Proactive, Reactive, and Interactive Risk Assessment and Management of URET Implementation in Air Route Traffic Control Centers

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Abstract

The current trend within air traffic management (ATM), as a part of the Next Generation Air Transportation System (NextGen), is to increase the airspace system capacity to operate in diminishing capacity conditions while improving standards of safety. An extensive body of research exists regarding introducing automation into air traffic control in order to create more flexible and cost-efficient operations. The User Request Evaluation Tool (URET) is a strategic support tool designed to assist controllers with timely detection of conflicts; it offers tools for checking the conflict resolution clearances. This study develops general proactive, reactive, and interactive approaches for the risk assessment and management of the system in order to achieve quality (safety and serviceability) and reliability; it also presents a case study of URET implementation in Air Route Traffic Control Centers in the past ten years. First, the reactive approach, used in URET deployment, is developed, followed by developing the complementary and necessary proactive and interactive approaches. Safety Management and Assessment (SMAS) evaluation is performed for the reactive approach. Findings show that many factors led to cases of URET usage deviating from that provided for in the original design, and for using URET less often than it was originally intended.

Keywords: Air Traffic Control, en route, URET, performance shaping factors, proactive, reactive, interactive, risk assessment and management, SMAS

I. INTRODUCTION

Human error contributes to air traffic management (ATM) incidents in the order of 90% or more [1], compared to the human error contributions in nuclear power (70-90%) or medical (98%) industries. However, ATM is unique because of its highly dynamic and time-critical environment, which is also very cognitive in the nature of its tasks. It is important to recognize that "human error is not, however, the only causal factor involved: incidents or accidents generally happen when several causes—possibly including human error—are combined." In addition, many of these factors are "latent," existing dormant within the system long before a major incident occurs. According to [2], some of the frequent latent contributors to incidents are: complex system design, poor man-machine interfaces, inappropriate work organization, awkward work procedures or policies, reduced or altered communication between human operators.

The ATM system is very reliable considering that every day air traffic controllers handle high numbers of aircraft movements without any incidents. Many redundant components in the system, as well as the structured communications between its players "have generally allowed a graceful recovery from failures, without accidents." Such errors, due to the system reliability and humans in the loop are "not likely to be damaging to system performance if they can be caught and corrected by error-tolerant systems" [5].

Many studies analyzed the means of meeting growing air traffic demand, as well as introducing automation and surveillance tools into the existing system. However, automation can be a "mixed blessing" and can actually heighten the importance and impact of human error.

Due to pressure on ATC to handle an increasing number of aircraft, the "tolerable error margin both for the pilot and the controller is shrinking as more traffic is packed into already crowded airspace" [6]. The current ATM struggle is to increase the airspace system capacity to operate in lower margin conditions while continuing to improve the current standards of safety.

As a response to the NextGen additional capacity and safety needs, this study addresses the following goals and objectives:

- addresses performance shaping factors relevant to air traffic controllers and provides a research and development foundation for the "next generation" ATC system
- discusses automation issues and introduces the specific automation tool, User-Request Evaluation Tool (URET), its intended use, and its actual use
- develops a reactive approach (Safety Management Assessment System—Braille Chart) for the "failure" of URET to be used in accordance with its designed usage

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- develops a proactive and interactive approach for applicability of URET deployment in Air Route Traffic Control Centers (ARTCCs)

II. ATC System Operations

Because the presented study focuses on Air Route Traffic Control Centers (ARTCCs), a general description of air traffic controller sector teams is presented below.

A sector controller team ranges from one to three persons, depending on the traffic-induced workload. A two-person controller team most commonly consists of:

1. Radar Controller (R-side) - fully certified controller responsible for maintaining prescribed separation between aircraft under his/her control using radar-displayed information. He issues altitude, heading or airspeed change clearances to accomplish this duty and handles all communication with pilots.
2. Radar Associate Controller (D-side) - either fully certified or developmental controller assists the R-side controller. Duties include flight strip management, coordination with other controllers, and identifying potential conflicts between aircraft that are not yet under the active control to the R-side controller.

