TOWARD IDENTIFYING RISK IN OPERATIONAL PERFORMANCE OF ATC PROCEDURES

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Managing operational performance to reduce risk in the execution of air traffic control (ATC) procedures depends on understanding human performance in relation to patterns established in procedures. Procedures specify performance requirements meant to minimize unintended variation that is outside expected performance criteria and tolerances. We define human performance risk as unintended variation outside the envelope of applicable procedures.

Managing human performance to reduce risk in the execution of air traffic control (ATC) operations is predicated, in part, on understanding the human performance prescribed by operational procedures. A procedure is defined as "an established or official way of doing something", and as "a series of actions conducted in a certain order or manner" (Oxford Dictionary). Procedures specify requirements for how work is to be done. Procedures represent the standard technique or techniques to be followed and applied each time a particular operation or situation occurs.

Procedures are the cornerstone for a high reliability organization to provide safe services. Procedures establish air navigation requirements such as for pilot-controller communications (e.g., phraseology), airspace design, and airport arrival and departures. Similarly, procedures are critical to the Technical Operations workforce, flight crew operations and aircraft maintenance.

Our goal for this paper is to propose an approach for identifying where risk is introduced in the human performance of ATC procedures. This approach identifies unintended variation in execution and uses unintended variation as an observable and measureable dependent variable.

In this approach, unintended variation in human performance can be considered a potential hazard to future operations and can be characterized using available information and data. For example, information that has been entered into voluntary safety reporting systems or recorded radar and voice data can be used to identify human performance that varies from expectations given the procedural requirements.

Procedures represent management controls that specify how work is to be done and prescribe work using the following dimensions:

- Either *required* (must be performed, i.e., steps in sequence) or *discretionary* (may be performed, i.e., judgment over which steps to perform)

  Required management controls prescribe the steps of a process to be performed, e.g., the sequence of steps for a procedure, how a decision support tool is to be used, etc. Discretionary management controls pertain to situations where judgment is allowed and execution is optional. Judgment is used to choose which steps are needed to best fit the operational situation.

- Either a *standard* (performance must meet a single point criterion) or a *tolerance* (performance must be within a range).

  Required management controls can stipulate that human performance must meet a particular standard or that it must be completed within certain tolerances, e.g., based on altitude or distance.

- Either a *process* (how to perform an operation), an *output* (the result of an operation) or an *outcome* (ensure safe separation).

  Required management controls can establish a standard for an outcome from a process, such as mitigating the risk of fatigue (outcome) as a result of shift scheduling (the minimum staffing requirements per shift, minimum number of hours between shifts, etc.).

Defining Unintended Variation

We discussed risk as unintended variation in more detail elsewhere (Davis and others, 2015, 2016). In brief, unintended variation in human performance means that performance is outside approved management controls for the procedure relative to any standard or criterion that human performance must meet. Unintended variation can occur despite management controls established to constrain or prevent it. Procedures are developed to mitigate unintended variation.

Human performance refers to "the performance of jobs, tasks, and activities by operational personnel – individually and together" (EUROCONTROL/FAA, 2010). The relationship between these terms is that human factors is the scientific discipline whose sole purpose is to enhance human performance, that is, human performance can be ensured by applying human factors science.

Unintended variation can occur in operational processes, outputs, or outcomes. A procedure can be specified as a process: a series of steps to be executed either in sequence or in parallel. Unintended variation is introduced when a step is skipped (an error of omission), a unrelated step as added (an error of commission), or steps are completed out of sequence.

Unintended variation can occur in the output or the outcome of the procedure or both. It may result, for example, because of a unique operational context the procedure did not adequately address. This can produce a result that is out of tolerance. In terms of human performance, this likely would be classified as a human error.

Common statements used by people to explain their actions can reveal unintended variation in a procedure and responses to it:

- "I wasn't trained for this situation so my first thought was this situation looked like A so I did B and expected it to work,"
- "I expected X but the situation turned out to be Y. I hadn't seen Y before so I did what I always do for X and expected it would work," and
- "When a situation like this occurs I know from experience that I can take a shortcut and get the expected result."

