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Comparing a multi-linear (STEP) and systemic (FRAM) method for accident analysis

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ABSTRACT

Accident models and analysis methods affect what accident investigators look for, which contributory factors are found, and which recommendations are issued. This paper contrasts the Sequentially Timed Events Plotting (STEP) method and the Functional Resonance Analysis Method (FRAM) for accident analysis and modelling. The main issue addressed in this paper is the comparison of the established multi-linear method STEP with the new systemic method FRAM and which new insights the latter provides for accident analysis in comparison to the former established multi-linear method. Since STEP and FRAM are based on a different understandings of the nature of accidents, the comparison of the methods focuses on what we can learn from both methods, how, when, and why to apply them. The main finding is that STEP helps to illustrate what happened, involving which actors at what time, whereas FRAM illustrates the dynamic interactions within socio-technical systems and lets the analyst understand the how and why by describing non-linear dependencies, performance conditions, variability, and their resonance across functions.

1. Introduction

Analysing and attempting to understand accidents is an essential part of the safety management and accident prevention process. Many methods may be used for this purpose (see [1,2] for overviews), each reflecting a specific perspective on accidents and how they come about, which may be called an accident model [3,4]. Analysis methods and thus their underlying (implicit or explicitly articulated) accident models affect what investigators look for, which contributory factors are found, and which recommendations are made [5]. Two such methods with underlying models are the Sequentially Timed Events Plotting (STEP) method [6] and the Functional Resonance Accident Model with the associated Functional Resonance Analysis Method (FRAM) [3,7].

Multi-linear event sequence models and methods (such as STEP) have been used in accident analysis to overcome the limitations of simple linear cause-effect approaches to accident analysis. In STEP, an accident is a special class of process where a perturbation transforms a dynamically stable activity into unintended interacting changes of states with a harmful outcome. In this multi-linear approach, an accident is viewed as several sequences of events and the system is decomposed by its structure consisting of interacting events in sequences or in parallel.

Researchers have argued that linear approaches fail to represent the complex dynamics and interdependencies commonly observed in socio-technical systems [3,4,8–11]. Recently, systemic models and methods have been proposed that consider safety as an emergent property of the socio-technical system as a whole.

The Functional Resonance Accident Model with its associated Functional Resonance Analysis Method (FRAM; [3]) embodies such a systemic approach. Rather than physical components and sequences of events, functions and function performance are the units of analysis. A function may be defined as "a set of actions that a system performs or is used for, which are valuable for the achievement of a set of goals" [12].

FRAM is based on four principles [13]. First, the principle that both successes and failures result from the adaptations that organizations, groups, and individuals perform in order to cope

Abbreviations: A/C, aircraft; AIBN, Aircraft Investigation Board Norway; APP, Oslo approach; CRM, Crew Resource Management; EFIS, Electronic Flight Instrument System; FRAM, Functional Resonance Analysis Method; ft, feet; FRQ, frequency; GA, go-around; G/S, glide slope; GPWS, Ground Proximity Warning System; L, left; LLZ, localizer; NAX541, aircraft identification call sign; NPF, non-pilot flying; OSL, Oslo Gardermoen airport; PF, pilot flying; R, right; RWY, runway; STEP, Sequentially Timed Events Plotting Method; TWR, tower

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with complexity. Success depends on their ability to anticipate, recognise, and manage risk. Failure is due to the absence of that ability (temporarily or permanently), rather than to the (organizational, human or technical) inability of a system component to function normally. Second, complex socio-technical systems are by necessity underspecified and only partly predictable. Procedures and tools are adapted to the situation, to meet multiple, possibly conflicting goals, and hence, performance variability is both normal and necessary. The variability of one function is seldom large enough to result in an accident. However, the third principle states that the variability of multiple functions may combine in unexpected ways, leading to disproportionately large consequences. Successes and failures are therefore emergent phenomena that cannot be explained by looking solely at the performance of (organizational, human or technical) system components. Fourth, the variability of a number of functions may resonate, causing the variability of some functions to exceed normal limits, the consequence of which may be an accident. FRAM as a model emphasizes the dynamics and non-linearity of this functional resonance, but also its non-randomness. FRAM as a method therefore aims to support the analysis and prediction of functional resonance in order to understand and avoid accidents.

