Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 179 (2017) 13 – 22

Procedia Engineering

www.elsevier.com/locate/procedia

4th European STAMP Workshop 2016

Application of STPA on Small Drone Operations: A Benchmarking Approach

Maria Mikela Chatzimichailidou[a]*, Nektarios Karanikas[b], Anastasios Plioutsias[c]

[a]*Imperial College London, Department of Civil & Environmental Engineering, South Kensington Campus, SW7 2AZ, London, UK*
[b]*Amsterdam University of Applied Sciences, Faculty of Technology, Weesperzijde 190, Amsterdam, 1097 DZ, the Netherlands*
[c]*National Technical University of Athens, School of Mechanical Engineering, Heroon Polytechniou 9, 15780 Zografou, Athens, Greece*

Abstract

The remarkable and continuous growth of the unmanned aircraft market has brought new safety related challenges, as those are recorded in various accident and incident reports. Although drones with an operating weight higher than 20-25Kgs are technologically advanced and often subject to standards (e.g., technical reliability, airspace management, licensing, certification), the regulatory framework for (ultra) light drones focuses almost exclusively on the limitations that the operator needs to consider. Thus, the protection from accidents seems to rely mostly on the competency of the operator to fly a drone safely, and his/her observance of the rules published by the respective authorities. In addition, the hazards lying in the interaction between an operator and a small drone have not been systematically studied. In this paper, we present (1) the first results from a System-Theoretic Process Analysis (STPA) based approach to the identification of hazards and safety requirements in small drone operations, and (2) an adaptation of the Risk Situation Awareness Provision Capability (RiskSOAP) methodology in order to quantify the differences amongst 4 drone models regarding the extent to which they fulfill the safety requirements identified through STPA. The results showed that the drones studied satisfy the safety requirements at low and moderate levels and they present high dissimilarities between them regarding the extent to which they meet the same safety requirements. Future work will include: (a) comparison of a larger sample of small drones against the safety requirements, as well as pairwise, and (b) assessment of the degree to which various regulatory frameworks worldwide address the safety requirements generated with STPA and assigned to the authority level.

© 2017 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license
(http://creativecommons.org/licenses/by-nc-nd/4.0/).

Peer-review under responsibility of the scientific committee of the 4th European STAMP Workshop 2016

---

* Corresponding author. Tel.: +44-7490-276975; fax: +44-20 7594 5929
E-mail address: m.chatzimichailidou@imperial.ac.uk

1877-7058 © 2017 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license
(http://creativecommons.org/licenses/by-nc-nd/4.0/).
Peer-review under responsibility of the scientific committee of the 4th European STAMP Workshop 2016
doi:10.1016/j.proeng.2017.03.091

Keywords: Benchmarking; Dissimilarity measures; Drones; RiskSOAP methodology; Safety Requirements; STPA

---

1. Introduction

The continuous increase of drones' population [1] has brought new safety challenges. The numbers of respective reports increase sharply [2,3] as drones might fly near airplanes and helicopters or be operated without permission close to airports [4]. EASA [5] has developed a database including accidents and serious incidents reported by accident investigation authorities in Europe. According to the RPAS (Remotely Piloted Aircraft Systems) database ([5], p.71, Figure 24), 40 occurrences were reported in 2013, this number increased to 90 in 2014, while in 2015 the number of occurrences was 400, thus almost 4.5 times higher than the previous year.

Despite the escalation of numbers of safety events with drones, a clear and universally accepted Unmanned Aircraft Systems (UAS) regulatory framework is not yet in place, and drone systems are currently managed under different regulations depending on the country they are flown. In February 2015, the Federal Aviation Administration (FAA) proposed the Operation and Certification of Small UAS [6], where a regulatory structure similar to the one of manned aircraft was utilized, including airman certification requirements. In March 2015, the European Aviation Safety Agency (EASA) published a Technical Opinion [7] that includes 27 suggestions for low-risk operations of unmanned aircraft, irrespectively of their maximum certified take-off mass. The purpose of the Technical Opinion is to serve as guidance for European Union (EU) Member States that are expected to develop or modify their UAS related regulations. Hence, it seems that the regulatory framework in the EU might become quite diverse due to the fact that the individual EU States are responsible for their own airspace, thus the establishment of a Cross-European standardization seems remote in time.

