A METHODOLOGICAL APPROACH TO SAFETY ANALYSIS OF AUTOMATED TASKS OF TWR ATCO

Yuri Maximilain Rottner Dirickson
Lúcio F. Vismari
João Batista Camargo Jr.
Escola Politécnica – Universidade de São Paulo
Av. Prof. Luciano Gualberto, 380, lane 3 - Butantã, São Paulo - SP, 05508-010 - +55 11 3091-5734

ABSTRACT

Due the increasing operations of civil aviation, the demand for the Air Traffic Management (ATM) system begun to exceed its capacity, resulting in losses for the world economy. ICAO States members started implementing their ASBU-Aviation System Block Upgrades programs in order to cope with the planning of the global ATM program, e.g. SESAR for European Community, NextGen for USA and SIRIUS for Brazil. One of the main points of the ASBU is the implementation of automated tasks for human operators, such as pilots and Air Traffic Controllers (ATCo). This paper proposes a methodology - being used in a wider research – for safety analysis of automated tasks of Air Traffic Controllers at Aerodrome Control Towers.

Keywords: Automation, Safety, Human factors, Systems Engineering.

1. INTRODUCTION

Due the continuous growth of the usage of civil aviation for transporting people and cargo, this demand begun to exceed the capacity of the air traffic services (ATS) to accommodate safely the actual air traffic, leading to negative consequences not only to the aviation itself, but also for the world economy (ICAO, 2013).

To address the problem 'capacity versus demand', the International Civil Aviation Organization (ICAO) created the concept called Communications, Navigation and Surveillance/Air Traffic Management (CNS/ATM) for all air traffic systems. The idea is to implement new technologies and techniques, with higher degrees of automation, which will help improving the capacity and safety of the air traffic systems (BROOKER, 2008; FAA, 2012).

As stated at ICAO (2005), several States members of ICAO started to plan for implementing CNS/ATM technologies, what helped in the recognition of the necessity of a new approach for the air traffic management (ATM) system, evolving the concept of CNS/ATM to a global and integrated ATM system. In order to achieve this global system ICAO created a strategy called Aviation System Block Upgrade (ASBU), which consists of a group of four blocks of improvements that the States must undergo in a certain period to achieve the objectives set forth in the global plan for CNS/ATM. The ASBU only shows a general timeline of improvements needed to achieve a modern ATM, but each State can decide what it will use based on its characteristics. Some of the initiatives aligned with ASBU and recognized by ICAO are the NextGen for United States (FAA, 2012), SESAR for Europe (EUROCONTROL, 2012) and SIRIUS for Brazil (DECEA, 2011).

As stated previously, one of the key improvements of the ASBU is the use of higher automated tools to increase the capacity of the ATM, which will change the way the human operators, specifically the Air Traffic Controller (ATCo), will communicate and interact with tools and other operators inside this complex ATM system (CHIAPPE; VU; STRYBEL, 2012). This increases the need for researchers to analyze how much of the way the ATCo works will change. There's a lot of studies on how much a specific technology will affect some of the human factors metrics, like situation awareness (SA) (CHIAPPE; VU; STRYBEL, 2012), workload (NEAL *et al.*, 2014) and response time (KOPALD; SMITH; STEVENS, 2012). One of the possible changes of the role of the ATCo is the change from the current active control to a more passive monitoring of the automated tools. It was noted that, even with no significant difference in the number of missed potential conflicts between a passive monitoring and the active control, the time needed to detect potential conflict in the passive monitoring condition in high traffic were significantly higher than with the active control condition. This shows some problems that an automated task might generates if it is not well designed (METZGER; PARASURAMAN, 2001).

A natural conclusion is that a higher degree of automation would reduce significantly the workload of a human operator to perform a specific task. Most of the experiments show the confirmation of this hypothesis. However, in some scenarios where there is a task significantly automated and this automation fails often, the workload observed is many times higher than when the manual operation fails often (GIL *et al.*, 2012). There is even a problem outside of the operation, such as in case when the automation tools can affect the training of new operators. VU *et al.* (2012) observed that ATCo trained to use only the new automated system had much more difficulty on doing their task than the ones trained in the manual system.

As appointed by VU (2012) and WICKENS *et al.* (1998), it is important that a human-centered approach on developing, testing and implementing new technologies and procedures must be considered in the next steps of the modernization of the global ATM, in order to guarantee the harmonization

between the human operator and the automation itself. Another important point is having a full system view in order to determine real system safety. Many of the actual systems, specifically ATM system, are complex and, because of this complexity, there are relations between the components of the system that cannot be predicted at design level (JOHANSEN; RAUSAND, 2014; NUSSUNZVEIG, 2003).

