous versions must be located and destroyed.				

Table 2
Benefits and Limitations of Dynamic Operating Document Systems[1]

Benefits	Limitations
• Change in real-time to reflect exact circumstances in effect at moment they are being used • Eliminate the need to search among multiple documents of the same type (e.g., tables, checklists, etc.) to find the one needed • Eliminate the need to navigate through conditional branches within procedures to locate only those steps that are pertinent at that moment • Combine information and data from multiple sources (some static, some dynamic) • Use data from multiple sources to perform complex calculations • Provide information that is needed when it is needed • Reduce operator workload • Reduce operator memory load (working memory, long term memory, prospective memory) • Reduce likelihood of errors due to interruptions and distractions • Reduce likelihood of some types of other cognitive and performance errors (e.g., habit capture) • Fewer requirements for manual data entry, error checker for manual data entry • Support more effective and timely operator decisions	• Poor design of interface and displays increases workload and gives rise to operator confusion • Operator loses situational awareness e.g. operator is not aware of what types of information from what sources have been used or combined • Information is not displayed at the correct time to support effective task management • Wrong information is accessed, combined, displayed • Dynamic information is unreliable or incorrect • Operator is unable to evaluate veracity of dynamic information • No procedure for what to do if dynamic documents/information is unavailable or unreliable

[1] Benefits are only possible if the dynamic document system is well designed. Some benefits listed (e.g., reduce operator workload) also exist for some types of integrated electronic document systems. Some limitations listed exist only if the dynamic document system is *not* well designed (e.g., wrong information is accessed, combined, or displayed)..