2. Research questions and approach

The main question addressed in this paper is which new insights this latter systemic method provides for the accident analysis in comparison to the former established multi-linear method. Since the accident analysis methods compared in this paper are based on a different understanding of the nature of accidents, the comparison of the methods focuses on what we can learn from both methods, how, when, and why to apply them, and which aspects of these methods may need improvement.

The paper compares STEP and FRAM in relation to a specific incident to illustrate the lessons learned from each method. The starting point of the study is the incident investigation report. A short description of STEP and FRAM is included. For a more comprehensive description, the reader is referred to references [6,3]. Since different methods invite for different questions to be asked, it was necessary to interview air traffic controllers, pilots, and accident investigators to acquire more information. The information in this paper was collected through interviews and workshops involving a total of 50 people. The analysis with STEP and FRAM was an iterative process between researchers and operative personnel.

3. Summary of the incident

A Norwegian Air Shuttle Boeing 737–36N with call sign NAX541 was en-route from Stavanger Sola airport to Oslo Gardermoen airport (OSL). The aircraft was close to Gardermoen and was controlled by Oslo Approach (APP). The runway in use at Gardermoen was 19R. The aircraft was cleared to descent to an altitude to 4000 ft. The approach and the landing were carried out by the co-pilot as ''pilot-flying'' (PF) and the captain as ''pilot non-flying'' (PNF). Shortly after clearance to 4000 ft, the crew was informed that runway 19R was closed because of sweeping and that the landing should take place on runway 19L. The position of the aircraft was instructed by air traffic control to land on 19L. Changing of the runway from 19R to 19L caused a change in the go-around-altitude from 4000 ft at 19R to 3000ft at 19L. The crew performed a quick briefing for a new final approach.

During the final approach, while the aircraft was established on the localizer (LLZ) and glide slope (G/S) for runway 19L, the glide slope signal failed. It took some time for the pilots to recognise G/S failure. At the same time APP instructed the pilots to switch to tower (TWR) frequency. The pilots acknowledged the new frequency but did not yet switch. Immediately after the glide path signal disappeared the aircraft increased its descent rate to 2200ft/min while being flown manually towards LLZ-minima. The aircraft followed a significantly lower approach than intended and was at its lowest only 460 ft over ground level at 4.8 DME. The altitude at this distance from the runway should have been 1100 ft higher. The crew initiated go-around (GA) because the aircraft was still in dense clouds and it drifted a little from the LLZ at OSL. However, the crew did not notice the below-normal altitude during approach. Later a new normal landing was carried out.

The executive summary of the Norwegian Accident Investigation Board (AIBN) [14] explains that the investigation was focused on the glide slope transmission, its technical status and information significance for the cockpit instrument systems combined with cockpit human factors. The AIBN understanding of the situation attributes the main cause of the incident to the pilots' incorrect mental picture of aircraft movements and position. The report concludes that the in-cockpit glide slope capture representation was inadequate. In addition, the report points to a deficiency in the procedure for transfer of responsibility between approach and tower air traffic control.

Five recommendations resulted from the AIBN investigation. The first recommendation is that the responsibility between controls centres should be transferred 8 NM before landing or at acceptance by radar hand over. The second recommendation is related to the certification of avionics displays, advising the verification of the information provided to pilots, with special attention to glide slope and auto-pilot status information. Third, training should take into account glide slope failures after glide slope capture under ILS approach. Fourth, Oslo airport should consider the possibility of providing radar information to the tower controller to be able to identify approach paths deviations. The last recommendation is for the airline to consider situational awareness aspects in the crew resource management (CRM) training.

4. Sequentially Timed Events Plotting

STEP provides a comprehensive framework for accident investigation from the description of the accident process, through the identification of safety problems, to the development of safety recommendations. The first key concept in STEP is the multi-linear event sequence, aimed at overcoming the limitations of the single linear description of events. This is implemented in a worksheet with a procedure to construct a flowchart to store and illustrate the accident process. The STEP worksheet is a simple matrix. The rows are labelled with the names of the actors on the left side. The columns are labelled with marks across a time line.

Second, the description of the accident is performed by universal events building blocks. An event is defined as one actor performing one action. To ensure that there is a clear description the events are broken down until it is possible to visualize the process and be able to understand its proper control. In addition, it is necessary to compare the actual accident events with what was expected to happen.