Dalamagkidis *et al.* [8] used a reliability assessment based on Failure Mode and Effects Analysis (FMEA) and Fault Tree Analysis (FTA) for particular UAS models, and they acknowledged the existence of a gap in data availability when newer systems, such as drones, may have not exhibited failures leading to accidents. In the work of Clothier *et al.* [9], a risk management framework for UAS was presented, founded on the notion that hazards and causal factors can be derived from methods such as Functional Hazard Analysis, Hazard and Operability Analysis (HAZOP) and FMEA. By using FTA and Dynamic Simulation, Kuchar [10] proposed new methods for ensuring collision avoidance between UASs. Lee *et al.* [11] were also concerned with the probabilistic safety assessment of UAS operations by calculating collision rates in high-traffic activity. In order to identify various ways in which human factors contributed to the loss of a heavy UAS flown for military purposes, Johnson [12] used the Events and Causal Factors accident analysis technique, and Loh *et al.* [13] pointed out the need for UAS developers to consider the safety certification for operations in the US national airspace.

Taking into account the indicative references above, the aviation community faces two challenges: (1) a common regulatory framework for UAS, especially for light drones, is missing and (2) linear approaches grounded on reductionism seem to prevail without adequately addressing the complexity of drone flights. An operator centric approach has resulted to the publication of directives and regulations that focus heavily on the drone operator (otherwise called as "end-user"), without several authorities having yet completely addressed requirements for small drones' design and certification, or their own responsibilities [e.g., 14,15,16,17].

Aiming to address the two abovementioned challenges along with the continuous advancements in small drone technology and capabilities, the authors have been developing an STPA-based approach to identify hazards and safety requirements (SRs) for small-drone operations. An analysis of a typical drone – operator system with STPA [18] provided a list of hazards and causal factors that might lead to unwanted events. The SRs produced with STPA were further assigned to the authority, manufacturer, operator and automation levels. Also, the authors compared 4 highly marketed models against the SRs generated with STPA by adapting the RiskSOAP methodology [19]. RiskSOAP was considered as the proper methodology because it is an STPA-based methodology and provides a means of quantification with the use of Rogers-Tanimoto dissimilarity measure [20]. The 4 models were also compared to each other.

2. Methodology

The following assumptions were made as a means to define the system under examination and the research scope:

- The drone system is not subject to civil aviation requirements (i.e. drone operating weight less than 25Kg for the US and 20Kg for the EU, according to current regulations and/or legislation).
- The generic drone system[†] consists of a remote controller, the drone and a display. The display is used for monitoring telemetry data, and might or not be part of the remote controller (e.g., software application in a smartphone).
- The drone is a rotary aircraft, thus is not subject to aerodynamic limitations.
- Mission losses due to factors other than degraded safety, were not addressed.
- Collisions with flying fauna were not considered.
- The drone system was analyzed down to the level of interaction between the operator and the drone (see Fig. 2). However, some implications for the higher hierarchical levels (see Fig. 1) were also drawn. Further decomposition (e.g., architecture and links of software and hardware subsystems) was out of the scope of this study.

The herein proposed approach is based on an adaptation of the RiskSOAP methodology [19][‡], consists of 4 key stages and 7 steps, as shown in Table 1 and explained further in this section:

(1) define the benchmarking system by utilizing STPA. In this study, the benchmarking reference is the list of the requirements derived through STPA for a generic light-weight drone system.

(2) map the original elements (i.e. SRs met by each drone) to the benchmarking system.

(3) employ the Rogers-Tanimoto dissimilarity measure for binary data (or other comparative tools) in order to depict the distance between the “ideal” (i.e. STPA based) and “real” systems (i.e. drones under study).

(4) use the aforementioned dissimilarity measure to calculate the differences amongst the drones pairwise.

Table 1. The RiskSOAP based benchmarking approach

The steps of the methodology	
1. Apply the STPA hazard analysis to a generic small-drone system	
2. Contemplate the STPA-derived safety requirements as the benchmarking reference	
3. Perform a gap analysis between the benchmarking “ideal” system and the “real” drone model(s) selected	
4. Assign “1” or “0” values depending on whether a safety requirement is met by the drone model(s) or not, correspondingly	
5. Calculate the value of the Rogers-Tanimoto dissimilarity measure for the benchmarking reference with each drone model for the manufacturer, operator and automation levels.	→Case A
6. Calculate the value of the Rogers-Tanimoto dissimilarity measure for drone pairs (e.g., Model 1 – Model 2, etc.).	→Case B
7. Interpret the results of Steps 5 and 6.	

