Trade-Offs Between Safety and Production During Technical Assistance of an Aircraft

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Abstract This paper examines the trade-off issues between production and safety within the scope of resilience engineering. A two-step empirical study was conducted in a maintenance control center in charge of the assistance to pilots and line maintenance: 1. Activity analysis to provide greater understanding of the technicians' activity. This analysis was complemented by a quantitative analysis of 380 technical assistance operations. All of these operations were analyzed and coded following a "predicate/argument" pattern; 2. Simulation of the same technical assistance task performed by each technician, followed by self-confrontation. This study revealed that adaptive safety is an unavoidable reality in a real and ultra-safe system that is subject to unforeseeable situations and performance challenges. Trade-offs between production and safety occur when rule-based safety does not permit to deal with the situation. A meaningful relationship between safety and production exists in which safety and production interests match. In a real situation, adaptive safety and rule-based safety coexist in the safe zone. In ultra-safe systems, however, rule-based safety leaves little room for adaptive safety. The discussion focuses on the articulation between adaptive and rule-based safety.

1 INTRODUCTION

The success stories of aviation safety are an example for other industries (e.g. healthcare, fishing), given the lower rate of accidents in aviation: 1.6 fatal accidents per 10 million flights were recorded for the decade 2002-2011 in Europe (European

Aviation Safety Agency [EASA], 2012). The strategies and tools of this ultra-safe system are based on International and National Aviation Authorities' regulations and policies internalized by airlines. Research has demonstrated that workers in aviation maintenance operations often perceive that safety and operational goals are in conflict (Eiff & Suckow, 2008). Conflicting safety and production demands can negatively affect safety, production, or both (McLain & Jarrell, 2007). Sacrificing safety at the expense of production may have catastrophic consequences. A number of accidents, such as the loss of space shuttle Challenger and of the Piper Alpha oil platform, have occurred because upgrades and/or maintenance operations were delayed in order to meet production goals or deadlines (Cowing, Paté-Cornell, & Glynn, 2004).

Aircraft maintenance is a critical component of the overall system for ensuring safety in aviation (McDonald, Corrigan, Daly, & Cromie, 2000). The 2010 International Air Transport Association (IATA) annual report showed that maintenance events, such as errors from maintenance crews, played a contributing role in approximately 11% of the accidents. Maintenance events may require air turn-backs, delays in aircraft availability, gate returns, in-flight shutdowns, maintenance rework, damage to maintenance equipment, and injury to maintenance personnel. Okorilo, Vozdenovic, Vasov, and Mirosavljevic (2010) determined the costs of unsafety caused by aircraft accidents, based on aircraft (type and age) and accident severity, to be between 34-211 million and 414-591 million Euros. Compared to these costs, airline delay-related costs are negligible: 4,000 to 20,000 Euros. In this case, the adage "an aircraft on ground does not make money" is meaningful for a short-term trade-off between safety and production.

This paper examines production and safety trade-offs in technicians' work in a maintenance control center in charge of pilot assistance and line maintenance. From a general point of view, the purpose of this paper is to present a discussion oriented towards the management of trade-offs between safety and production goals in different socio-technical systems (unsafe and ultra-safe systems).

2 THEORETICAL FRAMEWORK

According to Hollnagel et al. (2010), organizations are considered to be resilient if they are able to adjust their functioning to ensure the continuation of activities under both expected and unexpected conditions. Other authors consider resilience as the ability to manage great pressure as well as conflicts between safety and production objectives (Flin, 2006; Hale & Heijer, 2006; Woods, 2006). This definition of resilience places the issue of trade-offs between performance and safety at the center of research discussions, and thus of the prescribed safety vs. managed safety issue. Trade-offs between safety and performance exist in unsafe and ultra-safe systems. Workers have to reach both their safety and performance goals, neither of which should be achieved at the expense of the others. In the context of risk management, it is fundamental to understand why and how trade-offs between production and safety goals operate because decisions taken may have serious consequences on the safety of the system. Organizations are seeking ways to preserve their level of economic performance without degrading their safety margins. A number of studies have been conducted to understand managers' decision making when they are faced with conflicting situations between performance and safety goals (Morel, Amalberti, & Chauvin, 2008, 2009 ; Gomes, Woods, Carvalho, Huber, & Borges, 2009 ; Nascimento, Falzon, & Mollo, 2010; Cedergren, 2011). Nevertheless, there is insufficient understanding of how workers manage conflicting demands between production and safety in complex systems.

To examine these trade-off issues within the scope of resilience engineering, a two-step empirical study was conducted to analyze technicians' work in an airline maintenance control center in charge of pilot assistance and line maintenance.