Defining risk as unintended variation is different from the traditional approach to defining risk that uses consequence and likelihood, or probabilities. Use of probabilistic human reliability analysis to assess human performance failure in aviation has proven to be difficult.

ATC Procedures

There are two key FAA Orders that contain operational ATC procedures, Order 7110.65 and Order 7210.3. From time to time these procedures are updated to accommodate changes and introduction of new procedures. Updates are currently denoted with a suffix letter and previously with a change number.

FAA Order 7110.65W (change 2 effective December 10, 2015), Air Traffic Control – This Order documents the ATC procedures and phraseology required to be used by controllers who have the necessary expertise as it pertains to their operational responsibilities, e.g., en route or terminal. Controllers are required to exercise their best judgment if they encounter situations not covered by it. The Order covers all aspects of ATC operations including flight plans and flight progress strips, communications, terminal procedures, Instrument Flight Rules (IFR), radar and nonradar procedures, visual operations, offshore/oceanic procedures, special flights, emergencies, and decision support tools.

FAA Order 7110.65W is 784 pages in length. The Order was first published on January 1, 1976. When Order 71110.65, Change 7, became effective (July 1, 1977) it was 343 pages in length. Comparison between the 1977 and current versions provides some general observations, as follows:

- The 1977 version was organized so as to contain 1,773 numbered procedures.
- There are paragraphs in the 1977 version that no longer appear in the current version, e.g., removing procedures associated with ATC software capabilities that have been replaced by new systems.

- The 2015 version added numerous procedures for new operations and capabilities such as related to wake turbulence applications (for aircraft category, intersection departures, and intersecting runway/intersecting flight path operations).

The current FAA Order 7210.3Z (effective December 10, 2015, change 2 effective November 10, 2016), Facility Operation and Administration – The order contains direction and guidance for everyday operations of facilities and offices. The order currently spans 628 pages. Topics include familiarization/currency requirements for en route, terminal, and system operations facilities, watch coverage and supervision, national automation programs, flight service stations, and the traffic management system.

Other procedures pertain to various aspects of the National Airspace System (NAS). FAA Order 3120.4P (effective December 10, 2015), Air Traffic Technical Training – The order has instructions, standards, and guidance for training. The order addresses Academy qualification training, on the job training (OJT) for position certification, training of OJT instructors, and controller-in-charge training.

Additional FAA Orders address topics important to the NAS including contractions (7340.2), flight services (7110.10), location identifiers (7350.9), airspace (7400.2), Notices to Airmen or NOTAM (7930.2), special military operations (7610.4), traffic counting for determining facility classification levels (7210.57), the voluntary safety report program (7200.20), and occurrence reporting (7210.632).

Required and Discretionary Procedures

Procedures specify required and discretionary actions for what is intended for a particular operational situation. Required procedures prescribe that when a particular situation occurs there are certain actions that must be taken. Discretionary procedures recognize there is more than one course of action that can be taken. With discretionary procedures, there can be more than one pattern that is expected to occur. Discretionary management controls typically use such phrases as “the operator may discontinue the alerts if …” and “the documentation should include …” compared to required management controls indicated by such phrases as “the operator must discontinue the alerts if …” and “the documentation must include …” Discretionary procedures allow use of judgment to select the action to be taken.

Both required and discretionary procedures place limits on the actions so the pattern is predictable and consistent. By specifying the actions to be taken and any tolerances that are permitted, procedures intend to eliminate the potential for errors of omission (e.g., leaving a step out of the procedure) or commission (e.g., adding a unexpected step in the procedure), or that no action will be taken. The difference between required and discretionary procedures is shown in Table 1.

