THE IMPACT OF RIGOROUS METHODS ON AERONAUTICAL REGULATIONS

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Abstract

The purpose of this paper is to present an innovative methodology (consisting of methods, tools and procedures) that seeks to improve the rulemaking processes currently used to develop aeronautical safety and security regulations.

The two main contributions of this approach are: (1) its use of rigorous methods and tools to help improve the regulation's validation process, and (2) its capacity to help identify the impact of proposed amendments on enacting regulation (while helping mitigate regressions).

1 General Introduction

The chief objective of Civil Aviation Authorities (CAA) worldwide is to continuously guarantee the safety and security[1] of civil aviation. To ascertain this, they have implemented a set of complementing and hierarchical regulations at the international, national and local level.

These regulations impose standards and recommended practices specifically targeting the prevention (and mitigation) of either **accidental events** or **unlawful acts of interference** within a given domain. This ‘regulation enforcement’ approach to safety and security imposes that the regulation's innate quality and its homogenized and ubiquitous implementation become effectual factors to the achievement of their objective.

In what concerns a regulation's innate quality, [1] identified that **aviation regulations** have three esteemed traits steering their effectiveness, which are: *consistency*, *robustness* and *unambiguousness*. Presently, rulemaking procedures include a consultation and validation phase. In it, proposed drafts are analyzed and discussed until they are considered mature for adoption and publication. For this, special attention is placed in: (1) verifying their compatibility with existing rules, (2) attesting the exhaustiveness of their scope and (3) limiting their equivocalness (given the inherent ambiguity of natural languages). Nonetheless, operational feedbacks have proven that this current validation process is not adept at assessing these three qualities. This is of great significance since -analogously with safety-critical software- it is these qualities which ensure that the benchmark regulation being enforced by the CAAs is intrinsically effective.

To this effect this paper presents an innovative methodology that seeks to improve the innate quality of aeronautical safety and security regulations.

Furthermore, over the past few decades, technological and ideological changes have prompted amendments within the industry's established *Regulatory Framework*. The purpose of such amendments has been the continual assurance of safe, secure and efficient commercial operations under an enhanced state-of-affairs (through the exclusion, inclusion and/or evolution of affected regulations and/or procedures). The predicament is that, independently of their origin and dimension, regulatory and procedural amendments inevitably lead to the (unwilling) introduction of

[1] Safety relates to the prevention and mitigation of accidental events, which are detrimental to civil aviation whereas security is the prevention and mitigation of intentional acts, detrimental to planes or people.

new errors [2] and the obsolescing of sanctioned workarounds.

In other words, amendments lead the framework from an 'error-cognizant' state, where (an indicative part of) its inherent errors have been identified (and possibly solved or circumvented), to an 'error-incognizant' state.

Consequently, given that the capability to properly sustain the integrity of the regulatory framework depends heavily in the timely anticipation and prevention of regulatory incompatibilities, *the innovative methodology that is presented in this paper also seeks to provide civil aviation authorities with some methods and tools to help them identify the incompatibilities and regressions that could arise from regulatory amendments*

The outline of this paper is the following. In section 2 we provide a brief overview of the methodology that has been adopted, and extended, to comprise the two previously aforementioned improvements *(concerning the regulations' innate quality and the analysis of regressions).* Section 3 provides context to the new tools that were integrated into the extended methodology. Section 4 elaborates on the modeling and specification aspects of the methodology -in particular the graphical conceptual models- through some illustrative examples of security constraints. Section 5 discusses initial implementations that were undertaken in the domain of safety regulations while section 6 sets a wider implementation and appraisal perspective in the domain of safety regulations. Finally, section 7 presents the main findings and conclusions.

2 The Extended EDEMOI Methodology

In 2003, a group of French universities and research laboratories proposed the implementation of rigorous methods to assist in the analysis and validation of ground-based airport security regulations [3]. They named their project EDEMOI.