3 FIELD OF OBSERVATION, RESEARCH METHOD, AND RESULTS

3.1 The Maintenance Control Center

The maintenance control center (MCC) under investigation operates for a regional airline. At the time of the study, the organization consisted of 14 hot line technicians (HLT) with a permanent team of two HLTs on each morning/afternoon shift. The HLTs' job is to provide technical assistance to pilots in operation and line maintenance technicians during the day and evening. The main tasks of HLTs are to categorize and assess reported defects that could threaten the airworthiness of the aircraft and decide on actions to be undertaken. The data concerning the defects are always transmitted by phone from pilots or line maintenance technicians to the HLTs. They then analyze the data gathered, reach a diagnosis, and have to decide on the aircraft status: airworthy or not. If they judge the aircraft to be un-airworthy (NOGO status), the HLTs must stop the aircraft operation in order to perform appropriate maintenance. If they decide the aircraft is airworthy (GO status), the next flight may take place. The MCC is therefore an important link and co-ordination tool for safety between flight operations and aircraft maintenance.

HLTs are under constant pressure to make the aircraft operational within the time limit of its planned schedule. In regional aviation, most airplanes stop for a short period during the day. The turnaround time between two flights is about 30 to 40 minutes. The dynamics of the situation complicate the task of HLTs. Decisions have to be taken quickly in order to reduce flight delays or permit setting up alternatives for passengers: re-routing, flight charter, or using a spare aircraft (if available). If after they have diagnosed the defect, the HTLs cannot apply the deferrable rules of the Minimum Equipment List, the availability of parts and maintenance capabilities become constraints.

3.2 Research Methods

A two-step method enabled the assessment of the complexity and the variability of aircraft technical assistance operations:

- The first step was based on the analysis of each activity (organization, tools, reference manual) in order to gain greater understanding of the HLTs' tasks. This initial stage was complemented by a quantitative analysis of 380 technical assistance tasks. Over a period of 4 weeks, all 380 technical assistance tasks were analyzed and coded following a "predicate/argument" pattern.
- The second step was based on a simulation of the same technical assistance tasks performed by each HLT, followed by self-confrontation. It is this step that is reported on in this article.

This simulation study is empirical in nature and was modeled to represent specific realistic technical assistance situations. The simulation was based on the assumption that in some situations, the next flight is performed with an un-airworthy aircraft (defect NOGO). Given the variability of the HLTs' expertise and of the severity of the defects, it is to be expected that in a particular situation, decisions will vary: some HLTs will cancel the flight (safety) while others will allow the next flight (maintain production). The simulated task was based on an ecological scenario: "Just after landing at AAA airport, the Captain calls the MCC to report that he has noticed during the two previous flights a minor and non-permanent defect on the aircraft stand-by horizon. The HLT cannot apply the deferrable rules of the Minimum Equipment List; the aircraft is un-airworthy and the following flights have to be cancelled in order to perform a maintenance task (exchange of the stand-by horizon)." This type of defect (minor and non-permanent) does not necessarily entail that all HLTs will decide to stop the aircraft immediately. All constraints are fixed in order to place HLTs in a particular situation that will lead to a trade-off decision between production and safety. When analyzing results, HLTs were divided into two groups: novices and experts.

3.3 Results

The verbal content analysis provided detailed information regarding the building of the trade-off decision, the factors taken into account, and the role of rule-based safety and adaptive safety. This study revealed that in a particular simulated assistance situation, some HLTs took the decision to allow aircraft continued performance. When taking such a decision, these technicians do not earn more money or gain any personal benefit. They have in mind the passengers' expectations and the potential financial loss for the company. Faced by a minor defect to which the deferrable rules of the Minimum Equipment List cannot be applied, HLTs take this decision in order to keep the aircraft in service, and they organize the troubleshooting in a way that aircraft operation is the least perturbed. The flights scheduled are performed, and passengers are carried on time.

Trade-offs between safety and production: the expression of adaptive safety

The analysis of the simulations revealed that a majority of HLTs (10) found solutions to maintain production in assessing the severity of the defect, minimizing the risk taken, and seeking means to revaluate the situation. Only four technicians arbitrated in favor of safety by cancelling the flight. Novices made the decision to allow the next flights, but in a different way from other HLTs.

Assessing the severity of the defect

The analysis of the simulations showed that all HLTs arbitrated in favor of production according to their own criteria of defect severity, which excluded all defects classified as "important" by HLTs. For the experts, experience determines the acceptability of a defect. The experience criterion is associated with risk control and financial costs or the aircraft systems. For other HLTs, risk or safety is the criterion for determining the acceptability of a defect. This criterion is associated with defect assessment, airworthiness, type of defect, procedures, or trust in their relation with the Captain.

Minimizing the risk taken and seeking means to revaluate the severity of the defect

In the group of experts, we observed the implementation of an anticipation strategy enabling them to deal with the defect according to their experience-based knowledge. This strategy of anticipation may be assimilated to mitigation between safety and production. Anticipating the evolution of a defect enables the technicians to deal with it before it becomes a safety threat. The ability to deal successfully with unexpected assistance issues and implement strategies depends on technicians' practices and knowledge and may be a trace of resilience. Expert HLTs thus have the adaptive capacity to make trade-off decisions when facing conflicting goals.