Systems engineering researchers have been working together with sociologists and psychologists in order to understand the interaction between the system and the organization behind it. In order to identify all organizational and social features that will directly impact on system reliability and safety, developing new models and frameworks that helps them to analyze the length of the responsibility of the organization for system safety is required (DEKKER, 2004; HOLLNAGEL; WOODS, 2005).

When automating human tasks, one inherent question is how much should be automated. There are some studies showing that automation does not simply substitute the human tasks, but change them, often in ways unanticipated by designers, and poses new challenges of coordination among the ATCos (PARASURAMAN; SHERIDAN; WICKENS, 2000).

Considering all the points stated above, there is a need for a risk analysis of the ASBU upgrades on a system level, studying how these new technologies and techniques will cope with the other components, specifically the human operators, and how can the organization prepare itself for these changes.

This paper is part of a wider research, based on a systemic view of the ATM, on risk analysis of the safety of the implementation of ATCo automated tasks at the TWR. This work proposes a methodology for doing a systemic safety analysis. Section 2 discusses the case study chosen for this research: the ATCo from TWR. Section 3 describes the proposed safety analysis framework, describing each component and its flow. Section 4 discusses the status of the research, the future work and some conclusions.

2. AERODROME CONTROL TOWER (TWR)

The aerodrome control tower (TWR) is the ATC organization responsible for controlling and maintaining ordered and safely air traffic in the surroundings of the aerodrome. Its control authority is over the following flight phases: taxi, takeoff, initial climb, initial approach, final approach and landing (DECEA, 2013a). In order to cope with the demand of the aerodrome, the ATCo activities in TWR are divided in three subgroups (ATCo positions): clearance delivery (CLR), ground control (GND) and tower (TWR) (DECEA, 2013b). Each of these subgroups (positions) is responsible for a subset of tasks inside the TWR: CLR is responsible to manage the time slots accordingly; GND to coordinate all aircraft, vehicles and personnel on the taxiways; and the TWR to communicate with the surrounding aircraft on the runway and airborne. If the traffic is not demanding too much attention, then one position can assume the tasks of the other (first CLR to GND, then GND to TWR).

Figure 1 shows a statistical report of accidents by phases of flight occurred from 2003 to 2013. For the phases of flight under the responsibility of the TWR, there was a 79% of the total of fatal accidents (an accident that results in deaths) and 68% of the onboard fatalities (BOEING, 2013). These numbers reveal that most of the accidents occur at the jurisdiction of the TWR. However, the mean time elapsed on those same phases of flight is only of 18% of the flight time, i.e., even with relatively small time of the flight spent with the TWR, this is where most of the accidents happen, showing the importance of researching this area.

As for the causes of accidents, Table 1 summarizes the most common causes associated as root causes (PLANECRASHINFO.COM, [S.d.]). Pilot error related to weather represents accidents in which pilot error was the cause but brought about by weather related phenomena. Pilot error related to mechanical failure represents

Table 1: Fatal Accidents Causes

Cause	*1950s*	*1960s*	*1970s*	*1980s*	*1990s*	*2000s*	*All*
Total Pilot Error	57	56	43	46	51	54	51
Pilot Error	42	36	25	26	28	29	31
Pilot Error (weather related)	10	17	14	18	19	17	15
Pilot Error (mechanical related)	6	4	5	2	5	4	5
Other Human Error	2	9	9	6	9	7	7
Weather	15	9	14	14	10	8	12
Mechanical Failure	21	19	19	20	18	26	20
Sabotage	4	4	13	13	10	9	9
Other Cause	0	2	1	1	1	0	1

accidents in which pilot error was the cause but brought about by some type of mechanical failure. Other human error includes air traffic controller errors, improper loading of aircraft, fuel contamination and improper maintenance procedures. The most common root cause is associated with a pilot error, a small quantity driven by weather and mechanical failure, but the first line in the table shows that pilot error were the most common cause of the accident. Nevertheless, to have only one root cause in an accident is a non-systemic way of thinking, because this approach ignores all other factors, including organizational decisions, that may induce the pilot to make an error. As an example retrieved from LEVESON *et al.* (2009), pilots can decide to execute a go-around maneuver in case there is evident danger in landing the aircraft. This maneuver is somewhat default, yet according to LEVESON *et al.* (2009), there have been recent near misses where the maneuver caused the aircraft come too close to another one taking off on a nearby runaway. In this case, both pilot and ATCo do not have enough situational awareness (in a system-level context) to take a properly (optimal) decision – and considering the available time – to avoid this hazardous state. So, what could be a system design problem (lack of situational awareness that leads to an accident) is simplified to a pilot that decided to do a go-around in the wrong moment.