A third concept is that the events flow logically in a process. This concept is achieved by linking arrows to show proceed/follow and logical relations between events. The result of the third concept is a cascading flow of events representing the accident process from the beginning of the first unplanned change event to the last connected harmful event on the STEP worksheet.

The organization of the events is developed and visualized as a "mental motion picture". The completeness of the sequence is validated with three tests. The row test verifies that there is a complete picture of each actor's actions through the accident. The column test verifies that the events in the individual actor rows are placed correctly in relation to other actors' actions. The necessary and sufficient test verifies that the early action was indeed sufficient to produce the later event, otherwise more actions are necessary.

The STEP worksheet is used to have a link between the recommended actions and the accident. The events represented in STEP are related to normal work and help to predict future risks. The safety problems are identified by analysing the worksheet to find events sets that constitute the safety problem. The identified safety problems are marked as triangles in the worksheet. These problems are evaluated in terms of severity. Then, they are assessed as candidates for recommendations. A STEP change analysis procedure is proposed to evaluate recommendations. Five activities constitute this procedure. The identification of countermeasures to safety problems, the ranking of the safety effects, assessment of the trade-off involved the selection of the best recommendations, and a quality check.

5. Application of STEP to NAX541

The incident is illustrated by a STEP. Due to page and paper limitations, Fig. 1 illustrates a small part of the STEP diagram that was created based on the incident report. In Fig. 1, the time line is on along the *X*-axis and the actors are on the *Y*-axis. An event is considered to mean an actor performing one action. The events are described in event building blocks, for example "APP request to A/C to change to TWR frequency". An arrow is used to link events. Safety problems are illustrated on the top line by triangles in the incident process. Three such problems were identified: (1) no communication between aircraft 1 and tower (triangle 1 in Fig. 1); (2) changed roles between PF and PNF not coordinated; and (3) pilots not aware of low altitude (2 and 3 not shown in simplified figure).

6. Functional Resonance Analysis Method

FRAM promotes a systemic view for accident analysis. The purpose of the analysis is to understand the characteristics of system functions. This method takes into account the non-linear propagation of events based on the concepts of normal performance variability and functional resonance. The analysis consists of four steps (that may be iterated):

Step 1: Identifying essential system functions, and characterizing each function by six basic parameters. A function is defined as an action of a component of the system. The nature of the functions may be technological, human, organizational or a coupling between human, technology and/or organization. The functions are described through six aspects, in terms of their input (I, that which the function uses or transforms), output (O, that which the function produces), preconditions (P, conditions that must be fulfilled to perform a function), resources (R, that which the function needs or consumes), time (T, that which affects time availability), and control (C, that which supervises or adjusts the function), and may be described in a table and subsequently visualized in a hexagonal representation (FRAM module, Fig. 2). The main result from this step is a FRAM "model" with all basic functions identified.

Step 2: Characterizing the (context dependent) potential variability through common performance conditions. Eleven common performance conditions (CPCs) are identified in the FRAM method to be used to elicit the potential variability: (1) availability of personnel and equipment; (2) training, preparation, competence; (3) communication quality; (4) human–machine interaction, operational support; (5) availability of procedures; (6) work conditions; (7) goals, number, and conflicts; (8) available time; (9) circadian rhythm, stress; (10) team collaboration; and (11) organizational quality. These CPCs address the combined human, technological, and organizational aspects of each function. After identifying the CPCs, the variability needs to

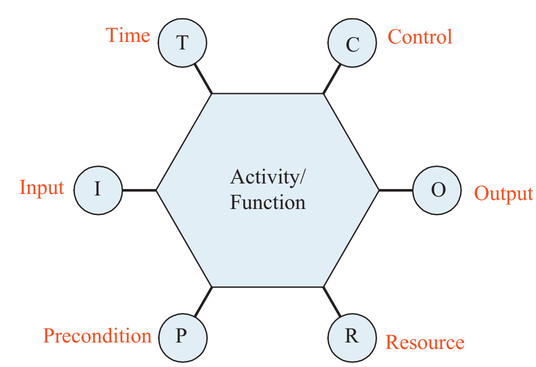

Fig. 2. A FRAM module.