Table 1.
Comparison of required and discretionary procedures

	Required Procedure	Discretionary Procedure
Performance Within Tolerance	Performance fits within one permitted pattern	Performance fits within one of multiple permitted patterns
Performance Outside Tolerance	Performance does not fit the one permitted pattern	Performance does not fit within any permitted pattern

Changes to procedures occur such as when new procedures are developed for changes to existing or implementation of new NAS capabilities. New procedures are developed in response to the emergence of operational conditions or situations not addressed in current procedures. New procedures can also be developed in relation to the occurrence of safety-related operational conditions.

Procedures are sometimes executed through use of control techniques. For purposes of this paper, control techniques are defined as local facility methods for executing procedures contained in FAA Order 7110.65. With control techniques, procedure steps are aligned with local agreements, airspace design, local software adaptation, and other potential considerations. The patterns expected with required and discretionary management controls in 7110.65 extend to the patterns provided by control techniques.

There are numerous ways human performance can involve unintended variation. Bias in decision making can interfere with correct identification of patterns such as through expectation bias, confirmation bias, association bias, frequency bias, and coincidence bias. These types of bias can change performance that goes outside of tolerance. During multi-tasking, attention shifts back and forth among tasks allowing unintended variation to occur. As attention shifts between tasks the potential for errors of omission and commission can increase. Unintended variation can result from tunnel vision in which attention is focused on a particular situation and other situations are not addressed according to procedures. Distractions detract from fully recognizing an operational situation and determining the appropriate procedure. Training intends to build knowledge and skills for consistent problem solving in applying the right procedures to operational situations.

Patterns of Variation

Conceptually, human factors studies examine patterns in operational performance and assess changes to these patterns from unintended variation. Patterns are established through procedures, airspace design, traffic flows, training, equipment design, staffing, and other human factors considerations. Patterns are measured through laboratory and field studies that show how advanced concepts and new capabilities intersect with human capabilities and limitations. Required and discretionary procedures define the steps to be followed so that patterns are maintained. Recognizing and establishing patterns within a system can provide predictability and insight into the relationship between performance and tolerance.

Examples demonstrate how unintended variation from procedures can occur. These examples include that facilities may show differences in use of new capabilities. Facilities may also show differences in operational practices. Controllers may use new capabilities when discretionary procedures permit judgment on how those capabilities are used.

Unintended variation with use of a new capability was demonstrated with initial implementation of the User Request Evaluation Tool (URET) at three facilities (Bolic & Hansen, 2005). Discretionary procedures permitted facilities to adopt its use during implementation. For example, one facility had a discretionary procedure that when both the Radar and Data controllers were trained on URET, they could use the tool and disregard paper strips. These facilities had been using URET prototypes for different numbers of year. Training on URET across facilities ranged from 36 to about 70 hours. Qualitative data were collected at each facility using exploratory open-ended interviews with Subject Matter Experts. Results showed that different sector teams used URET in different ways and in many instances URET usage differed from what was intended. The three facilities used URET display functions for electronic flight strips to replace paper strips and the associated manual workload from handling the paper strips. Two facilities found amending routes was useful when severe weather occurred. A key finding was that facilities developed their own control practices in relation to unique operational conditions. Discretionary procedures permitted this variation.

Variation in operational performance was shown through past ATO research trials of the Normal Operations Safety Survey (NOSS). NOSS is an observational technique for collecting safety data in everyday ATC operations. Controllers volunteered and were trained on conducting sector position observations and classifying data. Controllers also participated in aggregating data at the facility level. NOSS uses the threat and error management taxonomy to classify observations of external threats to the controller, errors the controller may make, and mismanaged threats and errors that may challenge safe operations. An example of unintended variation was demonstrated involving the Transfer of Position Responsibility (TPR). TPR involved a step-by-step process with controllers following a checklist in which the Relieving Specialist previewed the position, the Specialist Being Relieved provided a verbal briefing, and the two Specialists completed the assumption of position responsibility (reviewing the position including signing in and checking information and equipment). TPR data were collected at two facilities over a standardized one-hour observation period. As shown in Table 2, the two facilities varied in completing the TPR checklist. Unintended variation occurred when required management controls were not followed. At the time research was conducted with NOSS, data showed unintended variation occurred both at the individual controller level and at different frequencies across facilities. At Facility A, many instances of the TPR checklist not used and not completed were associated with airspace having seasonal effects with low traffic counts. By the time Facility B trialed NOSS, the ATO was using a challenge and response technique to reduce TPR checklist not used and incomplete checklist use. Also, controllers memorize the TPR checklist through repeated use and not manually refer to a printed checklist. It is important to note NOSS data showed that none of the unintended variation with TPR involved unsafe conditions. Also, NOSS research did not evaluate individual controller performance but rather intended to examine patterns of operational performance.