-Step 1-

Although the analysis was done for the two lower levels of the hierarchical control structure of a generic drone system (see Fig. 1; system marked with red dashed line), STPA also led to the formulation of SRs for other system controllers (i.e. authority and manufacturer). In reference to Fig. 1, the dashed arrows indicate that the operator is not always or necessarily supported by automated functions. The authors zoomed into the hierarchical control structure of Fig. 1, and performed the STPA analysis for the safety control structure of Fig. 2. The preliminary steps of STPA are given in Table 2.

[†] Drone models may differ in their design and functional units.

[‡] Due to the scope of this work, there is one RiskSOAP step missing from Table 1; see Conclusion. All seven steps listed in Table 1 are steps of the RiskSOAP methodology.

Next, the authors identified the Unsafe Control Actions (UCAs) (i.e. STPA Step 1) and the causal factors (i.e. STPA Step 2), as well as the SRs. Both STPA steps were performed iteratively and peer-reviewed by the researchers independently in order to ensure the quality and robustness of the results, by effectively combining technical knowledge in aviation and experience in the application of the method.

Although STPA Step 2 is typically followed by the development of scenarios that include combinations of multiple conditions, where control actions might be proven hazardous or ineffective, it was not in the scope of this study to perform this sub-step, which is required during the certification of systems.

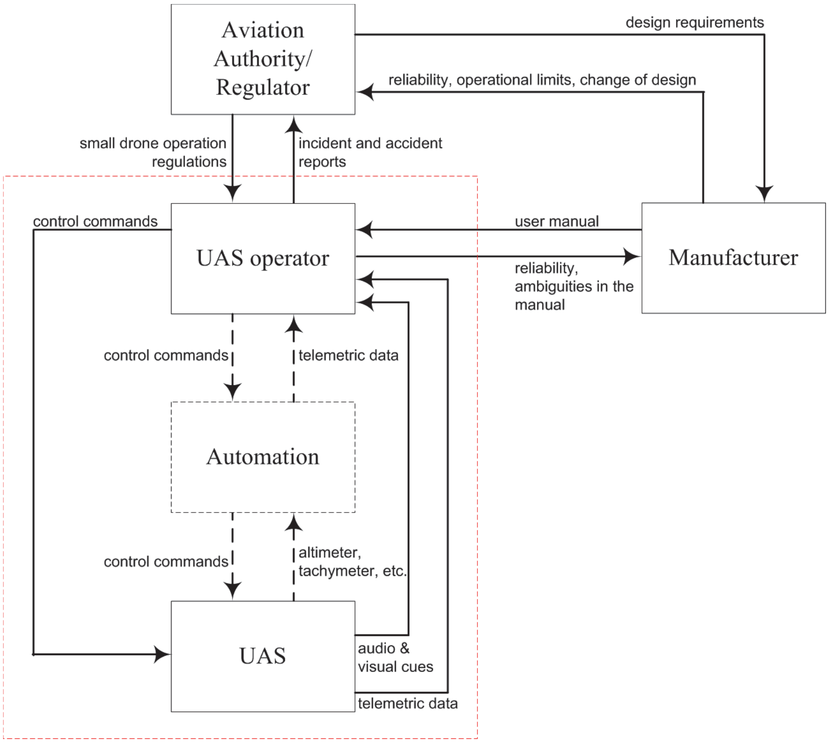


Fig. 1. High level hierarchical control structure

Table 2. Preliminary steps of STPA

Accident: Injuries or property damage resulting from the operation of drone	
High level hazards	High/system level safety requirements
[H1]: Unsafe separation from terrain / objects on ground during controlled flight	[SR1]: Drone should maintain a safe separation from terrain/objects on ground
[H2]: Uncontrolled flight over congested area	[SR2]: Drone should be under controlled flight
[H3]: Unsafe separation from other flying objects during controlled flight	[SR3]: Drone should maintain a safe separation from other powered flying objects