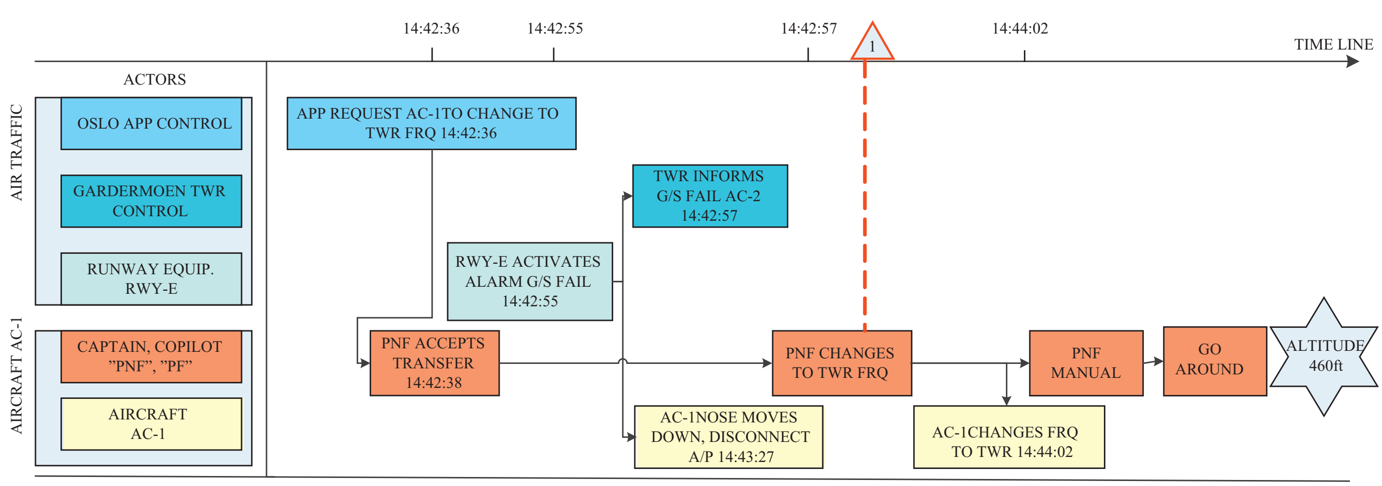

Fig. 1. STEP applied to NAX541 incident (simplified example).

be determined in a qualitative way in terms of stability, predictability, sufficiency, and boundaries of performance.

Step 3: Defining the functional resonance based on possible dependencies/couplings among functions and the potential for functional variability. The output of the functional description of step 1 is a list of functions each with their six aspects. Step 3 identifies instantiations, which are sets of couplings among functions for specified time intervals. The instantiations illustrate how different functions are active in a defined context. The description of the aspects defines the potential links among the functions. For example, the output of one function may be an input to another function, or produce a resource, fulfil a precondition, or enforce a control or time constraint. Depending on the conditions at a given point in time, potential links may become actual links; hence produce an instantiation of the model for those conditions. The potential links among functions may be combined with the results of step 2, the characterization of variability. That is, the links specify where the variability of one function may have an impact, or may propagate. This analysis thus determines how resonance can develop among functions in the system. For example, if the output of a function is unpredictably variable, another function that requires this output as a resource may be performed unpredictably as a consequence. Many such occurrences and propagations of variability may have the effect of resonance; the added variability under the normal detection threshold becomes a 'signal', a high risk or vulnerability.

Step 4: Identifying barriers for variability (damping factors) and specifying required performance monitoring. Barriers are hindrances that may either prevent an unwanted event to take place, or protect against the consequences of an unwanted event. Variability is materialised due to trade-offs in face of multiple conflicting goals within available time. In this context, it is necessary to have barriers that both damp the unwanted variability and facilitate desirable variability. Hence, barriers can be seen as both hindrances and enablers. On the one hand, barriers may either prevent an unwanted event from taking place, or protect against the consequences of an unwanted event. On the other hand, they may enhance the capabilities allowing the system to continue its operation. Barriers can be described in terms of barrier systems (the organizational and/or physical structure of the barrier) and barrier functions (the manner by which the barrier achieves its purpose). In FRAM, four categories of barrier systems are identified (each with their potential barrier functions):

(1) Physical barrier systems block the movement or transportation of mass, energy, or information. Examples include fuel tanks, safety belts, and filters.
(2) Functional barrier systems set up preconditions that need to be met before an action (by human and/or machine) can be undertaken. Examples include locks, passwords, and smoke detectors.
(3) Symbolic barrier systems are indications of constraints on action that are physically present. Examples include signs, checklists, alarms, and clearances. Potential functions encompass preventing, regulating, and authorizing actions.
(4) Incorporeal barrier systems are indications of constraints on action that are not physically present. Examples include ethical norms, group pressure, rules, and laws.