In terms of capacity, the pilot has the responsability of maintaining communication with the ATCo from the area its aircraft is passing and to handle the aircraft and its instruments. But, each ATCo must control several aircrafts inside the same area, maintain the communication with each one, search for probable conflicts and resolve them. All this multitask is one of the main reasons of the current limited capacity of the ATM (CHIAPPE; VU; STRYBEL, 2012).

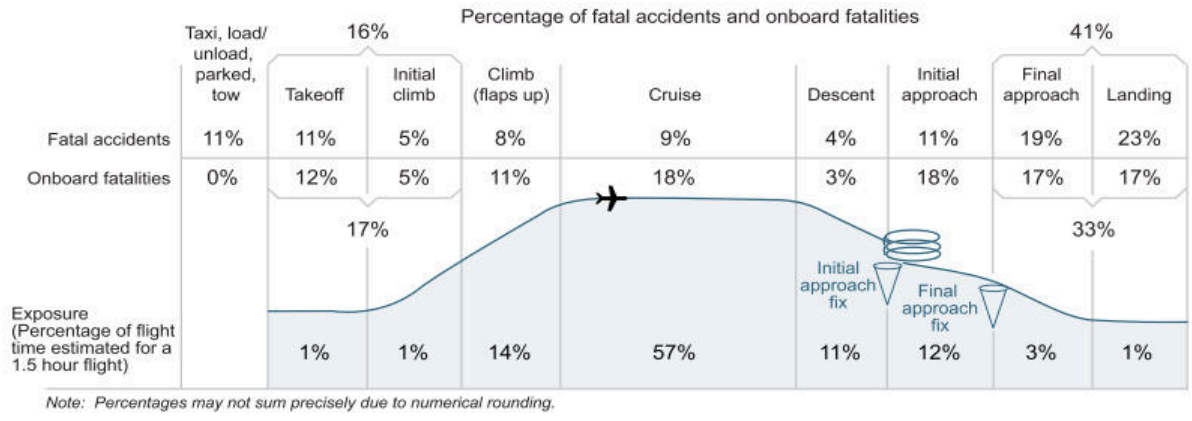


Figure 1: Boeing Statistical Summary.

3. PROPOSED METHODOLOGY

In this paper, we propose a methodology for safety analysis of automated tasks of the TWR ATCo's in a systemic view. This approach is comprised of five steps. A brief description of each step follows through the section.

Step I is the research of DECEA (*Departamento de Controle do Espaço Aéreo*) documents to understand all tasks demanded from the TWR ATCo's and the boundaries of their responsibilities. Using a System Engineering (SE) formal method called Enhanced Functional Flow Block Diagram (EFFBD) (NASA, 2007; SEIDNER; ROUX, 2008), models representing the TWR ATCo were made (DIRICKSON; VISMARI; CAMARGO, 2013). Through these models, it is possible to find each TWR subgroup (CLR, GND and TWR) boundaries and tasks.

Step II is to create a model that represents the tasks already automated, using a more generic formal SE method called SysML (FRIEDENTHAL, 2007; WEILKIENS, 2004). International Council on Systems Engineering (INCOSE) created SysML as a general purpose modeling language for SE applications. Extended from Unified Modelling Language (UML), it can represent the system structure, behaviors, requirements and all other SE needs. SysML standard is maintained by Object Management Group (OMG) ("OMG Systems Modeling Language", [S.d.]).

Through the models developed, Step III aims at delimiting the interfaces between the ATCo and the automation, defining how to transfer the information through the new system model.

In Step IV, the models are used in a two-part simulation. The first part is done in a controlled real time environment, the same used to train new ATCo. The second part will occur in a fast-time simulation to collect data, using the metrics obtained from the first part.

Then, analysis occurs in Step V using a method with a systemic view, like STAMP (LEVESON, 2004) or FRAM (HOLLNAGEL, 2012).

4. PRELIMINARY RESULTS AND FURTHER REMARKS

The aim of this paper was to propose a safety analysis methodology for automated tasks of TWR ATCo, using a systemic view and formal methods from systems engineering.