4 DISCUSSION

This study revealed that adaptive safety is an unavoidable reality in a real and ultra-safe system which is subject to unforeseeable situations and performance challenge. Trade-offs between production and safety occur when rule-based safety does not permit to treat the situation. A meaningful relationship between safety and production exists in which safety and production interests are matched (Atak & Kingma, 2011). In ecological situations, adaptive safety and rule-based safety coexist in the safe zone (see Fig.1). However, within ultra-safe systems, rule-based safety leaves little room for adaptive safety. The adaptive capacities of the system are therefore very limited, which can lead to loss of control in case of major perturbations.

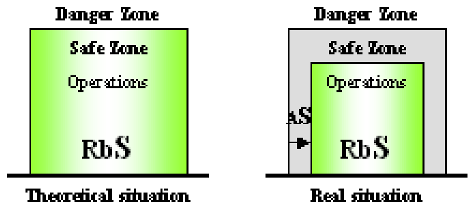

Fig.1. *Rule-based safety (RbS) and adaptive safety (AS) in an ultra-safe system*

If adaptive safety has been highlighted in an ultra-safe system, the organization may either reinforce rule-based safety at the expense of adaptive safety or, because there is no way to formalize its structure, it may play the ostrich to maintain performance goals. This is not good news for resilience.

The situation seems to be different in other systems, depending on the safety level and rule-based safety and adaptive safety levels. Professional sea fishing is among the world's most non-standardized and dangerous sectors of activity where the level of adaptive safety is very high and rule-based safety is virtually absent (Morel et al., 2008, 2009). It is therefore a remarkably resilient system, but it is unable to produce a high level of safety due to the lack of rules. The trade-offs are made in favor of performance at the expense of safety, but exposure to extreme conditions reinforces the fishermen's resilience (Morel et al., 2009). Like aviation, the railway system has an organized approach to safety management. In this ultra-safe and highly prescribed system, the organization (blunt-end) defines the rules to organize the activity at the sharp-end level. However, a looping top-down/bottom-up process permits to redefine the rules in terms of the activity requirements. The prescribed rules can therefore be adjusted to the requirements of the situation (Morel, Di Cioccio, Blatter, Karsenty, & Cuvelier, 2011). In the healthcare domain, the anesthesia system may point the way to the coexistence of the two forms of safety. Every anesthesia situation is a dynamic and complex process with changing and potentially risky issues. In this ultra-safe system, however, rule-based safety is built by the anesthesiologist's peers in such a way that it leaves room for anesthesia team autonomy. In practice, the rules do not stifle adaptive safety; rather, they provide a useful framework for risk management. The weight of adaptive safety is very high, and the two forms of safety are complementary rather than in fundamental opposition.

Finally, consideration of these four examples (aviation, sea fishing, railways, and anesthesia) highlights the following points: 1. The two forms of safety (i.e. adaptive and rule-based) are not necessarily opposed; 2. Adaptive safety alone is not able to produce significant results in terms of systems' safety level. Increasing the safety level of non-safe systems (like sea fishing) must involve providing a phase of significant prescription without limiting adaptive safety; 3. The example of anesthesia (Cuvelier, 2011) reveals that it is possible to preserve adaptive safety while strengthening prescription and reaching a very high level of observed safety. This system is built in order to adapt itself to the high variability/uncertainty of the complexity of the human body (as opposed to systems such as railway and aviation that are built to operate in nominal operation modes); 4. Rule-based safety does not provide the necessary means for efficient adaptation of actions. Adaptive safety is essential to manage unexpected situations, but also to manage trade-offs between production and safety requirements.

5 CONCLUSION

Trade-offs between safety and production are a reality, regardless of the safety level (safe or unsafe) reached by systems. Ultra-safe performance in complex systems cannot be achieved through rule-based safety only. Operators' and managers' ability to cope with trade-offs depends on adaptive safety, which permits to treat unforeseen or situations outside of any prescribed framework. In an ultra-safe system such as is found in aviation, the conditions needed to introduce adaptive safety must be discussed. Eliminating or passing over this reality may negatively affect both performance and safety. The question of trade-offs raises two issues: 1. How does one introduce adaptive safety in an ultra-rule system? 2. It is significant that in our modern societies, every accident results in prosecution, which brings out the issue of the responsibility of the person who made the trade-off.

It is necessary to keep in mind that accidents share a common sameness; abandoning adaptive safety may well lead to procedure-assisted accidents (e.g. Swissair Flight 111 in September 1998). The "successful" sea-landing of U.S. Airways Flight 1549 on the Hudson River in 2009 must convince us that adaptive safety can contribute to enhancing the safety level of systems that are already considered as ultra-safe.

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