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THREAT AND ERROR MANAGEMENT REVISITED

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Abstract

Threat and error management (TEM) is considered a key responsibility of pilots, flight instructors and flight examiners. This study presents a new model for teaching threat and error management related to flight instruction that is based on the system-theoretic process analysis (STPA) (Leveson, 2011). Currently a linear threat and error management model is used which lacks critical aspects related to the control hierarchy and multiple control. With STPA complex processes involving hierarchy, multiple controllers, non-linear relationships or feedback, that are typical for flight instruction can be modelled. This model includes the higher-level controllers in the hierarchy of the aviation system such as company management, authorities and industry associations that shape the interactions among flight instructor, trainee, automation and environment. The new model shows that each control instance in the system can contribute to threat and error management. Thus, the people from every control instance of the hierarchy can be better prepared to anticipate and deal with hazards related to their work. The STPA-based TEM model can be used for safety training, instructor training, for developing requirements, standards and for hazard analysis and prevention of instructional incidents and accidents.

Keywords: Threat and Error Management, TEM, STPA, Flight Instruction, Pilot, Safety. .

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1. Introduction

Threat and error management (TEM) is considered a key ability of pilots, flight instructors and flight examiners (ACG, 2014; EASA, 2011). Helmreich, Klinect and Wilhelm (1999) proposed a model of TEM which is focused on the front line operators. According to the original TEM model, the flight crew is responsible to manage expected or unexpected external threats and errors committed by other operators, to avoid committing additional errors or to manage their own errors, too (Figure 1). According to this model, the flight safety or the occurrence of an incident or accident are seen as a result of pilots' TEM performance.

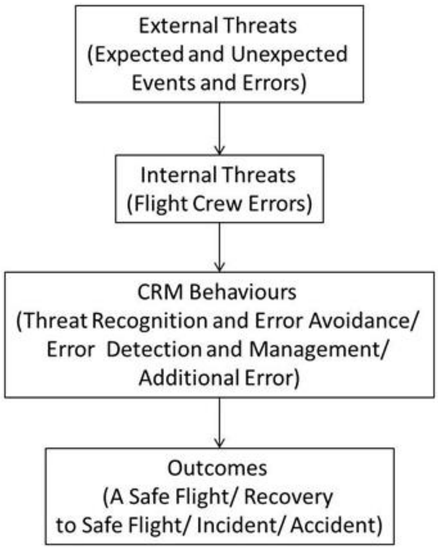

Figure 01. A Linear Model of Threat and Error Management (Koglbauer, 2016 adopted from Helmreich et al., 1999)

Using this linear model of TEM, Klinect (2005) investigated the TEM process at 10 airlines. He found an impressive number of 7,257 errors during 2,612 observation flights. The flight crews managed most of the errors and threats. Nevertheless, the crew could not detect and manage 27% of errors on time. In 1,347 cases the TEM process resulted in a hazardous flight status. This data is extremely important for raising awareness of the "statistical normality" of threats and errors in the daily activity of pilots who are front line operators of the aviation industry.

2. Problem Statement

The original model of TEM describes the inputs and outputs of TEM, but does not specify the process in between. Insight into the TEM process can aid training organizations in analysing hazardous processes and developing meaningful exercises. Furthermore, the original model of TEM (Helmreich et al., 1999) is focused on the pilots, as the main players in threat and error management and disregards other key players that more or less directly contribute to the process. It is very likely that the threats and errors encountered by the pilots are symptoms of deeper trouble in the system that could be resolved at another level. As system safety theorists and practitioners showed, the management, regulatory agencies, industry associations or even the government play a major role in shaping the work of front line operators (Dekker, 2006, 2011; Leveson, 2011; Koglbauer & Leveson, 2017; Rasmussen, 1997).

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The goal of a flight training course is to train candidates to the level of proficiency necessary to pass the assessment of competence for the required license/ rating. The outcome of TEM in flight training can be a safe flight, recovery to a safe flight or the occurrence of an incident or accident. An accident is an event that leads to injury, loss of life, damage of aircraft or property (Leveson, 2011). According to Rasmussen (1997) safety depends on the control of work processes for avoiding accidental harm. Accidents occur because safety constraints are not appropriate or are not properly enforced throughout the whole system, not only at the front line of operation. For avoiding accidents, hazards need to be controlled. A hazard is a "system state that, together with a particular set of worst-case […] conditions, will lead to an accident" (Leveson, 2011, p. 184). According to Leveson (2011) the safety is an emergent hierarchical system property, not a component property. Koglbauer (2016, 2017) proposed a preliminary system-theoretic model of TEM in flight instruction. The role that company management, regulatory agencies, industry associations or government can play in TEM needs further consideration and will be addressed in this paper.