The models for the ATCo tasks, using DECEA documents (DECEA, 2013b), were made using the EFFBD to represent the desired system behavior, based on some successful works (PFISTER *et al.*, 2012; SIMONS, 2012). SysML presents a more reasonable choice to model a generic automation (software or hardware), since it is based on UML, and the EFFBD can be mapped and incorporates as a behavior model inside a SysML model (CONRAD BOCK, 2005). Figure 2 and Figure 3 are examples of the EFFBD representing, respectively, landing and GND tasks (DIRICKSON; VISMARI; CAMARGO, 2013).

The choice for the two options of simulation is because none of them is complete. If the desired option is to understand how the real ATCo will interact with the new component or system, real time simulations is necessary. However, this kind of simulation demands a relatively high amount of time, and this is a huge cost for a research. If the need is to test a specific scenario, with determined inputs or outputs, then the fast-time simulation is a proper choice (ALMEIDA, 2013).

One of the main objectives of this paper is to point out a system view of the analysis, considering the impact on a system level of the automation itself, so STAMP or FRAM are the choices, since both have the capability to give a systemic analysis.

As stated before, this is part of an ongoing research. The next steps of this research are the modelling of the automation itself, using SysML, together with the boundaries of the automation with the human operator.

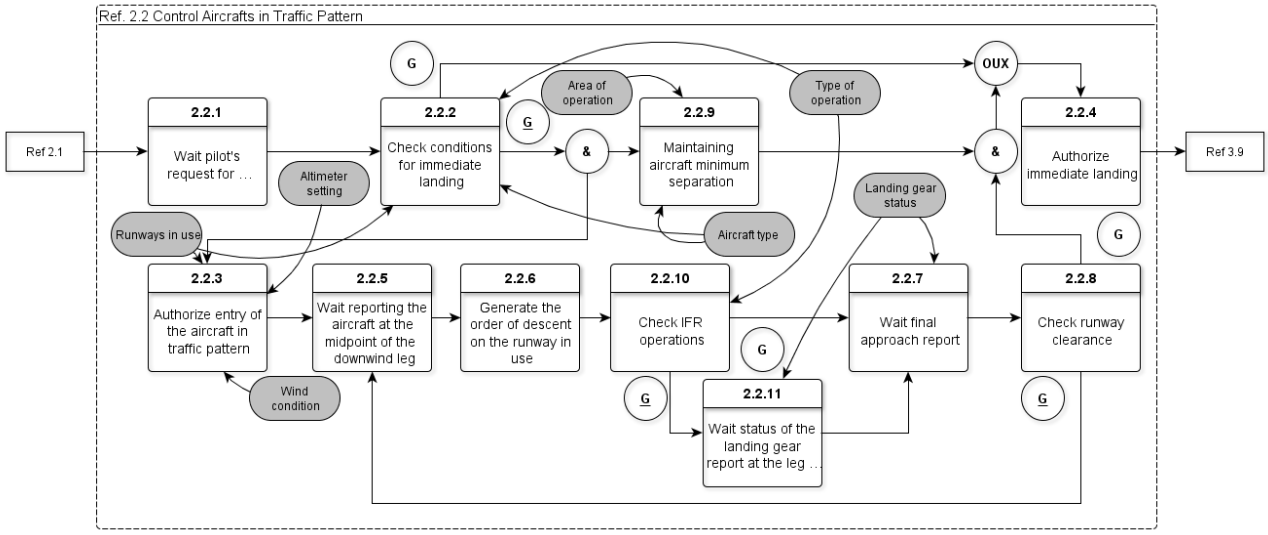


Figure 3: Control Aircraft in Traffic Pattern

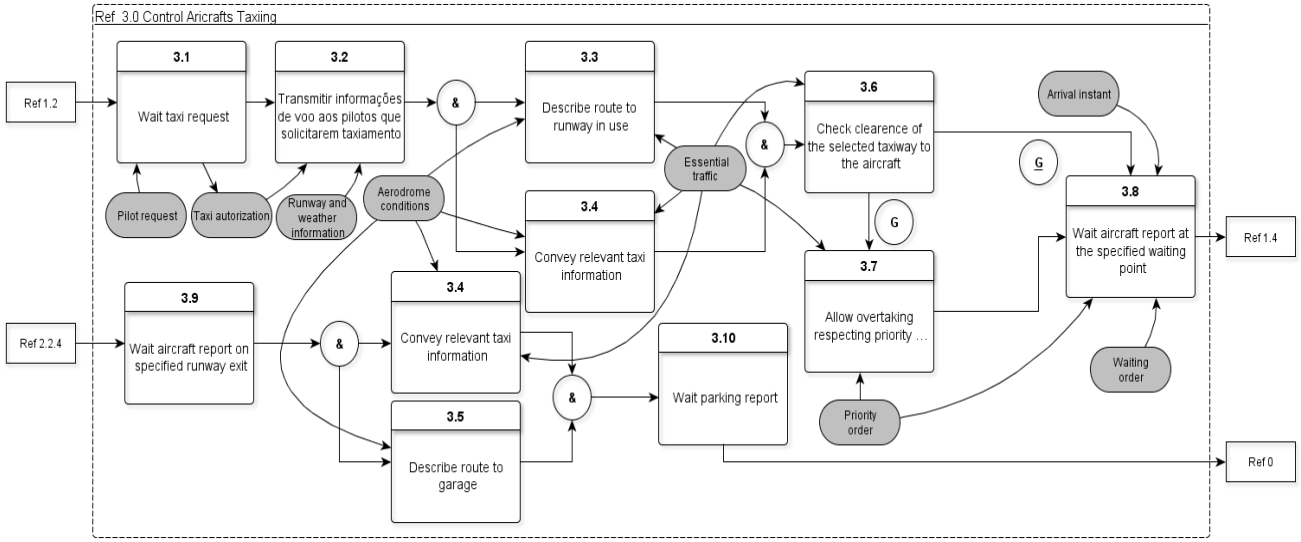


Figure 2: Control Aircrafts Taxing