At present, the EDEMOI methodology has been applied to the evaluation of key regulations influencing ground-based airport security in Europe. For this, both the *International Civil Aviation Organization's (ICAO) Annex 17 to the Convention on International Civil Aviation* and *Regulation (EC) 2320/2002 of the European Parliament* [4] were modeled and analyzed

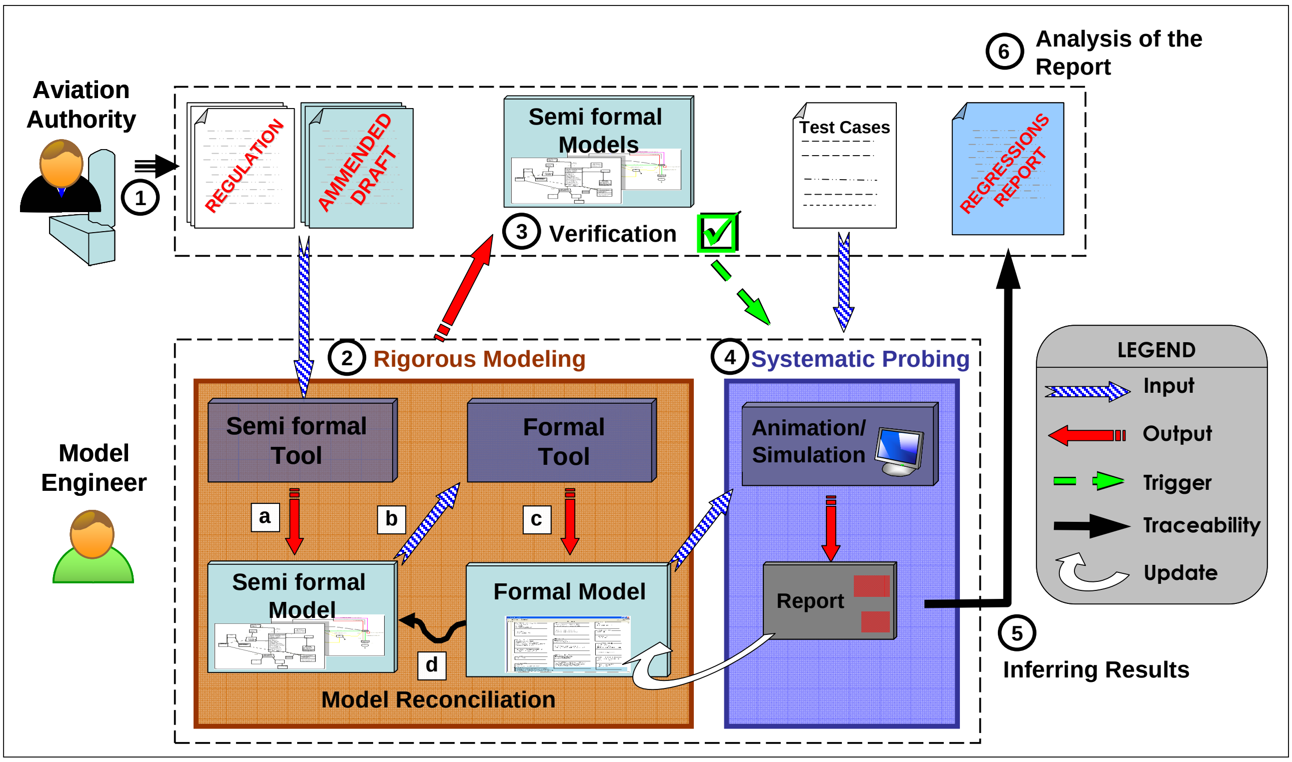


Fig. 1. The Extended Methodology

([1],[5]).

Thanks to this, the methodology's appropriateness (*i.e.* its aptitude to specify and assist in the design and validation) for security requirements has been established.

Still, as civil aviation authorities are concerned with ensuring both the safety and the security of civil aviation, and given that new regulations are evolutions of existing ones (prompting the study of their non-regression), an extension of this methodology was envisioned.