3. Research Questions

This study outlines a generic model of the system involved in threat and error management in flight training.

4. Purpose of the Study

This study presents an update of the system-theoretic model of TEM in flight instruction (Koglbauer, 2016, 2017). The system-theoretic model presented here addresses the higher-level controllers in the hierarchy of the aviation system such as company management, authorities and industry associations that shape the interactions among flight instructor, trainee, automation and environment.

5. Research Methods

The System-Theoretic Accident Model and Process (STAMP) developed by Leveson (2004; 2011) is at the core of STPA (Leveson, 2011). STPA can be used to model a sociotechnical system, identify unsafe control actions and safety constraints that can be enforced at different hierarchical levels of the system. Using STPA the process can be modelled using control loops. The controllers can be people (e.g. flight instructors, trainees, pilots, inspectors, managers, regulators) or automated (e.g., autopilot). The conditions necessary to control a process in a given time and space are the existence of clear goals, the reception of information/ feedback about the process, the knowledge and the ability to influence the process (Leveson, 2011). In addition, STPA enables the analysis of multiple controller hazards.

6. Findings

The generic system involved in flight training and modelled according to STPA is illustrated in Figure 2. At global level common policies, standards and recommendations are provided by international organizations. For example the International Civil Aviation Organization (ICAO, 2017) has the objective to improve the safety of air transportation by monitoring aviation safety metrics. ICAO promulgates risk management strategies, standards and recommends practices to facilitate harmonised regulations on a global basis (ICAO, 2017). The International Federation of Air Line Pilots' Associations (IFALPA, 2017)

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promotes aviation safety worldwide developing common policies and positions and promoting the adoption of such policies by ICAO, regulatory authorities and the State of each Member Association (IFALPA, 2017). EASA (2017) drafts implementing rules, promotes the use of European and worldwide standards, approves training organisations, and provides oversight. Generally, the national government is responsible for determining and enforcing the policy of the state. The national Civil Aviation Authority (CAA) is responsible to ensure that the aviation industry meets the required safety and security standards, and that consumers and the environment are protected. Usually the CAA provides standards for training and licensing flight instructors. The standards include details such as training objectives, syllabus, equipment, exercises and performance evaluation criteria. In addition the CAA issues the licenses of the flight training and flight examination personnel.

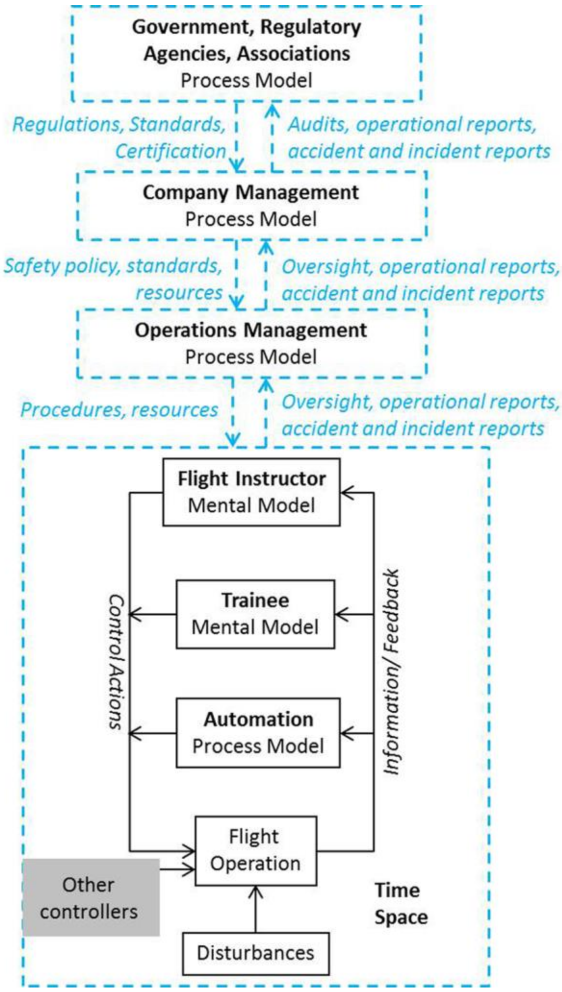

Figure 02. Generic Hierarchical Control Structure of Flight Training

At the company level the regulations are interpreted and implemented. The organization or company management establishes the operations management for flight training, and provides resources, policies and oversight of the activity. The CAA conducts investigations and audits of the certified training organization of the company. The CAA can also amend, limit, suspend or revoke the company's certificate when the conditions according to which it was issued are no longer fulfilled. The operations management is responsible for development and implementation of training programs, staff planning, scheduling,

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monitoring, record-keeping, and reporting. Finally, at the bottom level we meet the flight instructors and trainees involved in the productive process. The flight instruction work is monitored and shaped by externally given requirements and resources. Time and space are critical features of the process model.