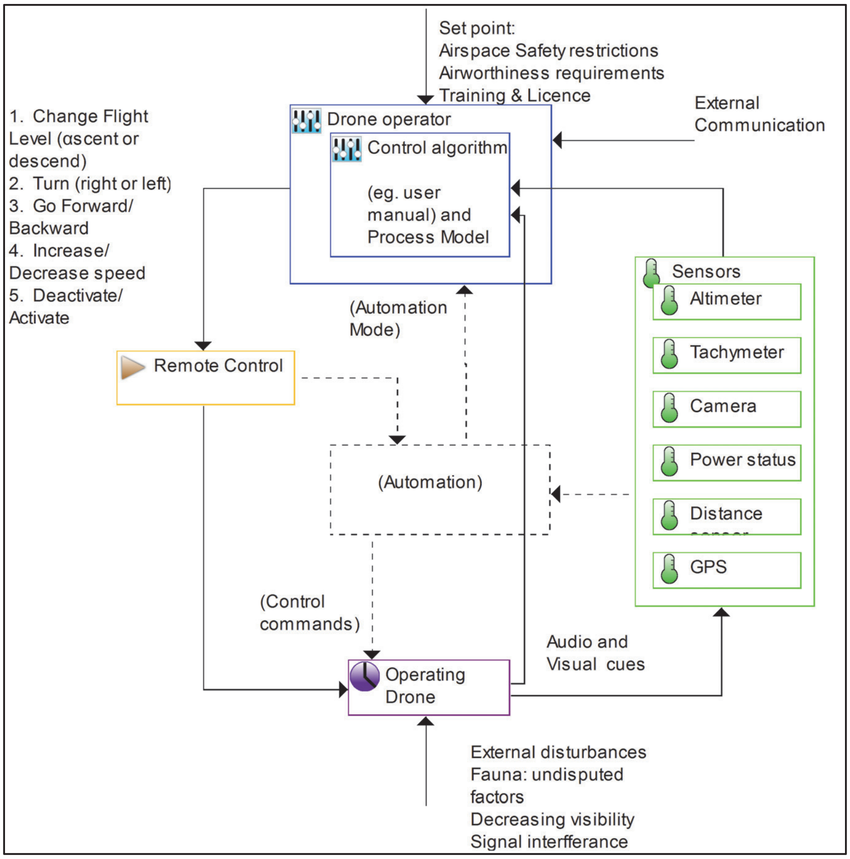


Fig. 2. Safety control structure for a generic small-drone system.

-Step 2-

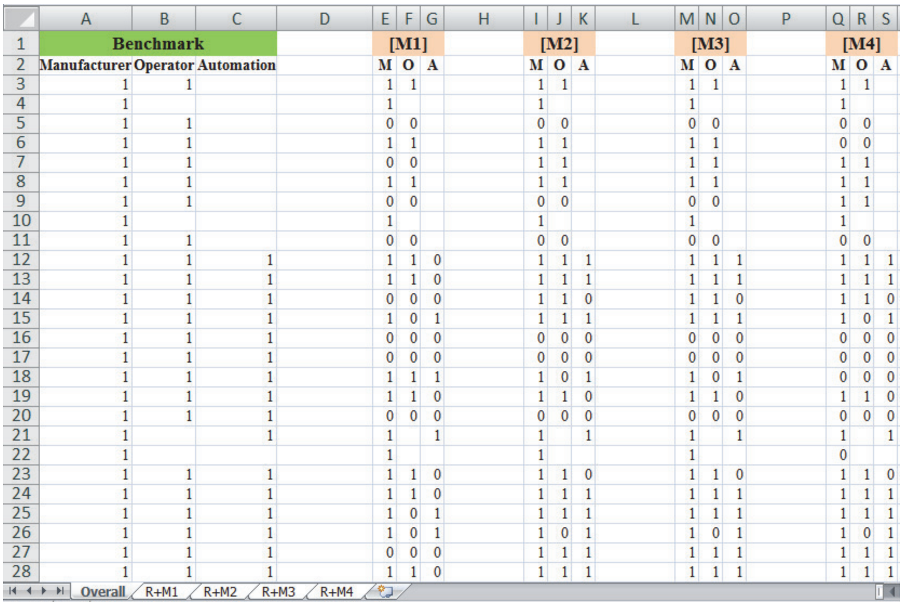
The analysis of the drone – operator system led to requirements across all main system controllers, thus, the STPA SRs were grouped into four categories, each one corresponding to each of the controllers of the larger system under study: authority, manufacturer, operator and drone automation.

-Step 3-

Four drone models were selected based on the availability of detailed manuals on the internet and their sale volumes. A gap analysis between the list of the SRs derived with STPA and the specifications of the 4 small-drone models was performed for the manufacturer, operator and automation. The consideration of the authority level was out of the scope of this study.