Currently the EDEMOI process has been extended to *(1) broaden its scope to include aviation safety regulations and (2) extend its usability to detect regression originating from regulatory amendments.*

Neither one of these two aspects was a simple, straightforward effort. Their realization entailed changes in the techniques proposed within the EDEMOI approach, to focus on the specificities of safety regulations and to assist in the identification of regulatory regressions. The study of non-regressions was a challenge on its own, based on the use of animation and proof techniques on the regulation's model, in order to compare successive versions of a regulation and detect regressions.

The extended methodology (see Figure 1) is centered on a two-step approach, involving two stakeholders: the civil aviation authorities, which enact regulations within the domain of civil aviation, and the model engineers, who translate these natural language documents into formal models that can be tested.

As was done in the appraisal of ground-based security regulations, the process begins with capturing an apposite interpretation of a regulation using (part of) the **Unified Modeling Language**[2] **(UML)** *(Figure 1, Step 2.a)*. The use of this graphical (semiformal) notation helps circumvent the inherent ambiguity of natural languages by acting as a language-independent, conceptual layout of the regulation.

Afterwards, a validation step *(Figure 1, Step 3)* allows the aviation authority officials to verify, and helps establish, the adhesion of this conceptual layout to their 'official' interpretation of the regulation.

Once validated, the semiformal model is translated *(Figure 1, Step 2.b)* to a formal model (*i.e.* a model developed using rigorous methods) using translation rules between the notations (in this case, from UML to the formal Z[3] notation). This ensures that the methodology will fully benefit from the integration of both approaches: the intuitive structured notation of the semiformal approach and the precise semantics of the formal approach.

Finally, when both of these models have been deemed mature enough (in regards to their notation and their faithfulness to the regulation) an animation or verification tool *(Figure 1, Step 4)* is used to test the formal model's consistency (through simulation [6]) and robustness (through counterexample checking). The results of these tests and simulations can then be inferred back to the regulatory text thanks to traceability relations that link the formal model's specification back to the regulatory requirements. By comparing successive versions of these requirements one is able to analyze if there were any regressions *(Figure 1, Step 5)* owing to regulatory amendments.

3 A New Tool for the Extended Methodology

Given that safety regulations cover a very wide domain, there are various domain-specific regulations whose scope is focused in governing a single aspect of the safety domain. This has given rise to the situation where we have an entity to which various regulations are applicable, each of them relating to a particular aspect. *For such cases, a graphical modeling tool could prove useful in helping manage the inter-regulatory requirements imposed, and facilitating the observance of the global regulatory consistency.*

Also, the introduction of new paradigms in civil aviation entails the need to adapt the regulatory framework. For this reason, the stakeholders to these undertakings -such as the aircraft manufacturers, service providers and

[2] UML: http://www.uml.org

[3] Z notation: J. Michael Spivey. The Z Notation: a reference manual, 2nd edition, Prentice Hall International Series in Computer Science. (1992)

safety regulators- are concerned with determining the regulatory enhancements that will be required to ensure safe, secure and efficient operations under new states-of-affairs.

In terms of regulative evolution, it is primarily safety regulations that need to be more adaptive to the industry's constantly evolving state-of-affairs, helping steer developments instead of contriving their progress. This refers to the fact that, in aeronautics, advancements are the result of a fragile compromise between what is technologically achievable, what is economically profitable and what is cautiously acceptable. For this reason, civil aviation authorities must allow their safety requirements to be duly adaptable so as to promote safety without hindering developments.

This comes back to the previously identified need of *tools to help in the analysis of regressions*. However, this also hints *the need for a better means of 'pre-assessing' the impact of adjusting factors*[4] *on the regulations, and vice versa.*

Consequently, given these two new specificities, an enhancement in the graphical tools used by the methodology was warranted. Therefore in [7] we proposed the creation of an interactive (adaptable) graphical tool, centered on the legislation's applicability criteria, which affords a pithy description of the regulatory requirements, and which goes in the direction of satisfying the two abovementioned enhancements. This graphical tool was developed as a complementary tool to the extended methodology. It assists in managing a more global and complete view of the regulations, thereby providing a better means of estimating their inter-regulatory consistency and the influence of adjusting factors.