Besides recommendations for barriers, FRAM is aimed at specifying recommendations for the monitoring of performance variability, to be able to detect unwanted variability. Function definition and characterization allow understanding aspects that affect performance. These aspects are candidate for indicators. Instantiations can be used as a basis to consider the effect of the variability across and within functions. Relevant indicators of the spreading of variability may be related to beneficial or disadvantageous changes in potential, expected, and actual couplings. Functional modelling with FRAM aims identification indicators that provide information about the variability of normal performance of the system.

7. Application of FRAM to NAX541

Step 1 is related to the identification and characterization of functions: A total of 19 essential functions were identified and grouped in accordance to the area of operation. There are no specified rules for the 'level of granularity', instead functions are included or split up when the explanation of variability requires. In this particular analysis some higher level functions, e.g. 'Oslo APP control', and some lower level functions, e.g. 'Change frequency (frq) to TWR control'.

The operative areas and functions for this particular incident are:

- Crew operations: change runway (RWY) to 19L, new final approach briefing, auto-pilot approach (APP), change APP frq to TWR frq, manual approach, GO-AROUND, landing, approach, receiving radio communication, and transmitting radio communication
- Avionics functions: disconnect auto-pilot (A/P), Electronic Flight Instrument (EFIS), and Ground Proximity Warning System (GPWS)
- Air traffic control: Oslo APP control, RWY sweeping, glide slope transmission, and Gardermoen TWR control
- Aircraft in the vicinity: aircraft (A/C)-2 communication and A/C-3 communication

The NAX541 incident report contains information that helps to define aspects of functional performance. Essential functions are described with these aspects. Table 1 shows an example of the aspects of the function 'manual approach'. Similar tables were developed for 18 other functions.

In step 2 the potential for variability is described using a list of common performance conditions (CPCs). Table 2 presents an example of CPCs for the function 'manual approach'.

The description of variability is based on the information registered in the incident report combined with a set of questions based on the CPCs. Since little of this information regarding variability was available, it was necessary to interview operational personnel (air traffic controllers, pilots). An example is for CPC 'human–machine interface (HMI), operational support', a question was how aware pilots are of these EFIS, GPWS discrepancies, some stated "Boeing manuals explain which information is displayed, it is normal to have contradictory

Table 1
A FRAM module function description.

Function: manual approach	Aspect description
Input	GPWS alarms, pilot informed of G/S failure
Output	Altitude in accordance with approach path, Altitude lower/higher than flight path
Preconditions	A/P disconnected
Resources	Pilot flying, pilot non-flying
Time	Efficiency thoroughness trade-off, time available varies
Control	SOPs

Table 2
Manual flight approach CPCs.

Function: manual approach	Performance conditions	Rating
Availability of resources (personnel, equipment)		Adequate
Training, preparation, competence	PF little experience on type	Temporarily inadequate
Communication quality	Delay to contact tower	Inefficient
HMI operational support	Unclear alerts	Inadequate
Avail. procedures		Adequate
Work conditions	Interruptions?	Temporarily inadequate?
# Goals, conflicts	Overloaded	More than capacity
Available time	Task synchronisation	Temporarily inadequate
Circadian rhythm		Adjusted
Team collaboration	Switched roles	Inefficient
Org. quality		

information. In this case, understanding of the system as a whole is required. Pilots needs to judge relevant information for each situation." An additional example of questions for the function "Runway change", was if it is normal and correct to request runway change with such a short notice? The interviews identified that there are no formal operational limits for tower air traffic controllers, but for pilots there are. Thus an understanding of performance and its variability was obtained.

In step 3 links among functions are identified for certain time intervals. States are identified to be valid during specific time intervals, which define links among the aspects of functions, hence instantiate the model. An example instantiation is presented in Fig. 3, where links during the time interval 14:42:37–14:43:27 of the incident are described as an instantiation of the FRAM that resulted from step 1. Many more such instantiations may be generated, but here only one example can be shown.