According to Bea [7], quality can be defined as the ability to satisfy the requirements of serviceability (use for purpose for conditions), safety (acceptability of risks), compatibility (acceptability of impacts), and durability (freedom from unanticipated degradation). Because the goal of ATC is to facilitate the "safe, orderly and expeditious flow of air traffic" [6], to satisfy goals of both safety and efficiency can, however, be contradictory. Indeed, in the ATC, safety always supersedes efficiency. Given the economic pressures from airline management and the increasing number of airplanes trying to utilize the airspace, it is easy to see that this could become a starting point for compromises in system integrity that could ultimately lead to failures. Airspace capacity maximization needs to take into account the fact that controller's workload increases with the number of aircraft under control, and therefore we should not insist on reducing aircraft separation to the levels where the systems failure recovery is difficult to achieve. Means to increase capacity, which bring about increase in the controller workload, and sometimes need for separation reduction, have been turning to automation for help.

III. AUTOMATION IN ATC

Traditionally, automation is implemented in an attempt to reduce the operator's workload during peak periods of task load. However, this may not always be the actual outcome. For example, automation can reduce mental workload when workload is already low, or increase mental workload when workload is already high, better known as "clumsy automation" [10].

Automation technology in ATC has been advancing over time. Even so, humans are still essential to the system to monitor the system using automation tools, act as controllers, and need to be able to keep the system operating even when automation fails, which is a major concern in automation implementation. Several studies indicate that operators may require more time to intervene under automation than under manual control because they first need to regain awareness of the state of the system. When operators are actively involved in creating the state of the system (as opposed to passively monitoring automation), they develop a more complete situational awareness of the system state [10], which is of paramount importance in ATC, and the state-of-the-art in many areas of ATC.

User Request Evaluation Tool is one of the automation tools introduced. It was intended to be a strategic support tool for the D-side controller of an en route sector team. With URET, the "D-side controller should be able to help the R-side controller to resolve potential conflicts of aircraft that are not yet under the sector's active control, to check if the clearances the R-side controller is issuing are conflict free, and to better perform other D-side duties" [11]. URET notifies the controller of the potential conflicts by continuously checking current flight plan trajectories for strategic conflicts up to 20 min into the future. It was expected that URET would enable the controller team to handle more aircraft due to the decreased workload resulting from the automation as well as the availability of more accurate information. In addition, URET was expected to help controllers provide more direct routings and better flight profiles to airlines. Currently, URET is installed and in use in all Air Route Traffic Control Centers (ARTCCs). However, URET's actual usage differs from the designed one. For example, a very small percentage of controllers use it to check for the potential conflicts of aircraft not under the active control. On the other hand, they all use the electronic flight strip replacement functionality and a majority of controllers find it very helpful, above all because it reduces their manual workload.

URET deployment and integration into the system took ten years. Many factors contributed to such a long period of integration: ATC system safety, organizational factors (FAA and controller union), automation tool itself, etc. Still, the tool is not being used in a designed way, which can be considered as an implementation failure in terms of serviceability, and reliability as viewed from the engineered systems' reliability point of view. The following text describes the performance shaping factors further used to develop approaches to achieving reliability in the URET implementation management engineered system.

IV. Performance Shaping Factors

Performance Shaping Factors (PSF) are "influences that can result in an increase in the mean rates of human errors" and are "useful in helping develop quantification of the potential effects of changes in organization, hardware, procedures, and environments on the base rates of human errors" [7]. PSF can be divided into the following categories: impairments, training, workload, organizational, communications, societal, and environmental.

Impairment of a subject can come from one of four major causes: fatigue, well-being, medical, and drugs. Fatigue is the most studied in the human performance field. Work-rest schedules and shift work address these fatigue issues.

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Training can be subdivided into routine task performance, unfamiliar events, and emergency response. The effectiveness of training can greatly impact a controller's performance.

The workload PSF "entails the effects of demands imposed upon the subject by assigned and unassigned tasks." An individual's demand can be subdivided into the following categories: occupation (direct and indirect), regulatory (laws, codes governing the subject's work and/or personal life), societal, and personal [7].

The organizational PSF is a very powerful one, with culture (in particular, risk acceptance) being a dominant PSF. Teamwork both among controllers and between controllers and pilots is critically important for safe and efficient air traffic control [7].

The communications PSF can be subdivided into oral, written, and nonverbal. The effectiveness of communications also depends on shared assumptions, a shared mental model [9], or shared situation awareness between speaker and listener**,** which is critically important for a safe and efficient ATC

Societal and external environments are both PSFs that are not addressed in this study as they are not as significant or relevant to the ARTCCs as the other PSFs.