[4] An adjusting factor is any operational, ideological and/or technological change whose introduction, into the civil aviation system, obliges a change in the contemporary regulations to preserve the appropriate overall functioning of the system.

4 An Illustrative Example of the Regulation's Modeling

As was mentioned in Section 2, the extended methodology propounds a stepwise process that yields formally specified conceptual models of the regulations, which can be used to analyze, and therefore improve, their inherent quality.

The basis of this approach is notably the use of rigorous methods. The reason is that, rigorous methods are a specification technique whose notation (*i.e.* their specification language) is based on the well-formed rules of mathematical logics. Consequently, they can be used to enrich the *conceptual model*s of a system in a manner that is compatible with their analysis.

Our approach implements the use of graphical (semiformal) models to build the conceptual models of the regulations, followed by the use of rigorous methods to enrich their specification.

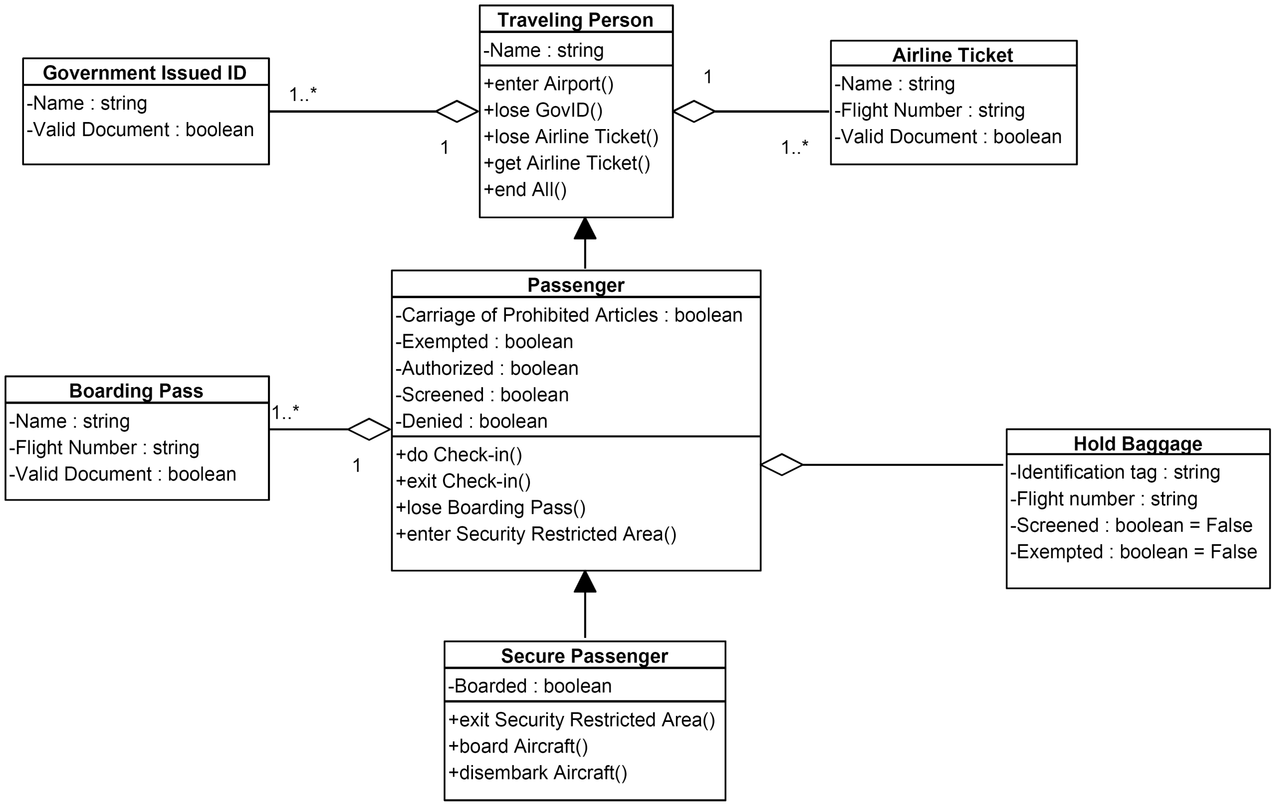
For this task, the UML notation profiled itself as the most appropriate graphical notation, since it enables the creation of abstract, but graphically intuitive models that can be systematically translated to a more rigorous notation.