Using the STPA-methodology (Leveson, 2011) generic unsafe control actions (UCAs) can be systematically determined for each hierarchical level and controller/ agent. A set of generic control actions and UCAs related to flight instruction are listed in Table 1.

Table 01. Classification of Unsafe Control Actions (UCAs) Related to Flight Instruction

Control Action (CA)	**CA causes hazard**	**Lack of CA causes hazard**	**CA too early/ too late/ wrong sequence**	**CA too long or too short causes hazard**
Government, Regulatory Agencies	Provides inadequate laws, regulations and standards for approval and operation; Approves inadequate organisations; Conducts inadequate investigations and audits of the certified training organization;	Does not provide regulations and standards for critical aspects of flight training; Laws and regulations fail to promote a just culture (e.g. Janezic, 2016); Does not amend, limit, suspend or revoke the company's training certificate when the conditions according to which it was issued are no longer fulfilled	Provides laws, regulations and standards too late; Conducts investigations and audits of the certified training organization of the company too late; Amends, limits, suspends or revokes the company's training certificate too late	-
Associations	Provide inadequate recommendations, reports	Do not provide required recommendations, reports	Provide recommendations, report too late	-
Company Management	Provides inadequate safety policy, standards, resources; Promotes a blame culture; Excessive pressure to fulfil concurrent goals on costs of safety	Does not promote a safety culture (e.g., Ioannou et al., 2017); Does not provide necessary resources;	Provides resources and standards too late	-
Operations management	Provides inadequate procedures, resources, staff planning/ scheduling	Lack of procedures, resources, oversight;	Provides resources, procedures and standards too late	-
Flight Instructor	Provides conflicting or uncoordinated control inputs; Provides inadequate instruction or CAs	Does not follow the procedures when required; Does not provide CAs or does not take over the control	Provides control inputs too late; Takes over the control too late	Provides too short or too long control inputs; too short instruction before and after practical sessions; too long verbal instructions during practical flight
Trainee	Provides inadequate CAs	Does not perform a required CA; Does not follow the instructor's command	Provides CA too early, too fast, too late or in the wrong sequence	Provides too short or too long CAs
Automation	Provides inadequate CAs	Does not provide a required CA	Provides CA too early, too fast, too late or in the wrong sequence	Provides too short or too long control inputs
Other controllers	CA causes hazard	Lack of CA causes hazard	CA too early/ too late/ wrong sequence	CA too long or too short

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When two or more controllers are performing CAs, the outcome may be unsafe because of conflicts or incoordination among controllers. For two controllers, four typical cases can be determined (Ishimatsu, Leveson, Fleming, Katahira, Miyamoto & Nakao, 2011; Leveson, 2011):

- Only one safe control action is provided. For example, when the company management provides appropriate standards but the operations management does not provide the necessary resources to the employees for implementing the standards; or when the operations management reports safety problems and the company management does not addresses them (Ioannou et al., 2017);
- Multiple safe control actions are provided resulting in excessive inputs (e.g., additive stick inputs of the flight instructor and of the trainee);
- Both safe and unsafe control actions are provided (e.g., the international associations provide adequate recommendations, but the national authorities implement them inadequately);
- Only unsafe control actions are provided. For example, when the legislation does not implement a just culture (Janezic, 2016) the instructors who should report incidents or errors may fear unfair treatment and do not report them. If errors and incidents are not addressed, the people and organizations cannot learn from them and safety problems are repeating.