With the given background on performance shaping factors for air traffic controllers, the consideration of automation in the future air traffic control system is logical. The next section proceeds with the discussion about the research dedicated to learning about the benefits and costs of automation into the system.

V. Methodology

This paper focuses on the quality attributes of safety (acceptability of risks), serviceability and reliability. Reliability is defined as the "probability that a given level of quality will be achieved during the design, construction, and operating life-cycle phases of an engineered system [7]. The authors view the system as consisting of seven components (see Table 1).

There are three fundamental approaches to achieving reliability in engineered systems: proactive, reactive, and interactive. These approaches are inter-related, interdependent, interactive, and complimentary. The proactive approach includes measures employed before accidents and incidents; the reactive approach includes measures employed after accidents and incidents, and the interactive approach includes measures employed during the evolution of accidents and incidents. Each of the three approaches has its own strengths and weaknesses. The objective is to "define a combination that can be most effective and efficient in maintaining the desirable and acceptable quality and reliability of systems" [7].

First, we introduce and define the following important terms:

- System = the implementation of URET in ARTCCs sectors (1995-2005) and the organizations involved in its implementation
- Failure = system usage different from the designed one

In the first step, an overview of the existing methodology was conducted based on [11] that involves interviews of Subject Matter Experts (SMEs) (air traffic controllers) at the Oakland center (which did not have URET at the time), and the Indianapolis, Jacksonville, and Washington centers (with URET). The interview results provide useful information about:

1. The specifics of controller team operations, in both URET and non-URET environments
2. Specific uses of URET
3. Center culture

In the second step, data for an in-depth reactive approach are gathered, collecting 3 grades (low bound, most probable, and high bound) for each factor in each of the 7 system components, and an explanation of why the particular grades are chosen.

Further, based on the system (URET implementation in ARTCCs), a reactive approach is developed in order to understand why the system usage differed from its original usage design. This is necessary in order to further develop a proactive and interactive approach (plan and monitor) for a successful implementation of URET.

VI. Reactive Approach

The reactive approach is based on analysis of the failure of a system, where the system usage differs from the designed one.

Development of the approach relies on gathering all available information on the failure and the life-cycle characteristics of the system. The information should address the following three categories:

- *Initiating events and factors* that may have triggered the accident sequence
- *Propagating events and factors* that may have allowed the accident sequence to escalate and result in the accident, and
- *Contributing events and factors* that may have encouraged the initiating and propagating events.

Rather than considering a particular "accident" or "incident" that many reactive approaches are based on, the considered "incident" in this study is defined as follows: (i) URET is not achieving its original purpose, (ii) URET is not used as much as expected, and (iii) if used, it is used mostly for unintended purposes.

Information gathered in the three mentioned categories should address the seven system components, as well as the life-cycle characteristics and history of the system including design, construction, operation, and maintenance.

Furthermore, information is used in the Safety Management Assessment System (SMAS) protocol. SMAS is intended to be used as a proactive measure to help identify potentially important problems or flaws in systems, and to help determine how these potential problems or flaws might best be remedied. The focus of SMAS is on those human and particularly organizational factors (HOF) that influence the safety of the system. SMAS can be used through all three approaches (proactive, reactive and interactive).

The SMAS evaluation incorporates a qualitative assessment of the factors listed in Table 1 in each of the seven key system components: 1) operators, 2) organizations, 3)

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procedures, 4) equipment, 5) structure, 6) environments, and 7) interfaces. The evaluation of component factors relies upon experienced and trained assessors to assign a threefold grade: the lower and upper bounds of the most probable estimate, allowing assessors to capture their uncertainty when making an evaluation. Grading scale is composed of discrete values from one to seven where: 1 is "outstanding in all standards and requirements", 4 is average, 7 is very poor, and the intermediate grades are used to express evaluations between these anchor points. A mean grade, standard deviation of the grade (St. Dev.) and coefficient of variation (COV) of the grade are determined for each attribute.