In order to exemplify this type of graphical model, we shall briefly go over some insightful parts of a 'UML Class diagram' (Figure 2), and a 'UML State-transition diagram' (Figure 3). Both of which were obtained from the study of Regulation (EC) 2320/2002, a European Union regulation that sets common rules in the field of civil aviation security.

4.1 Modeling the Static Aspects

This first diagram (shown in Figure 2) is a 'UML Class diagram'. It depicts the static (or structural) aspects of different entities, as well as the relationships amongst them.

Each of the boxes shown in Figure 2 represents a different *type of entity* (or class). These boxes are divided into three parts because these will contain one the following (from top to bottom): the class' name, its attributes (or properties), and its operations (or allowed behaviors).



With this in mind, one can notice that the diagram shown in Figure 2 is composed by 6 classes (one per box), which are: '*Traveling Person*', '*Passenger*', '*Secure Passenger*', '*Government Issued ID*', '*Airline Ticket*', and '*Boarding Pass*'.

The graphical symbols that link these boxes are in fact a relationship tag, where (a) (◀—) depicts the notion of specialization and (b) (◇—) depicts the notion of composition.

Focusing our analysis to the inter-box relationships, Figure 2 must be univocally interpreted as follows:

- Every '*Traveling Person*' has (◇—) at least one «1…*» '*Government Issued ID*' and one or more «1…*» '*Airline Ticket*'. The diagram also imposes that both of these documents are exclusively his/hers « 1 ».
- Every 'Passenger' is a type of (◀—) 'Traveling Person' and therefore he/she inherits all of inter-box relationships from this box. In other words, the '*Passenger*' will possess at least one '*Government Issued ID*' and at least one '*Airline Ticket*'. But, in addition, every '*Passenger*' has his/her own particular relationships, evidenced here by the possession of at least one '*Boarding Pass*' (exclusively his/hers).
- And finally, that every '*Secure Passenger*' is a type of '*Passenger*'. In which, in addition of having at least one valid '*Airline Ticket*' and '*Government Issued Identification*', has at least one '*Boarding Pass*'.

Now, the intra-box analysis imposes that:

- A '*Traveling Person*' has only one security-related attribute, 'Name', which in fact represents any unique personal identifier, which can be used to reconcile the subject's identity.

More interestingly, its operations (shown in the lowest part of the box) reflect the fact that a '*Traveling Person*', as such, cannot enter

Security Restricted Areas (S.R.A.). This is imposed by limiting the domain of application of their operations, going from the airport's exterior (*'enter Airport'*) to just before the entrance to S.R.A.

- In a similar fashion to the inheritance of the inter-box relationships, the *'Passenger'* will also inherit the attributes and operations that had been previously defined for the *'Traveling Person'* class. And, it will also have its own security-related attributes, such as: *'exempted'* from the security screening process, *'authorized'* to carry prohibited articles, or *'screened'* (to the standard imposed by 2320/2002). These attributes have been declared as Boolean, so their values will be limited to the logical *True* or *False* value.

Again, the operations for the *'Passenger'* class are also restricted in terms of their domain of operation. This is because the entry into any of the airport's S.R.A. requires a successful completion of the security controls carried out at its entry points. This led to the creation of a special category of passengers termed *'Secure Passenger'*, designating those passenger whose attribute values comply with the regulatory requirements to enter the S.R.A.

- The *'Secure Passenger'* class inherits all the properties and operations of both the *'Traveling Person'* and *'Passenger'*.