-Step 4-

A binary representation (i.e. 1/0) of the requirements that the 4 small drones met, or not, served as a first indication of the extent to which those drones embedded safety “by design”. To translate the SRs from textual terms into binary data, a simple rule was used: the “0” value expressed the absence and the “1” value the presence of an SR. Fig. 3 is a screenshot of the binary data created for all 4 drone models and the benchmarking basis. “[M]” indicates the manufacturer; “[O]” the operator; “[A]” the automation. “[M1]”, “[M2]”, “[M3]”, “[M4]” are the 4 selected and compared models.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1	Benchmark				[M1]				[M2]				[M3]				[M4]		
2	Manufacturer	Operator	Automation		M	O	A		M	O	A		M	O	A		M	O	A
3	1	1			1	1			1	1			1	1			1	1	
4	1				1				1				1				1		
5	1	1			0	0			0	0			0	0			0	0	
6	1	1			1	1			1	1			1	1			0	0	
7	1	1			0	0			1	1			1	1			1	1	
8	1	1			1	1			1	1			1	1			1	1	
9	1	1			0	0			0	0			0	0			1	1	
10	1				1				1				1				1		
11	1	1			0	0			0	0			0	0			0	0	
12	1	1	1		1	1	0		1	1	1		1	1	1		1	1	1
13	1	1	1		1	1	0		1	1	1		1	1	1		1	1	1
14	1	1	1		0	0	0		1	1	0		1	1	0		1	1	0
15	1	1	1		1	0	1		1	1	1		1	1	1		1	0	1
16	1	1	1		0	0	0		0	0	0		0	0	0		0	0	0
17	1	1	1		0	0	0		0	0	0		0	0	0		0	0	0
18	1	1	1		1	1	1		1	0	1		1	0	1		0	0	0
19	1	1	1		1	1	0		1	1	0		1	1	0		1	1	0
20	1	1	1		0	0	0		0	0	0		0	0	0		0	0	0
21	1		1		1		1		1		1		1		1		1		1
22	1				1				1				1				0		
23	1	1	1		1	1	0		1	1	0		1	1	0		1	1	0
24	1	1	1		1	1	0		1	1	1		1	1	1		1	1	1
25	1	1	1		1	0	1		1	1	1		1	1	1		1	1	1
26	1	1	1		1	0	1		1	0	1		1	0	1		1	0	1
27	1	1	1		0	0	0		1	1	1		1	1	1		1	1	1
28	1	1	1		1	1	0		1	1	1		1	1	1		1	1	1

Fig. 3. Screenshot of the binary data representing present/absent safety requirements.

-Step 5- (Case A)

Dissimilarity measurements were conducted amongst the benchmarking model defined with STPA and the 4 drones across the manufacturer, operator and automation levels. The comparisons were made pairwise by using the binary data of Step 4 above; that is, Benchmark - [M1], Benchmark - [M2], etc. The aim was to reveal the extent to which the 4 drones met the SRs according to the STPA benchmarking basis. The comparison was performed by using the Rogers-Tanimoto dissimilarity measure, which was the preferred binary dissimilarity measure mainly because it gives weight to the dissimilarities between the compared vectors (i.e. ideal and real systems) by multiplying them by two. It is a normalized dissimilarity measure, with a minimum dissimilarity of "0" (i.e. exactly similar systems), and a maximum dissimilarity of "1" (i.e. the vectors are completely dissimilar). The equation is given below:

$$RTd\,(i,r) = \frac{2S10 + 2S01}{S11 + S00 + 2S10 + 2S01} \tag{1}$$

The terms "$S00$", "$S01$", "$S10$" and "$S11$" of Eq. (1) denote the total number of the corresponding (0,0), (0,1), (1,0) and (1,1) pairs of binary integers, of the two compared (each time) vectors. The vectors under comparison shall have the same number of rows because there is a one-to-one relationship between the binary integers.

-Step 6- (Case B)

Dissimilarity measurements were also conducted amongst the 4 drones for all three system controllers (i.e. manufacturer, operator and automation). The aim was to reveal the extent to which those 4 drone models fulfilled the same SRs.

3. Results

The application of STPA Step 1 resulted to 28 UCAs, and 24 causal factors were identified through STPA Step 2. In total, 67 SRs were obtained by STPA, one of which was assigned exclusively to the authority level and was not considered in the dissimilarity calculations. The lists of UCAs, causal factors and SRs (see rows in Fig. 2) are not reported in this paper due to space limitations, but are available to the reader upon request to the corresponding author; those lists will be included in a journal paper, which is already under review. The 66 SRs were translated into binary data and then a gap analysis was performed. The binary-like results are depicted in Table 3. The terms "$S00$", "$S01$" are not shown in Table 3 because the benchmarking system fulfils all requirements by default. Based on the values of Table 3, the values of the Rogers-Tanimoto dissimilarity metric were calculated (Table 4). Those refer to the benchmarking-4 models comparison (Case A). According to the results:

- From both Table 3 (see "Dissimilarities") and 1st row of Table 4, it is apparent that at all levels of controllers, [M1] fulfils the least of the STPA SRs in comparison with the rest 3 models.
- Table 4 indicates that at a manufacturer and automation level, [M2] and [M3] perform the same and yield the best corresponding values.
- The manufacturer and automation levels concerned, [M4] scores lower than [M2] and [M3], but better than [M1].
- [M3] satisfies most of the requirements for the operator, followed by models [M4], [M2] and [M1] in ascending order of dissimilarities.