TABLE I. EVALUATION CATEGORIES AND FACTORS [7]

Operating Teams	**Organizational**	**Procedures**
Process auditing Safety culture Risk perception Emergency preparedness Command and control Communications	Process auditing Safety culture Risk perception Emergency preparedness Command & controls Training Communications resources	Operating Maintenance QA/QC Contractor selection Pre-start up review Emergency response Management of change Validations
Equipment	**Structure**	**Environmental**
Design guidelines and specification Materials Demand systems Power systems Configurations Control systems	Design guidelines & specs Materials Loadings Structure configuration Computer programs Research, development and testing background	External (Weather) Internal Social external – (Regulatory, Society) Social (internal) (within organization and operating team)
	Interfaces	
Operators & other Organizations & other	Procedures & other Environmental & other	Equipment & other Structure and other

A "Braille" (Pareto) chart is then developed, summarizing the mean grades developed by the assessment team for each of the factors. The 'high' grades, those above 4, indicate components and their factors that are mitigation candidates. The coefficients of variation associated with each factor indicate the range of uncertainty associated with the ratings. The assessors are able to back track and identify the factors and attributes that result in a particular grade along with the recorded comments that provide the rationale for the grading. This provides a strong interpretative and evaluative component in identifying the best actions to improve a grade.

Although the SMAS factors gradings are performed for each of the seven components, we are presenting an explanation for the grading of the first system component only (Operating Teams), whose results are shown in Table II.

A. *SMAS Evaluation of Operating Teams Component*

The following six factors were evaluated for the first system component, Operating Teams:

- **Process Auditing** – The controllers do not have an actual, formalized auditing process of URET. In the exploratory interviews, controllers emphasized they only perform the processes for which they were adequately trained and consequently, they were not fully utilizing URET.
- **Safety Culture** – Safety is their top priority (above efficiency and strategy).
- **Risk Perception** – Air traffic controllers do not want to come into any risk-related situation; they want to avoid such situations at all costs.
- **Emergency Preparedness** – The most probable grade of 2.5 depends on how long the controllers have been using URET, and how they control traffic. For example, those that extensively used paper strips felt that handling paper strips helped them be more aware of situation, and hence, felt more prepared to respond quickly to emergencies. Switching to the electronic flight strip replacement made them feel that their mental picture was inadequate. Furthermore, they felt that procedures for use are insufficient to prepare them for emergencies.
- **Command & Control** – The most probable grade of 4 is based on the fact that the tool is used differently from its designed purpose. The controllers are not using URET for its intended use (conflict probe), but more for its electronic flight strip functions that replaced paper strips.
- **Communications** – The implementation of URET should have improved controller team communications. Some centers' communications did indeed improve, but primarily on an individual basis, rather than on a system-wide basis. Some centers' communications actually worsened. Interestingly, before the use of URET, most controllers worked in teams of 2; with URET, there were more occurrences where controllers were working alone.

TABLE II. OPERATING TEAMS GRADING

Operating Teams	Lower Bound	Most Prob.	High Bound	Mean	St. Dev.	COV
Process Auditing	2	3	5	3.3	0.6	0.2
Safety Culture	1	2	4	2.3	0.6	0.3
Risk Perception	1	1	2	1.3	0.2	0.2
Emergency Prepared-ness	1	2.5	4	2.5	0.6	0.2
Command & Control	3	4	6	4.3	0.6	0.1
Training	4	5	7	5.3	0.6	0.1
Communi-cations	2	4	6	4.0	0.8	0.2
GRADE (Category Mean)				3.3		

Braille chart is developed based on the grading of all the factors listed in Table I, including the remaining six system components (Organizational, Procedures, Equipment, Structure, Environment and Interfaces). The chart summarizes the mean grades developed for each of the factors, as depicted in Figure 1.

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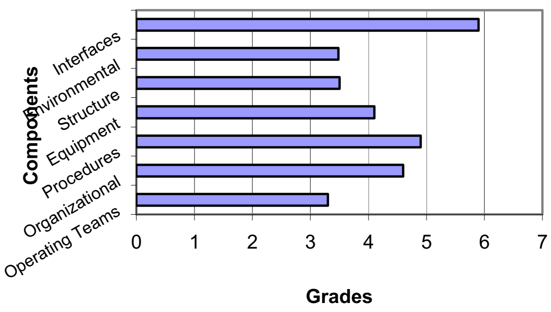