The *'Secure Passenger'* class is used to group those passengers that have been granted access into a S.R.A. such as: screened passengers (where the attribute Screened is set equal to True), diplomatic passengers (Exempted=True) and in-flight security officers (Authorized=True and Screened=True).

Correspondingly with the security objective (which entails that only secure passengers are allowed to board an aircraft), the list of operations available for *'Secure Passenger'* is extended to include those required inside Security Restricted Areas. Specifically, the attribute *'Boarded'* is added.

It is important to notice that for all three of these aforementioned classes (*'Traveling Person'*, *'Passenger'* and *'Secure Passenger'*), an evolution seems to suggest itself, exposing the dynamic facet of a travelers' transition through the airport.

4.2 Modeling the Dynamic Aspects

Such transitions were depicted using a 'UML State-transition diagram'. In it, each distinct 'State' represents a unique combination of the class' attribute values; with the corresponding transitions leading to them.

For example, the diagram shown in Figure 3 graphically represents how a nominal *'Passenger'* that is in the state *'out of Security Restricted Area'* becomes a *'Secure Passenger'* following the *'enter Security Restricted Area'* transition.

The state will consequently be *'in Security Restricted Area'*. In this state, we guarantee that the attribute *'Screened'* will take on the value of *'True'*. The *'Secure Passenger'* will be able to then change state, either to board the aircraft (state-transition *'board Aircraft'* into the *'Boarded'* state) or to exit the SRA (state-transition *'exit Security Restricted Area'* into the *'out of Security Restricted Area'* state). This sole portion of the 'UML State-transition diagram' abstractedly describes the robust behavior of any nominal passenger whishing to board the aircraft after having cleared the different security controls.

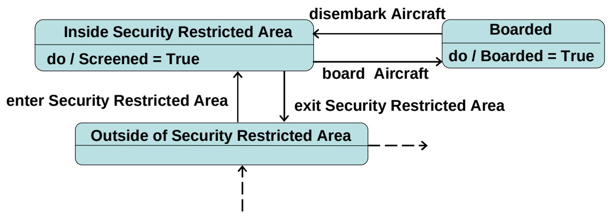


Fig. 3. Abstract from a Secure Passenger's State Transition Diagram

4.3 Integration of the Regulatory Principles

It is important to state that the two aforementioned models are indeed highly correlated. In fact, while the *'Passenger'* and *'Secure Passenger'* entities were defined (along with their attributes and operations) in the model shown in Figure 2, the consequences of their operations are described by the model shown in Figure 3.

The traceability between both of these models is ensured by the entities, their attributes, their operations and their inter-relationships.

And, while these graphical models are not able to specify the regulations (and their requirements) as amply as the rigorous methods, they already provide us with a rigorous enough refinement of certain aspects.

For example, the behavior described in Figure 3, of a *'Secure Passenger'*, is by all means robust. Whereupon the state *'in Security Restricted Area'* has only two exiting transitions. A *'Secure Passenger'* would transition out either by boarding an aircraft (state-transition *'board Aircraft'*) or by exit the airport's SRA (state-transition *'exit Security Restricted Area'*).

This brings into the attention the working assumption that an airport's SRA will have only these two possible exits (*i.e.* onboard the aircraft or through the exits leading to the airport's landside area).

Indeed, as the methodology focuses on the regulation's inherent quality, the pragmatic shortfalls that could occur, due to a faulty implementation of the regulatory requirements, are not taken into account. The requirements imposed by the regulation must be considered as intransgressible[5] constraints, to be capable of analyzing their innate quality.

Under this premise, no other exit transition is possible, from within the airport's SRA.

5 Seeking New Applications

In section 3 we discussed that safety regulations are more susceptible to the adjusting factors due to the industry's push to adopt and integrate technological and/or operational changes.

A prime example of this situation is the NACRE (New Aircraft Concept Research) project[6] since, as part of this European project, unconventional aircraft cabin concepts were proposed, designed and assessed.

The cabin designs were, for example, comfortable passenger compartments –such as those found in a luxury trains and boats– that could be used during the aircraft's take off, landing and sometimes during the cruise phases.