Table 3. The values of the Rogers-Tanimoto terms per drone model, per controller.

Drone models	Rogers-Tanimoto terms	Manufacturer	Operator	Automation
[M1]	Similarities (S11)	36	18	17
	Dissimilarities (S10)	30	29	30
[M2]	Similarities (S11)	48	26	30
	Dissimilarities (S10)	18	21	17
[M3]	Similarities (S11)	48	28	30
	Dissimilarities (S10)	18	19	17
[M4]	Similarities (S11)	43	27	23
	Dissimilarities (S10)	23	20	24
	Total safety requirements per controller	66	47	47

Table 4. Total results (Case A): dissimilarities between benchmarking system and 4 drone models.

Drone models	Manufacturer	Operator	Automation
[M1]	0.6250	0.7632	0.7792
[M2]	0.4286	0.6176	0.5313
[M3]	0.4286	0.5758	0.5313
[M4]	0.5169	0.5970	0.6761

Table 5 presents the dissimilarities between the 4 drone models, without taking into account the benchmarking system. Those dissimilarities are categorized on the basis of system controllers, i.e. (a): Manufacturer, (b): Operator, (c): Automation. In Case B, there was no intermediate unit for comparison, i.e. benchmarking reference, but the 4 drone models are compared to each other directly. According to Table 5, the results showed that:

- The highest dissimilarities are observed between [M1] - [M2] and [M1] - [M3] at the level of automation. Practically, this means that one drone model supports the maintenance of safety controls through automation, rather than relying vastly on the human operator.
- A high dissimilarity is also apparent between [M1] and [M4] at the manufacturer and operator levels.
- Models [M2] and [M3] bear great resemblance to each other across all levels of controllers. They are also produced by the same manufacturer, which can explain their in-between low dissimilarity.
- Overall, [M1] has the highest dissimilarities to the other models, which indicates that [M1] not only meets the least SRs (i.e. Case A above), but those are highly different compared to the other 3 drone models.

Table 5. Total results (Case B): pairwise dissimilarities between all 4 drone models for (a) the manufacturer, (b) the operator and the (c) automation.

Controller	(a) Manufacturer				(b) Operator				(c) Automation			
Drone models	[M1]	[M2]	[M3]	[M4]	[M1]	[M2]	[M3]	[M4]	[M1]	[M2]	[M3]	[M4]
[M1]		0.3902	0.3902	**0.5169**		0.3509	0.4068	**0.4839**		**0.5313**	**0.5313**	0.5079
[M2]			0.0588	0.2857			0.1569	0.2593			0	0.3214
[M3]				0.2857				0.2593				0.2593
[M4]												

4. Discussion

The STPA hazard analysis followed in this work led systematically to the identification of 28 hazardous states and 24 causal factors associated with 3 high-level safety hazards in the operation of a typical small-drone system, and drove the generation of 67 SRs. Those requirements were assigned to the main system controllers (i.e. authority, manufacturer, operator and drone automation), and were used as a benchmarking basis to assess the safety “embedded” in 4 small drone models of the current market. The requirements proposed in this study cover a range of hazards and causal factors, not yet explicitly nor holistically addressed in published risk analyses and regulations.

The proposed benchmarking approach was an adaptation of the RiskSOAP methodology [21], which offers a quantification of the degree to which the drone system meets the SRs derived from STPA. The available documentation for drone models allowed for the assessment of all the STPA-derived SRs and the analysis followed was sufficiently comprehensive to measure dissimilarities. The only prerequisite of this method is to have two systems so as to compare them with each other. In Case A, the one unit under comparison is always the benchmarking system, determined by the STPA hazard analysis and depicting the “ideal” system, while the other is an existing drone system. In Case B, both units represent real drone systems with identified gaps regarding the SRs they incorporate, based on the specifications documented in their published manuals. Also, it is useful to be mentioned that instead of the Rogers-Tanimoto measure, the analyst may choose another dissimilarity measure depending on the examined case; that is system particularities, behavior and attributes, problem statement and focus of interest.

In this work, the authors chose 4 drone models in order to demonstrate how a benchmarking approach might work and what conclusions can be drawn from the adoption of dissimilarity measures in terms of drone safety. Based on the cases A & B, the analysis of the 4 small drones did not only show that they cover the STPA SRs at low to moderate level, but also indicated high dissimilarities regarding the extent to which those drones met the same SRs at the manufacturer, operator and automation levels.