Figure 1 Braille Chart for URET Evaluation Categories and Factors

Based on the previously presented grading scale, this Braille Chart indicates that the majority of our system components do not meet the average standards (grade of 4). Four out of the seven components—Organizational, Procedures, Equipment, and Interfaces—are below average (between grades 4 and 7), whereas the other three components— Structure, Operating Teams, and Environmental—were barely above average (between grades 1 and 4). The operating teams (controllers) are not ranked poorly because the responsibility cannot be placed on them for using URET less often than was intended, as well as for not using URET for its intended purpose. The causes of the current style of URET implementation are rooted in the organizational factors, upstream from the operators themselves (i.e. lack of funding and attention for training and procedures). The worst ranked components were the Interfaces between Procedural + Operating, Procedural + Organizational, and Hardware + Procedural. These grades support the argument for integration of automation into the existing system, where separate system components (e.g. procedures, operating, organizational, hardware) are developed separately and independently.

B. *Event Category Findings*

The initiating events— that may have triggered the outcome of URET not being implemented as originally planned—are predominantly at the organizational level.

URET's adoption decision was made at the organizational level, but individual users were then left to "adopt, re-invent or reject the innovation during its implementation" [12]. The FAA decided to deploy URET to all ARTCCs in the United States in 2002, after more than 20 years since the beginning of URET development. Its continued development is a result of its robustness through the changing objectives of ATC management. The final deployment decision was based on automation performance metrics and cost-benefit assessment rather than on the analysis of controller performance when using URET.

The compounding/propagating factors—those that may have allowed the event sequence to escalate and result in the accident (e.g. the unintended usage and lack of usage of URET)—include the performance shaping factors of workload and stress. It was expected that by fully using URET, the controller team will not only be able to handle more aircraft (because of reduced manual workload from automation and availability of more accurate information), but will also be able to provide more direct routings and better flight profiles to airlines. Since URET is designed as a decision support tool for the D-side controller to support the sector team strategic planning function, "full use of the tool is virtually impossible if only one controller works the sector" [12]. URET's electronic flight strip replacement function caused an unintended consequence - the reduction of teams from two-controller into one-controller teams. However, URET was designed for a two-controller team. In situations of increased traffic, if only one controller is working, and does not have the other controller's support and communication, the workload and stress do not allow controller to apply strategic approach (what URET is designed for), but make him/her to work tactically. Moreover, in such situations URET becomes a low priority—the controller does not even have the time to use it, when presumably he would need it the most - an unintended outcome.

The contributing factors—those that may have encouraged the initiating and propagating events—are insufficient training, lack of procedures, cultural differences, staffing, and structure of the center airspace.

Training was one of the most significant contributing factors that led to the system usage that was different from the designed one. According to [11], "there was a lack of requirement for new controllers completing any on-the-job training to have URET proficiency." Currently, training is done primarily on the job with more experienced controllers acting as teachers. Furthermore, this form of training is not efficient because most of these controllers are "more proficient in the pre-URET ATC, and less in the 'proper' URET use" [11].

For four of the new centers, URET training lasted only for four days, with the majority of the time spent on "buttonology"-explanations of how each function works and how to use the computer-human interface. The training did not address how URET would be integrated into existing practices, nor the creation of new procedures incorporating it. The training was not extensive enough to provide the controllers with full knowledge of URET and its use. Hence, they lack the ability to use the full range of URET functionality [11].

Although URET is installed in all ARTCCs, the FAA Order on Air Traffic Control, which contains the ATC procedures, covers Decision Support Tools (e.g. URET and Ocean-21) in a single, very brief chapter (Chapter 13). Most of the URET procedures assume a pre-URET environment. For example, flight strips are rapidly becoming obsolete, and yet, the chapter that covers the use of flight strips is quite long and elaborate. Although URET is intended to change the way controllers do their jobs, these changes are still not addressed in any training or work procedures. According to exploratory interviews with the SMEs and controllers, it was found that no appropriate ARTCC procedures exist for using URET [11].

VII. PROACTIVE APPROACH

The proactive approach is intended to study the physical aspects of systems and procedural-human aspects, identify potential improvements and critical flaws, and identify ways to improve the quality of the systems and procedures. Proactive approaches include system design measures (e.g. design for robustness), and life-cycle ergonomic design.