Evidently, the viability of all of these passenger-driven cabin concepts laid primarily on the question of compliance with the current regulations.

Indeed, one of the motivations behind the NACRE project was to test the limits of what is feasible under the current regulatory landscape. For this reason, this passenger-centered cabin concept needed to meet the applicable regulations.

The pertinent European authority whose purview includes certifying cabin concepts is the European Aviation Safety Agency (EASA). And, for the cabin concept to be certified as airworthy, it must comply with the specifications imposed in the European CS 25[7].

Within this context, our methodology was used to 'pre-assess' the conformity of the new cabin concept to the specifications prescribed in the CS25. For this, both the cabin's static and dynamic aspects were modeled and compared with the relevant items of the CS25.

However, an atypical application of our modeling techniques was performed in the context of CS 25.803 (related to emergency exit). A part of this item specifies that:

> *(c) For aeroplanes having a seating capacity of more than 44 passengers, **it must be shown that the maximum seating capacity,** including the number of crew members required by the operating rules for*

[5] This approach is in contrast with one seeking to establish the regulations' responsiveness to violations or their effectiveness under a crippled implementation. Refer to [8] for a discussion on this type of approach.

[6] NACRE Project: http://ec.europa.eu/research/transport/news/article_ 6357_en.html

[7] The Certification Specification (CS) 25 is composed of 2 books: Book1 is comprised the airworthiness codes, and book2 relates to the acceptable means of compliance. In other words, book1 gives the technical interpretation of the airworthiness requirements that must be satisfied whereas Book2 refers to the demonstration of compliance.

which certification is requested, ***can be evacuated from the aeroplane to the ground under simulated emergency conditions*** *within 90 seconds***.** *Compliance with this requirement must be shown by actual demonstration using the test criteria outlined in Appendix J of this CS–25 unless the Agency find that a combination of analysis and testing will provide data equivalent to that which would be obtained by actual demonstration.*

The modeling of this requirement led to the diagram shown in Figure 4, which is a timing diagram. This diagram allows one to follow what a passenger can do (during an emergency evacuation scenario), on request of crew members and as soon as there is an unoccupied space unit for the passenger to advance towards the emergency exit.

In this diagram the passenger was assumed to be both *participative* and *cooperative*. The first is in the sense that the passenger would actively seek to move towards the exit, and the second in the sense that the passenger could and would obey the order given by the crew members.

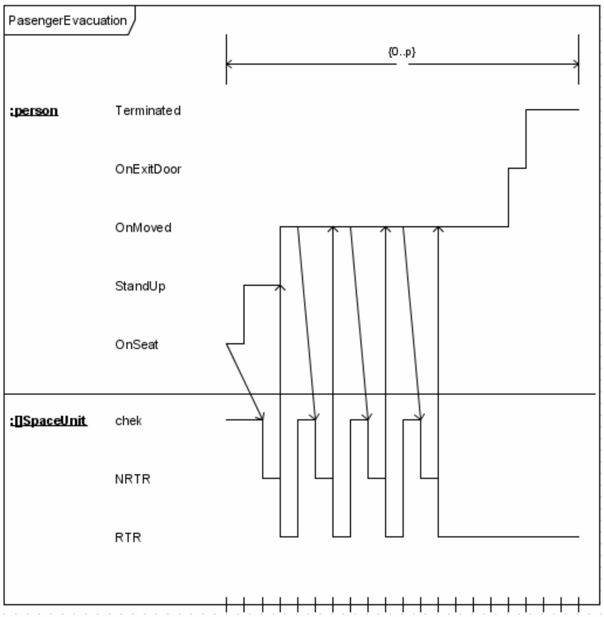


Fig. 4. A Cooperative Passenger's Evacuation Timing Diagram

These first and novel applications of the methodology, within the domain of safety regulations, provide a comfortable assurance of its relevancy in such tasks. Consequently, a much larger implementation of the regulation will be undertaken to continue appraising the methodology, as described in the following section.