It is also noted that the approach proposed in this paper differs from the Systems-Theoretic Early Concept Analysis (STECA) [22], which is a concept analysis being performed in the interval between the conceptualization and the requirements of a system. The challenges that STECA deals with are: limited design information, absence of specifications, informal documentation and concept of operations [22]. Practically, when applying STECA, the analyst is based on a narrative or textual description of the system under development. Nevertheless, our approach is localized later in the life-cycle, when the system is already designed and operated, still being subject to modifications though. In this phase, user (i.e. operator) manuals and design specifications are already available. Therefore, the proposed benchmarking approach regards systems that already exist; the controllers, the actuators and the sensors are known actors and their responsibilities are already defined, or at least to an extent. The 4 drone models, for instance, are already built and the safety control structure for a generic small-drone system was derived after reading several user manuals explaining how those systems actually work.

5. Conclusion

The existing or still under finalization regulatory framework for small drones is quite diverse and focuses almost exclusively on the limitations that the operator needs to consider. To date, published risk assessments for UAS are based mainly on data collected from manned aircraft and not on a systematic hazard analyses for small drones operated in uncontrolled airspaces. Although there is some research on UAS safety, this is mainly based on statistical analysis and specific accident scenarios or UAS models, while at the same time it is not clear whether there is a structured hazard analysis behind those studies. Therefore, a regulatory framework which is grounded on a systematic and system-wide risk analysis is yet missing.

In this study, we showed that the STPA analysis provides the analyst the ability to reach to concrete results in a structured and systematic manner. It is expected that the results of the STPA analysis, which was not fully presented here due to space restrictions, can comprise a starting point to move towards the development of a holistic and methodologically justified standardization scheme for small-drone flights. On one hand, the dissimilarity analysis performed herein between the benchmarking reference and the 4 drone models might function as a method to evaluate "embedded" safety and improve the latter in existing drone systems over time. The comparison between the 4 models, on the other hand, can be used as a practical indicator for measuring the extent to which drone models offer the same controls over safety constraints.

A future research step might be the application of the complete RiskSOAP methodology; that is, employment of the EWaSAP [23] early warning sign identification approach. In this way, the analyst will define the sensor characteristics and, in turn, embed the appropriate sensors that enhance the awareness of the regulator – operator – drone system over the threats and vulnerabilities that surround them and may put the overall system under risk. Furthermore, future improvements in sensor technology may allow their integration into drones, without increasing their weight significantly or generating major safety issues that call for further examination (e.g., the potential overwhelming of the operator with numerous feedbacks from the system and his/her confusion in prioritizing the maintenance of safety controls when multiple safety constraints are violated at the same time [24]).

In its current form, RiskSOAP is binary-based, although SRs can be fulfilled to some degree; that is, variables may have a value between "0" and "1". For that reason, future work is intended to involve fuzzy logic, to cope with crisp variables, and adopt continuous variables instead. The assignment of weights to SRs may also be considered based on the criticality of the system functions they address.

So far, the authors have been extending their analysis to a sample of 19 drone models, aiming to provide broader results from the comparative analysis, and support the call for establishing a common and holistic risk management framework for small drones. In addition, the authors have been analyzing the regulations published by several authorities in order to perform a dissimilarity analysis amongst them and show the extent of diversity of the current rules and standards about small-drone flights. We claim that the aforementioned research will collectively demonstrate the need to cope timely with the safety challenges, and to control the possible hazards of existing drone systems before negative events happen.

Acknowledgements

The authors would like to thank Dr Ioannis Dokas for his idea to apply an adaptation of RiskSOAP in order to indicate the differences amongst the compared drone models in a quantitative manner. The authors are also grateful to the two peer-reviewers for their valuable comments and suggestions that helped improve the manuscript.

References

[1] Radiant Insights I. Commercial drones: *Highways in the sky, commercial unmanned aerial systems(UAS), market shares, strategies, and forecasts, worldwide, 2015-2021.* http://www.radiantinsights.com/research/commercial-drones-highways-in-the-sky-commercial-unmanned-aerial-systems-uas-market. Published January 8, 2015. Accessed July 23, 2016.

[2] Vanian J. *More drones are flying too close to comfort to airplanes and airports*. Tech. http://fortune.com/2016/03/28/drones-flying-too-close-airplanes-airports/. Published March 28, 2016. Accessed April 10, 2016.