REFERENCES

ALMEIDA, Luis Eduardo Gomes De. Simulação em Tempo Acelerado . DECEA: [s.n.]. , out. 2013

BOEING. Statistical Summary of Commercial Jet Airplane Accidents Worldwide Operations. [S.l.]: Boeing, 2013.

BROOKER, Peter. SESAR and NextGen: Investing In New Paradigms. The Journal of Navigation v. 61, n. 02, p. 195–208 , 2008.

CHIAPPE, Dan; VU, Kim-Phuong L.; STRYBEL, Tom. Situation Awareness in the NextGen Air Traffic Management System. International Journal of Human-Computer Interaction v. 28, n. 2, p. 140–151 ,2012.

CONRAD BOCK. SysML and UML 2 Support for Activity Modeling. Wiley InterScience p. 160–186 , nov. 2005.

DECEA. Concepção Operacional ATM Nacional. Controle do Espaço Aéreo, nº DCA 351-2. [S.l.]: Departamento de Controle do Espaço Aéreo, 2011.

DECEA. Regras do Ar. , ICA., nº 100-12. [S.l.]: Departamento de Controle do Espaço Aéreo, 2013a.

DECEA. Serviços de Tráfego Aéreo. , ICA., nº 100-37. [S.l.]: Departamento de Controle do Espaço Aéreo, 2013b.

DEKKER, Sidney. Ten Questions About Human Error: A New View of Human Factors and System Safety. Mahwah, N.J.: CRC Press, 2004. 240 p.

DIRICKSON, Y.M.R.; VISMARI, L.F.; CAMARGO, J.B. Elicitation of Operational Requirements in ATC Activities Automation Process: The TWR Case. In: 2013 III BRAZILIAN SYMPOSIUM ON COMPUTING SYSTEMS ENGINEERING (SBESC), dez. 2013, [S.l: s.n.], dez. 2013. p.149–154.

EUROCONTROL. European ATM Master Plan. [S.l.]: EUROCONTROL, out. 2012.

FAA. NextGen Implementation Plan. [S.l.]: Federal Aviation Administration, mar. 2012.

FRIEDENTHAL, Sanford. A Practical Guide to SysML, Second Edition: The Systems Modeling Language. 2 edition ed. Waltham, MA: Morgan Kaufmann, 2007. 640 p.