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According to [7], a large variety of sample cases were studied in detail in which "errors made during and in the design of the system lead to the failure (lower than desired quality) of the system." Organizations that were involved in the system designs are the dominant cause of system design related failures. Many of these errors are caused by the lack of the culture to promote quality in the design process. To improve and assure sufficient quality in system design, the priorities where one should devote attention and resources to are organizations, individuals, and procedures [7].

A. Design Organizations

High-reliability organizations (HRO) can reduce the probabilities of errors by enacting the following [13]: command by exception, redundancy, procedures and rules, training, appropriate rewards and punishment, and the ability of management to 'see the big picture.'

Command by exception is essentially migrating decision making responsibility to the persons with the most expertise in making the decision when unfamiliar situations arise. In systems like ATC, and its automation, the decision making (when automation introduction is in question) should be made by a group of experts that is comprised from controllers, tool designers, human factors experts—an interdisciplinary group.

Redundancy involves people, procedures, and hardware. Currently, URET is on a different power source than the other tools, providing a form of redundancy in case one power source goes out. However, in some ARTCCs where URET unintentionally reduced the two-controller team to a one-controller team, redundancy in terms of controller decision-making was reduced. Thus, it is recommended that a minimum of two-controller teams at all times becomes a standard, even when workload is low.

Another important aspect of HRO are procedures that are "correct, accurate, well organized, well documented, and are not excessively complex" [7]. In addition, HRO could develop constant and high-quality training programs. As discovered in exploratory interviews, training and procedures were two of the major problems contributing to the failure of intended and sufficient URET use. The current ATC training is performed on the job by experienced controllers who are more proficient in pre-URET than post-URET environments. More attention could be devoted to developing high-quality training.

According to [11] it was suggested that in order for the developers to become a HRO, they need to focus on integration, rather than leaving controllers to "adopt it and adapt it on their own".

B. Design Teams and Quality Assurance

According to [7], the design teams are the "first line of defense to prevent and/or detect and correct system design engineering malfunctions." This category includes personnel selection and training, as well as the formation of cohesive teams and teamwork.

It is suggested that these design teams become more cross-functional, where the design teams incorporate researchers and programmers, as well as the operators themselves. If the end-users are incorporated early on in the design process, this could lead to less re-work downstream and would serve the purpose better.

Quality assurance (QA) includes the activity conducted prior to an operation to 'assure' that the desired quality is developed. QA is the proactive element of QA/QC, where Quality Control (QC) is the interactive element (discussed in the following section). QA methods take into account the quality attributes of the system (serviceability, safety, durability, and compatibility), and focus both on error prevention as well as error detection and correction.

C. Design Procedures

In the next generation system design procedures and guidelines, it is now clear that human and organizational factors (HOF) should be taken into even greater and more serious consideration.

It is suggested that the design teams take into account the lessons learnt in the past and incorporate them into their design procedures. Not only could these organizations focus on developing and incorporating QA/QC into their procedures, but they could also continue to work on proactively incorporating HOF in order to continually improve the design. It is further suggested that the QA/QC is incorporated into both the procedures of how to use URET, and a way for the controllers and auditors to continually and easily check that URET is being used as intended. Another suggestion would be to institutionalize QA/QC into everyday work, rather than sporadically though large-scale studies. For example, it could become part of the controller's daily or weekly routine during their short breaks to evaluate their performance relative to URET.

D. Ergonomic Design

Ergonomics is the "science and practice of designing systems to fit people" [12]. Micro-ergonomics addresses the man-machine interface design at the local work station level, whereas macro-ergonomics "addresses the design of the work system as a whole" [15]. In micro-ergonomics, engineered systems are designed in order to decrease the likelihoods and consequences of failures associated with human-system interfaces, and sometimes, increase the likelihoods of detection and correction of failures. By understanding the impacts and the significance of micro-ergonomics, there will be a better grasp and implementation of proactive risk assessment and management.

Since many of the ARTCC sectors have reduced the teams to a one-controller team, different aspects of URET design could be considered to allow more flexibility for each individual ARTCC. URET has been demonstrated to be unsuitable for use by a one-controller team. URET has a separate trackball for information input, meaning that in situations of only one-controller working, he will need "to use two trackballs and two keyboards if he wants to use URET functions other than flight strip replacement one," [11] which makes URET more complex to use. It is further suggested to re-design URET to accommodate both situations of one-controller and two-controller teams.