[3] EASA. *Annual Safety Report 2016*. Brussels: European Aviation Safety Agency, 2016.

[4] Campion-Smith B, Ottawa Bureau. *Drone close calls near airports spur proposed regulations, Toronto star*. Canada. https://www.thestar.com/news/canada/2016/06/11/drone-close-calls-near-airports-spur-proposed-regulations.html. Published June 11, 2016. Accessed July 10, 2016.

[5] European Aviation Safety Agency, *Anual safety review 2016*, publication date: 07/2016, online: https://www.easa.europa.eu/system/files/dfu/209735_EASA_ASR_MAIN_REPORT.pdf

[6] FAA. *Operation and Certification of Small Unmanned Aircraft Systems*. Washington, DC: Federal Aviation Administration, 2015.

[7] EASA. *Introduction of a regulatory framework for the operation of unmanned aircraft.* Cologne: European Aviation Safety Agency, 2015.

[8] Dalamagkidis, K., Valavanis, K.P., & Piegl, L.A. *On integrating unmanned aircraft systems into the national airspace system: issues, challenges, operational restrictions, certification, and recommendations.* Springer Science & Business Media, 2011.

[9] Clothier, R.A., Greer, D.A., Greer, D.G., & Mehta, A.M. Risk perception and the public acceptance of drones. *Risk analysis* 35, no. 6 (2015): 1167-1183.

[10] Kuchar, J.K. *Safety analysis methodology for unmanned aerial vehicle (UAV) collision avoidance systems.* In USA/Europe Air Traffic Management R&D Seminars, vol. 12. 2005.

[11] Lee, H.T., Meyn, L.A., & Kim, S.Y. Probabilistic safety assessment of unmanned aerial system operations. *Journal of Guidance, Control, and Dynamics* 36, no. 2 (2013): 610-617.

[12] Johnson, C.W. The Hidden Human Factors in Unmanned Aerial Vehicles. *Proceedings of the 25th International Systems Safety Society Conference*; 2007 Aug 13-17; Baltimore, MD; 2008.

[13] Loh, R., Bian, Y., & Roe, T. UAVs in civil airspace: Safety requirements. *IEEE Aerospace and Electronic Systems Magazine* 24, no. 1 (2009): 5-17.

[14] Civil Aviation Authority, *Requirements for operating in airspace*, online: http://www.caa.co.uk/Commercial-industry/Aircraft/Unmanned-aircraft/Unmanned-Aircraft/

[15] Federal Aviation Administration, *Unmanned Aircraft Systems; Fly for Fun*, online: http://www.faa.gov/uas/getting_started/fly_for_fun/

[16] US Department of Transportation, *Advisory Circular, Small Unmanned Aircraft Systems*, publication date: 06/2016, online: http://www.faa.gov/uas/media/AC_107-2_AFS-1_Signed.pdf

[17] Australian Government, *Federal Register of Legislation, Civil Aviation Safety Regulations 1998*, publication date: 05/2013, online: https://www.legislation.gov.au/Details/F2013C00316/Html/Volume_3

[18] Leveson, N. *Engineering a safer world: Systems thinking applied to safety*. Mit Press, 2011.

[19] Chatzimichailidou, M.M., & Dokas, I.M. RiskSOAP: introducing and applying a methodology of risk self-awareness in road tunnel safety. *Accident Analysis & Prevention* 90 (2016): 118-127.

[20] Zhang, B., & Srihari, S.N. Properties of binary vector dissimilarity measures. In *Proc. JCIS Int'l Conf. Computer Vision, Pattern Recognition, and Image Processing*, vol. 1. 2003.

[21] Chatzimichailidou, M.M., & Dokas, I.M. Introducing RiskSOAP to communicate the distributed situation awareness of a system about safety issues: an application to a robotic system. *Ergonomics* (2015): 1-14.

[22] Fleming, C.H, & Leveson, N. Integrating Systems Safety into Systems Engineering during Concept Development. In *INCOSE International Symposium*, vol. 25, no. 1, pp. 989-1003. 2015.

[23] Dokas, I.M., Feehan, J., & Imran, S. EWaSAP: An early warning sign identification approach based on a systemic hazard analysis. *Safety science* 58 (2013): 11-26.

[24] Plioutsias, A., & Karanikas, N. Using STPA in the Evaluation of Fighter Pilots Training Programs, Proceedings of the 3rd European STAMP Workshop, STAMP EU 2015, 5-6 October 2015, Amsterdam, The Netherlands, *Procedia Engineering*, 128(1), pp. 25-34. 2015.