To understand the events in relation to links and functions in this instantiation, numbers 1–5 and letters a–d have been used to illustrate two parallel processes. Following the numbers first, the APP controller communicates to the pilot that they should contact TWR at the TWR frequency (1). This is an output of 'Oslo APP control', and an input to 'receiving radio communication'. This latter function thus has as output the state that transfer is requested to the TWR frequency (2), which matches the preconditions of 'change APP frq to TWR frq', and 'transmitting radio communication'. The fulfilment of this precondition triggers the pilots to acknowledge the transfer to TWR to the APP controller (3), an output of transmitting function, input to 'Oslo APP control'. The pilots however do not switch immediately after the transfer is requested, hence the output is that the frequency still is set to APP, for a much longer time than would be intended (indicated by the red 'O'), and the pilots do not contact TWR (6) until much later. This has consequences for the precondition of receiving/transmitting (4), which is being on the same frequency with the control centre that has responsibility for the flight. With the delay in frequency change, the link that the pilot is in-formed of the G/S failure (5) is also delayed.

At about the same time, following the letters in Fig. 3, 'glide slope transmission' changes output to that there is no G/S signal at 14:42:55 (a), because of a failure of the G/S transmitting equipment (a resource, R in red). This makes the TWR controller in-form pilots on the TWR frequency of the G/S failure (b), excluding the incident aircraft crew because of the unfulfilled precondition because of link (4), de-laying the point that the pilot is informed of G/S failure (d). Concurrently, the loss of G/S no longer fulfils the precondition of the auto-pilot function, with the resulting output of A/P being disconnected (c) about half a minute after G/S loss. This in turn no longer fulfils the precondition of an auto-pilot approach and instead matches the precondition for a manual approach. All of this in turn results in variability on the manual approach, e.g. with decreased availability of time, inadequate control because of PF-PNF collaboration problems, and inadequate re-sources (e.g. displays unclear indications of A/P and G/S) resulting in highly variable performance (out-put) of the manual approach.

Step 4 addresses barriers to dampen unwanted variability and performance variability monitoring where variability should not be dampened. AIBN recommendations could be modelled as barrier systems and barrier functions, e.g. "responsibility between control centres should be transferred 8 NM before landing, or at acceptance by radar hand over." (AIBN, p. 31, our translation). In FRAM terminology this can be described as an incorporeal prescribing barrier. This barrier would have an effect on the variability of the APP and TWR control functions through the aspect of control and the links between input and output in various instantiations describing communication and transfer of responsibility. New suggestions for barriers also result from the FRAM. For example, a proactive communication from TWR to APP when a flight does not report on frequency would link their output and input (see link (*X*) in Fig. 3), triggering instantiations of links 1–6 so that control and contact is re-established. This barrier may be implemented in various systems and functions, such as through regulation, training, procedures, checklists, and display design, etc. The FRAM also points to the interconnectivity of air traffic control and pilot functions, suggesting joint training of these operators with a wide range of variability in the identified functions. As with any method, FRAM enables the suggestion of barriers (recommendations), which need to be evaluated by domain experts in terms of feasibility, acceptability, and cost effectiveness, among other factors.

The FRAM and the instantiations that were created here also point to the future development of indicators for matters such as overload and loss of control when cockpit crew has significant experience differences. Indicators may be identified by considering the variability of the functions and their couplings. In the case, indicators are related to proactive communication between TWR control and APP control or information between TWR and pilots.

8. Comparison

Accident models, implicitly underlying an analysis or explicitly modelling an adverse event, influence the elicitation, filtering, and aggregation of information. Then, what can we learn from the applications of STEP and FRAM to this incident?

STEP is relatively simple to understand and provides a clear picture of the course of the events. However, STEP only asks the question of which events happened in the specific sequence of events under analysis. This means that events mapped in STEP are separated from descriptions of the normal functioning of socio-technical systems and their contexts. For example, the STEP diagram illustrates that the PNF's switch to TWR frequency was delayed, but not why. Instead, STEP only looks for failures and safety problems, and highlights sequence and interaction between events. FRAM refrains from looking for human errors and safety problems but tries to understand why the incident happened. Since FRAM addresses both normal performance variability and the specifics of an adverse event, FRAM broadens data collection of the analysis compared to a STEP-driven analysis: Thus the development of the incident is contextualized