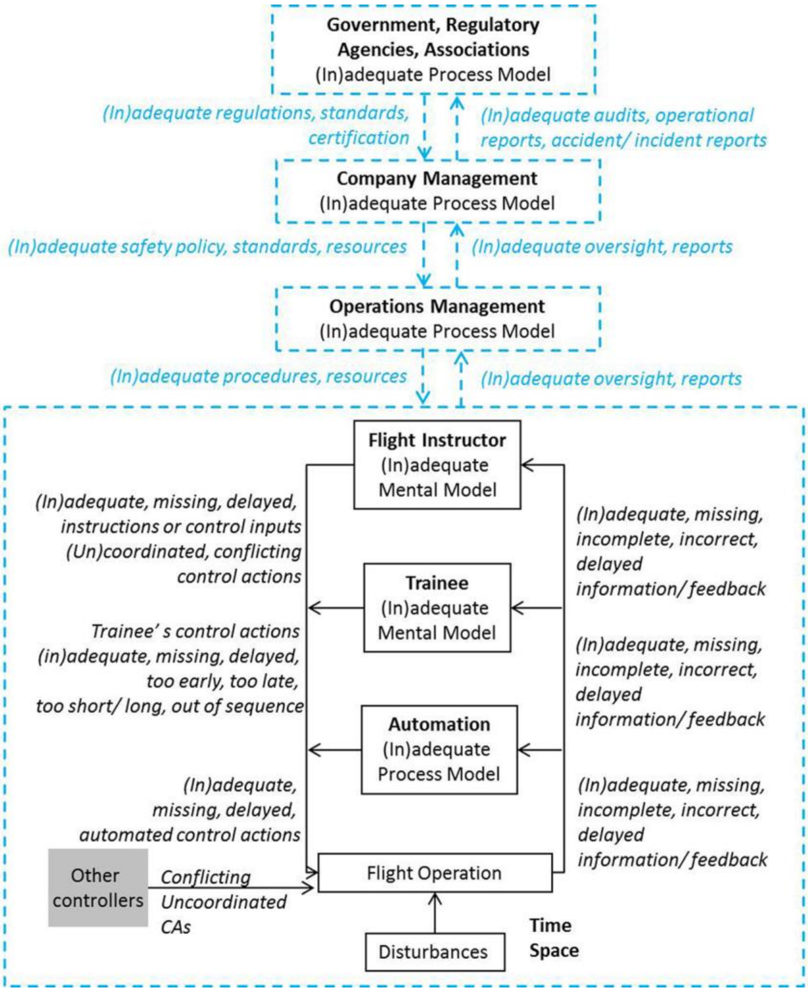

Figure 03. A Generic TEM Model for Determining Causal Scenarios of UCAs Related to Flight Instruction

Using the STPA-methodology (Leveson, 2011) causal scenarios for the identified unsafe control actions can be determined by examining the parts of the control loops: information/ feedback, knowledge (mental or process models), control actions, time, space and disturbances. For determining threats and errors related to flight training the generic control structure illustrated in Figure 03 can be used as a starting point. The dynamics of the system (Sterman, 2000) should be considered, too. The analysis may be more efficient when the role of the controller in the hierarchy or role of the hierarchical level is considered, instead of a particular person (Sterman, 2000). It is well known that a major barrier in improving the TEM in practice is the existing blame culture at national, professional and organizational levels. In a blame culture the efforts are concentrated on searching for “substandard” or “guilty” persons to “blame” for errors, incidents and accidents. By placing blame on individuals and failing to address the real problems, similar errors continue to occur (EUROCONTROL & FAA, 2008). In contrast, in the context of a positive safety culture and just culture the efforts concentrate on reporting occurrences, addressing the real problems, learning and improving safety (EUROCONTROL & FAA, 2008; Kearns & Schermer, 2017; Ioannou et al., 2017).

7. Conclusion

This paper proposes a generic model of threat and error management for flight instruction based on the System-Theoretic Process Analysis (STPA) (Leveson, 2011). The new model shows that not only the pilots/ instructors, but each control instance, at each hierarchical level of the system can contribute to threat and error management in flight instruction. Thus, the people from every control instance of the hierarchy can be better prepared to understand the system, to anticipate and deal with hazards related to their work. The STPA-based model of TEM can be used for safety training, instructor training, for developing requirements, standards, for hazard analysis and prevention of instructional incidents and accidents. Future work with the STPA-based TEM model will focus on refining the causal scenarios and developing instructor training programs. The model can be also used as a frame for incident/ accident investigations and elaboration of safety requirements for preventing future accidents.

Acknowledgments

Preliminary versions of this study have been presented in the 2016 European Proceedings of Social & Behavioural Sciences (Koglbauer, 2016), and at the STAMP Workshop organized by the MIT Partnership for a Systems Approach to Safety, on March 30, 2017 at the Massachusetts Institute of Technology, Cambridge, MA (Koglbauer, 2017).

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