GIL, Guk-Ho et al. Effects of modes of cockpit automation on pilot performance and workload in a next generation flight concept of operation. Human Factors and Ergonomics in

Manufacturing & Service Industries v. 22, n. 5, p. 395–406 , 2012. Acesso em: 30 jul. 2013.
HOLLNAGEL, Erik. FRAM: the functional resonance analysis method : modelling complex socio-technical systems. Surrey: Ashgate, 2012.
HOLLNAGEL, Erik; WOODS, David D. Joint Cognitive Systems: Foundations of Cognitive Systems Engineering. [S.l.]: CRC Press, 2005. 237 p.
ICAO. 2013-2028 Global Air Navigation Plan. , DOC., nº 9750. [S.l.]: International Civil Aviation Organization, 2013.
ICAO. Global Air Traffic Management Operational Concept. , DOC., nº 9854. [S.l.]: International Civil Aviation Organization, 2005.
JOHANSEN, Inger Lise; RAUSAND, Marvin. Defining complexity for risk assessment of sociotechnical systems: a conceptual framework. Proceedings of the Institution of Mechanical Engineers, Part O: Journal of Risk and Reliability p. 1748006X13517378 , 3 jan. 2014.
KOPALD, Hunter D.; SMITH, Elida C.; STEVENS, Ronald K. Controller Response Times to Surface Safety Alerts. In: HUMAN FACTORS AND ERGONOMICS SOCIETY ANNUAL MEETING, 1, 1 set. 2012, Boston, USA. Anais... Boston, USA: [s.n.], 1 set. 2012. p.2040–2044.
LEVESON, Nancy. A new accident model for engineering safer systems. Safety Science v. 42, n. 4, p. 237–270 , abr. 2004. Acesso em: 29 ago. 2014.
LEVESON, Nancy et al. Moving Beyond Normal Accidents and High Reliability Organizations: A Systems Approach to Safety in Complex Systems. Organization Studies v. 30, n. 2-3, p. 227–249 , 1 fev. 2009.
METZGER, Ulla; PARASURAMAN, Raja. The Role of the Air Traffic Controller in Future Air Traffic Management: An Empirical Study of Active Control versus Passive Monitoring. Human Factors: The Journal of the Human Factors and Ergonomics Society PMID: 12002002, v. 43, n. 4, p. 519–528 , 1 dez. 2001.
NASA. System Engineering Handbook. SP-2007-6105 Rev1 ed. Washington, DC: National Aeronautics and Space Administration, 2007.
NEAL, Andrew et al. Development and Validation of a Multilevel Model for Predicting Workload Under Routine and Nonroutine Conditions in an Air Traffic Management Center. Human Factors: The Journal of the Human Factors and Ergonomics Society v. 56, n. 2, p. 287–305 , 1 mar. 2014.
NUSSUNZVEIG, H M. Complexidade e Caos. 2. ed. [S.l.]: UFRJ, 2003.
OMG Systems Modeling Language. OMG SysML. Available In: <http://www.omgsysml.org/>. PARASURAMAN, R.; SHERIDAN, T.B.; WICKENS, Christopher D. A model for types and levels of human interaction with automation. IEEE Transactions on Systems, Man and Cybernetics, Part A: Systems and Humans v. 30, n. 3, p. 286–297 , maio 2000.
PFISTER, F. et al. A proposed meta-model for formalizing systems engineering knowledge, based on functional architectural patterns. Systems Engineering v. 15, n. 3, p. 321–332 , 2012. Acesso em: 1 ago. 2013.
PLANECRASHINFO.COM. Accidents Statistics. Available In: <http://planecrashinfo.com/cause.htm>.
SEIDNER, C.; ROUX, O.H. Formal Methods for Systems Engineering Behavior Models. IEEE Transactions on Industrial Informatics v. 4, n. 4, p. 280–291 , 2008.
SIMONS, M. A functional analysis of integrated arrival, departure, and surface operations in NextGen. In: DIGITAL AVIONICS SYSTEMS CONFERENCE (DASC), 2012 IEEE/AIAA 31ST, 2012, [S.l: s.n.], 2012. p.3B2–1–3B2–12.
VU, Kim-Phuong L. et al. How Does Reliance on Automated Tools During Learning Influence Students' Air Traffic Management Skills When the Tools Fail? In: HUMAN FACTORS AND ERGONOMICS SOCIETY ANNUAL MEETING, 1 set. 2012, Boston, Massachusets USA. Anais... Boston, Massachusets USA: [s.n.], 1 set. 2012. p.16–20.
VU, Kim-Phuong L. Human Factors and Human–Computer Interaction Considerations in NextGen. International Journal of Human-Computer Interaction v. 28, n. 2, p. 75–76 , 5 jan. 2012.
WEILKIENS, Tim. Systems Engineering with SysML/UML: Modeling, Analysis, Design. 1 edition ed. Amsterdam ; Boston: Morgan Kaufmann, 2004. 320 p.
WICKENS, Christopher D. et al. The Future of Air Traffic Control: Human Operators and Automation. Washington, D.C: National Academies Press, 1998. 336 p.