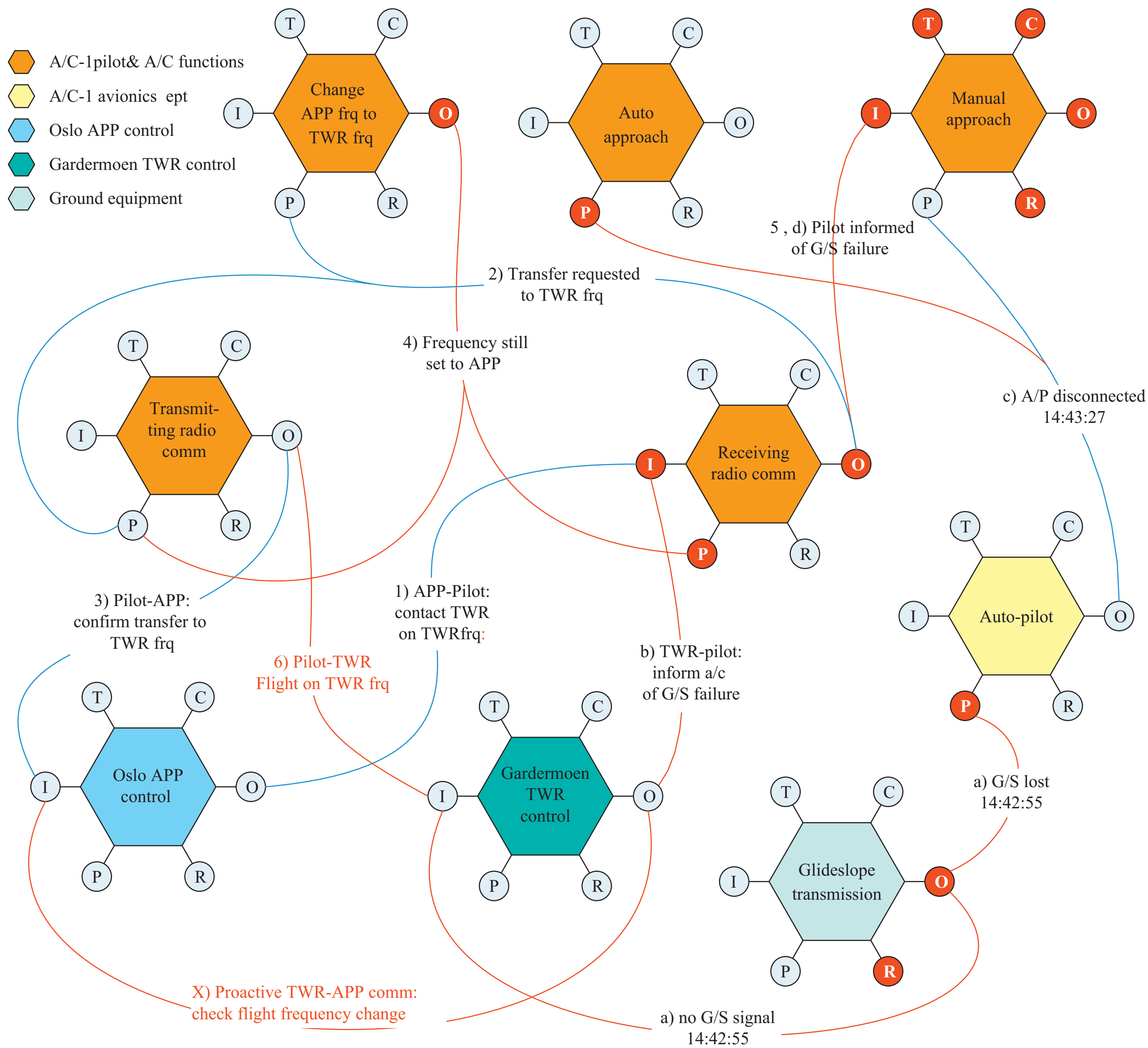

Fig. 3. A FRAM instantiation during time interval 14:42:37–14:43:27 with incident data.

in a normal socio-technical environment. Through asking questions based on the common performance conditions and linking functions in instantiations, FRAM identified additional factors and the context of why performance varied becomes apparent: For example, the operational limits for runway change for different operators were discussed; the question of why the frequency change was delayed gets answered based on the normal variability in pilot-first-officer-interaction patterns in cases of experience difference; the pilots' unawareness of the low altitude is understandable with regard to variability related to e.g. team collaboration and human–machine interface issues.