6 Appraising the Methodology for Safety Regulations

A more general appraisal of this methodology will be achieved through its implementation to the study of the discerning operational certification requirements for Very Light Jets (VLJs) in Europe and the United States of America.

These small but relatively high-performance airplanes are a potential adjusting factor to a large part of the regulatory infrastructure presently established within civil aviation. This is due, in part, to the considerable contrast between their small size/weight (seating between 5-8 passengers with an MTOW under 4,536 kg) and their relative high performance (Cruise speed: ~ 0.62 M). But more particularly, by the fact that they were designed to fly within the same flight band (and terminal airspace) as that of commercial-aviation airplanes (FL 330-350) with an "in-design" compatibility for both single and double flight-crew operations.

Concerned with this situation, both EUROCONTROL and the European Aviation Safety Agency (EASA) have taken steps to ensure the smooth entry of this new "technology" while seeking to alleviate the ripple effects that it will have on the civil aviation system. For example:

Under current mandates, VLJs are not required to be equipped with an Airborne Collision Avoidance System (ACASII) to operate within the EUR region.

But, given their forecasted growth and their incompatible speed (with respect to large commercial airplanes), EUROCONTROL may seek to impose the mandatory equipping of VLJs with an ACASII system; to continue ensuring a high level of safety and efficiency in the pan-European Air Traffic Management (ATM) system.

EASA, on its part, has opted to limit the airplanes' operational envelope by restricting it to double-crew operations. This decision was based, in part, on the increased likelihood of: level busts, airspace incursions, runway incursions and fatigue in single pilot operations [9]. This is in clear contrast with the Federal Aviation Administration's (FAA) decision of certifying single flight-crew operations under a special scheme[8].

These concerns not only demonstrate some of the regulatory enhancements that will ensue the VLJ concept, they also hint the (possible) need for a larger and more comprehensive regulatory enhancement; namely the evolution of the regulations' applicability criteria. A shift from the current criteria is required; the aircraft's weight and passenger seating capacity can no longer be regarded as the main parameters for determining its regulatory requirements. New criteria must be adopted, to effectively highlight that it is the aircraft's operating environment and its performance which are determinant.

Unlike our previous works, which were concerned with a single regulation, the introduction of VLJs requires studying the evolution of several regulations, through the modeling and comparison of the affected regulations and procedures, before and after their amendment are enacted (regression analysis). These regulations would include: ICAO's Annex 6 "Aircraft Operations", the future EASA "Air Operations" regulation (if available), the Federal Aviation Regulations (FAR) 23 and the Certification Specification (CS) 23, and ICAO's Supplementary Regional Procedures (Doc 7030).

7 Conclusions and Future Work

The introduction of new paradigms in civil aviation entails the need to adapt the regulatory framework dictating the behavior and the interactions of airplanes.

In this paper, we advocate that techniques, similar to those used in computer science for software development, can be useful for regulation development. Such modeling techniques have been successfully applied in the context of airport security regulations.

Based on the methodology's performance in the NACRE project, we are confident that the introduction of VLJs into the civil aviation system represents an excellent opportunity to appraise this methodology in the context of safety regulations. For this, we shall benefit from the discerning operational certification requirements for VLJs in Europe and the United States of America. Since VLJs in Europe are not going to be certifiable for single crew operations (in contrast with the FAA's decision for Part 135 operations), this gives us a "Δ" (delta) between two state-of-affairs which can be used as a "before" and "after" state to compare (and tweak) the performance of our proposed tools. The systematic probing would focus on the regressions introduced by the amendments implemented in the USA, with regards to its VLJ stance.

However, the work will not be a clear-cut translation of the requirements (into a graphical and formal model). There is a complexity in specifying all of their aspects; with a potential loss of connotation during the conversion. This problematic is inherent to the passage from a natural language to the semi-formal and formal notation. Nevertheless, the converse is also true; the translation to formal notation helps enrich the requirements by imposing precision in terms and relations.

Additionally, work is being pursued to determine the possibility (and the interest) of extending this same methodology onto other aspects of civil aviation, such as flight procedures and manuals.

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