VIII. INTERACTIVE APPROACH

Since the aviation industry is highly dynamic and time critical, this interactive approach is crucial to the local operators to deal with threats to quality and reliability themselves. In other

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words, the proactive and reactive approaches are not sufficient. Reference 3 has developed the proactive and reactive approaches, but there is a third and crucial element missing: the interactive (real-time) approach. According to [7], this interactive approach needs to be recognized and further developed.

This interactive approach is based on the argument that in essence, the aspects that influence or determine system failures in the future are unpredictable and unknowable. Reference 7 provides an interactive theory that is based on organizations and teams "interacting" with the system to return it to a safe state, hence turning an accident or failure into an incident or "near miss." The goal is to increase the proportion of successful interventions as events unfold by developing the operators' cognitive skills so that they can manage an unimaginable event before them.

Interactive management has two fundamental approaches with the objective to achieve quality in systems: 1) to improve the management of the causes to reduce the incidence of HOE, and 2) to improve the management of the consequences to reduce the effects of HOE. There are three time frames in which one can focus HOE management activities: 1) to prevent errors before the activity, 2) to detect and correct errors during the activity, and 3) to reduce the consequences of the errors after the error is committed [7].

In managing a crisis, training can reduce the amount of cognitive processing required to determine what should be done. In addition, observations themselves are crucial in crisis management. They provide clues about whether implementation is producing the desired results. A crucial aspect of operator training managing a crisis is a true, detailed understanding of URET in relation to ATC. It is not enough that the operator knows how to "push buttons" and use the Computer-Human interface. The operator needs to know each of URET's 4 functions deeply, how they function in *relation* to one another and to the system as a whole.

There are two fundamental approaches to improving crisis performance [9]: 1) providing people support, and 2) providing system support. Providing people support includes selecting the right personnel and in the case of ATC, it is crucial that these operators are audited, trained, and re-trained in order to fully implement all the functions and intentions of URET. The training should include crisis management strategies. System support is the second approach to improve crisis performance, which includes factors such as maintenance of equipment and procedures so that they can be relied upon when a crisis occurs.

In ATC, human factors have traditionally been considered only during the design of the new tool (proactive), where the designed is expected to address all potential problems and consequences. However, once the tool has been implemented, the design is assumed to be sound, and the human factors specialists move to research the next innovation—there is not enough follow-up and observation on the implementation process [11]. It is suggested that the usage of URET is continuously being monitored and observed throughout. More importantly, the auditors would need to know and understand what exactly they are measuring because the end result could be misleading.

In summary, it is suggested that the developers could learn more from field evaluations, and implement an interactive, real-time approach to monitoring the implementation of URET, in order to achieve a quicker evolution of air traffic management capabilities. In order to achieve this successful interactive approach, the selection of well-qualified operators and perpetual training and re-training is necessary to produce highly cognitive operators who can apply crisis management strategies while successfully navigating the crisis management loop. There needs to be more interactive, real-time monitoring on how controllers adopt/adapt URET and how its usage in turn impacts the overall ATC system.

IX. SUMMARY OF THE STUDY RESULTS

A Braille Chart is produced as a result of the analysis of seven factors as shown in the previous section in Table I. Based on the grading scale with 1 being outstanding, exceeding all standards and requirements, and 7 being very poor, and not meeting any standards or requirements, a Braille Chart indicates that the majority of the system components do not meet the average standards (grade of 4). Four out of the seven components—Organizational, Procedures, Equipment, and Interfaces—are below average (between grades 4 and 7), whereas the other three components— Structure, Operating Teams, and Environmental—were barely above average (between grades 1 and 4). The operating teams (controllers) are not ranked poorly because the responsibility cannot be placed on them for using URET less often than was intended, as well as for not using URET for its intended purpose. The causes of the current style of URET implementation are rooted in the organizational factors, upstream from the operators themselves (i.e. lack of funding and attention for training and procedures). The worst ranked components were the Interfaces between Procedural + Operating, Procedural + Organizational, and Hardware + Procedural. These grades support the argument for the integration of automation into the existing system, where currently the separate system components (e.g. procedures, operating, organizational, hardware) are developed almost separately and independently.