STEP provides a "mental motion picture" [6] illustrating sequences of events and interactions between processes, indicating *what* happened *when*. FRAM instead sketches a 'functional slide show' with its illustrations of functions, aspects, and emerging links between them in instances, indicating the *what* and *when*, and common performance conditions, variability, and functional resonance, indicating *why*. FRAM's qualitative descriptions of variability provide more gradations in the description of functions than the bimodal (success/failure) descriptions typical for STEP.

In relation to the question of when each method should be used, the type of incident and system to be analysed needs to be taken into account. STEP is suited to describe tractable systems, where it is possible to completely describe the system, the principles of functioning are known and there is sufficient knowledge of key parameters. FRAM is better suited for describing tightly coupled, intractable systems [15], of which the system described in this paper is an example. Because FRAM does not focus only on weaknesses but also on normal performance variability, this provides a more thorough understanding of the incident in relation to how work is normally performed. Therefore, FRAM may lead to a more accurate assessment of the impact of recommendations and the identification of factors left unexplored with STEP that may have a safety impact in the future. While the chain of events is suited for component failures or when one or more components failed, they are less adequate to satisfactorily explain system accidents [4]. This can be seen in the STEP–FRAM comparison here. The STEP diagram focuses on events and does not describe the systems aspects: the understanding of underlying systemic factors affecting performance is left to experts' interpretation. FRAM enables analysts to model these systemic factors explicitly.

9. Conclusions and practical implications

This paper presented two accident analysis methods: the multi-sequential STEP and systemic FRAM. The question of how to apply these methods was addressed by discussing the steps of the methods, illustrated by applying these methods to a missed approach incident. This paper concluded that FRAM provides a different explanation about how events are a result of normal variability and functional resonance, compared to STEP. The main finding is that STEP helps to illustrate what happened, whereas FRAM covers what happened and also illustrates the dynamic interactions within the socio-technical system and lets the analyst understand the how and why by describing non-linear dependencies, performance conditions and variability, and their resonance across functions. Another important finding is that it was possible to identify additional factors with FRAM. STEP interpretation and analysis depend extensively on investigator experience, FRAM guides the analyst more into asking questions for systemic factors and enables the explicit identification of relevant aspects of the accident based on day-to-day operational data. The example also illustrates how unwanted variability is propagated such as the information about G/S failure and the undesired resonance with the differences in pilots' experience. However, several incidents in different contexts would need to be analysed to validate and generalize these findings.

The variability of normal performance which most of the time is unproblematic and actually necessary for the underspecified system to work in practise, may suddenly and unexpectedly resonate with variability in other functions and escalate to a dangerous level. A theoretical implication is that FRAM modelling may violate the binary or sequential logic of other accident models. STEP is based on the description of the accident as a process where a failure for each of the components is described, and the occurrence of a system failure is determined by the state of the components. FRAM qualitative descriptions of variability provide more states in the descriptions of the functions than the bimodal (success/failure) descriptions typical for STEP. FRAM is one of the first methods that moves away from linear cause and effect models of thinking about safety providing a functional systemic approach.

Three practical implications are found. The first is that FRAM provides new ways of understanding failures and successes, which encourages investigators to look beyond the specifics of the time sequence and failure under analysis, moving the analysis into the conditions of normal work. The second is that FRAM models and analyses an intractable socio-technical system within a specific context. Third, since STEP and FRAM are based on different understandings of the nature of accidents, their combined application during accident analysis provides complementary perspectives and may contribute to a more comprehensive understanding of and more effective learning from an incident or accident.

While FRAM as a model has been accepted in the majority of discussions with practitioners in this study, and seems to fill a need for understanding intractable systems, FRAM as a method is still young and needs further development. This article contributes to the development of the method by outlining a way to illustrate instantiations of models for limited time intervals. Moreover, this article indicates the potential of and need for strategies to actively combine methods for incident/accident analysis as part of the analyst's toolbox in order to enable understanding, learning, and prevention. An additional need is the identification of normal/abnormal and desired/undesired variability which this paper has addressed briefly. Remaining challenges include a more structured approach to generating recommendations in terms of barriers, indicators, and redesign of functions, as well as evaluating how well FRAM is suited as a method to collect and organize data during early stages of accident investigation.

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