Table 2.
NOSS trends for Transfer of Position Responsibility

Facility	Total One-Hour Observations	Number of TPRs	Checklist Not Used	Checklist Not Completed
A	90	96	47%	10%
B	147	220	10%	4%

Unintended variation has been examined in the laboratory with use of new capabilities. Kraut and others (AIAA, 2013) conducted a simulation studying how controllers applied a route planning tool to manage arrival traffic. Controllers used discretion to begin aircraft descent from cruise altitude before handing off the aircraft to a low altitude sector. A primary goal was to deliver aircraft to the meter fix within a parameter time of the scheduled time while maintaining standard separation. Results showed controllers used the tools and automation in both strategically and tactically different ways and this diverged further during high traffic demand situations. For example, when demand increased, some controllers deferred to manual control because it resulted in quicker action than the strategy of using the route planning tool. A conclusion from this paper was that tool designers should be concerned with how and when tools will be used and the training needed for their use.

Studies of advanced concepts and new capabilities often focus on assessing system benefits compared to baseline operational conditions. Unintended variation can be a useful perspective to examine how performance may vary from intended use with consequent limitations on intended benefits.

Future Directions

In the future, specific methods should be developed to more closely examine when and where unintended variation occurs and the circumstances associated with it. Once identified, the effects of unintended variation on operations can be examined and better understood. Methods could include use of radar and voice tapes, and systematic observation of ATC operations.

Patterns in unintended variation can also be examined in use of advanced capabilities. For example, simulation studies could assess patterns and variance in operational performance using within subjects experimental designs. Also, training and human-centric design of ATC automation should be examined for their effect on mitigating unintended variation.

Key challenges that can be addressed include whether and how unintended variation in operational performance can be identified. This includes whether unintended variation in operational performance would be minimized by limiting use of discretionary procedures. Another challenge is whether differences in control techniques for the same procedure can lead to unintended variation.

In a laboratory setting, safety is sometimes considered and measured using such measures as losses of separation, controller ratings, and anecdotal evidence. In contrast, examining variation in human performance provides increased understanding and insight into unintended variation and how it influences safety in the design and use of prototype capabilities. Consistency and predictability of ATC operations can be complicated by individual control techniques for executing a procedure. That is, a controller may adapt a control technique they have used successfully many times before to a new capability even if that technique is not well suited to the capability and operational condition. This can introduce unintended variation and may result in performance outside tolerances for that procedure.

Conclusion

Unintended variation must be identified before it can be managed. The evidence for recognizing unintended variation can be derived through field and laboratory measurements. Unintended variation acts as a marker of performance risk. Establishing management controls for required performance in executing an operational procedure creates shared expectations of consistent and predictable performance. Management controls keep human performance within expected performance tolerances.

This paper proposes to use the concept of unintended variation to better understand risks to NAS safety. Unintended variation in human performance can create risk to the safety of NAS operations. Examples of three areas were provided where unintended variation in human performance creates potential for risk. Further work is needed to develop and validate measures as indications of human performance risk.

In future studies, researchers and engineers should consider methods to identify unintended variation in human performance and its relationship to operational processes and outcomes. As a result of this approach, implications for training and human-centric design of ATC automation can be identified along with potential risks in system design.

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