For the purpose of developing the Factors Grading Braille chart, in calculating the means for each system component, it is assumed that each of the factors in the components had distributed weights. For example, in the Operating Teams component, the Training factor most likely contributed the most to the overall component grade. However, the purpose of this study was not to go into such detail, but rather, to bring to the surface the factors of concern that the proactive measures should address.

In the next step, the study addressed proactive measures to implement in terms of 1) design organizations (high reliability organizations), 2) design teams, 3) quality assurance, 4) design procedures, and 5) ergonomics. These proactive measures are developed from lessons learned from the reactive approach, and are intended to identify potential improvements, critical flaws, and ways to improve the quality of the systems and procedures. However, it is important to acknowledge that proactive measures cannot predict everything, especially in such complex and dynamic systems such as ATC, where it is critical that safety never be compromised. Thus, it is crucial that, in this stage of intense research, development, and transition, a strong, robust interactive approach be developed to ensure the smooth and successful implementation of automation tools (e.g. URET)

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into the system. For the current state, several interactive measures are proposed to constantly monitor the impact of URET on the controllers and the system. Also, it was pointed out that it is important for the organizations to know what they are measuring. For example, [7] has also mentioned that even if one is correctly measuring something, this may not mean anything since he or she may be measuring the wrong thing.

X. Validation

It is important to determine the validity and reliability of the study's analytical methods and processes:

A. *Validity*

This paper has both external and internal validity. External validity is the extent to which the method (approach) is generalizable—the degree the results of its application to a sample population can be attributed to the larger population— or transferable—the degree the method's results in one application can be applied to another similar application. Internal validity "is the basic minimum without which the method is uninterpretable," addressing the rigor with which the method was conducted—in terms of the design, the care taken to conduct measurements, and decisions concerning what was/wasn't measured [17]. The design of the method and care with which it was conducted was very carefully performed. We graded nearly every component and factor in the ATC-URET system, and provided justification and explanation for each grade.

The method of interviewing and developing three risk assessment and management approaches is very appropriate for its intended purpose. Reference 3 has developed extensive studies in the proactive and reactive approach. Reference 7 has extended these studies further, spending much time in developing the theories and applications of the missing element—the interactive approach. By applying this study on the implementation of URET in ARTCC sectors, this work also validates the work performed in [7] in how necessary and crucial it is to ensure that URET is monitored and interactively studied to improve its integration into the current system.

The generalizability of this method is both intended to assess the current state, as well as being applicable to the future state of URET, since it is constantly being studied and improved, in addition to other innovations. Also, the method and three approaches developed in this study have been validated by [7], where proactive, reactive, and interactive approaches were efficiently applied to the specific field of geotechnical engineering. The authors recommend that this way of approaching problems can be applied to any industry, so long as there are human and organizational factors involved (e.g. hospitals, nuclear plants, NASA)—finding an industry upon which to apply these concepts should not prove too difficult.

XI. Conclusions and Future Work

This study has developed reactive and proactive approaches to the integration of URET in en route air traffic control centers. Following these approaches, we then developed an interactive approach for ARTCCs.

There is a great deal more research needed to proactively develop, in particular, improved training and procedures as well as effective interactive measures. In order to develop a strong proactive approach, both the reactive and interactive approaches need to continuously feed information and lessons into one another—they are each complementary and necessary. By interactively studying the impacts of URET (and other future automation tools to be adopted and implemented) on the performance of air traffic controllers, as well as its very adoption and adaptation, usage, and integration, the gap between our current system and the next generation ATC will finally begin to diminish.

When automation introduction is in question, decision making should be made by a group of experts that is comprised from controllers, tool designers, human factors experts— all in an interdisciplinary group. By having these interdisciplinary groups apply these three approaches to studying automation introduction and implementation, they get closer to the ultimate goal of achieving quality (i.e. safety and serviceability).

We believe that the proposed approach to studying URET automation tool can be applied to other emerging automation, communication or surveillance tools in the near future. The lessons learnt from URET can be incorporated in applying sound proactive measures in other new implementations (e.g. other tools such as data link or ADS-B), so that the organizations will not have to start with learning from a reactive standpoint, and can move directly to a proactive and interactive system. We believe that the work completed in this paper is an excellent starting place for bringing proactive, reactive, and interactive quality management tools to this dynamic, complex field of introducing automation into the already stressed national airspace system.

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