Airline Disruption Management: A Naturalistic Decision-Making Perspective in an Operational Control Centre

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Operations Control Centres (OCCs) are critical structures used by airlines to oversee the execution of all planned flights, managing punctuality, regularity and customer support. In this study, we investigated the decision-making during flight disruptions inside an OCC from the naturalistic decision-making perspective. We conducted a mini-ethnography case study in a major South American airline, focussing on how functions critical to the flight disruption management cope with variability. Data collection included document analyses, field notes, direct observations and interviews. The functional description of work-as-done revealed how the OCC constantly and actively looks for signs of disruption while monitoring the normal operation and rebalancing resources. The decision-making process is distributed and decentralised across multiple functions, where experts from each function rely on a repertoire of strategies to deploy innovative solutions to dynamic scenarios. Five different mechanisms were identified that converge functions to disarm potential disruptions before they compromise the flight network, and continuously create and reinforce system buffers.

Keywords
airline management, disruption management, FRAM, operation control centre, naturalistic decision-making

INTRODUCTION

Unattended flight disruptions can halt airline operations, creating chaos for passengers and elevated costs for the companies. Airlines use Operations Control Centres (OCCs) as specialised structures to manage and contain unexpected disruptions, to deal with variability in real time and to maintain the continuity of the flight networks (Bouarfa et al., 2018). These Centres employ a range of specialised decision makers to ensure high punctuality, regularity, customer expectations and safety levels while optimising the resources available. Central to this process is the operations controller, who coordinates and converges the decision making inside OCCs (Bruce, 2016; Nicolas et al., 1998). The nature of the operations controllers' work requires the development of solutions that usually have a limited effectiveness window to be implemented and may conflict with other goals (Castro & Oliveira, 2008; Woods & Branlat, 2010).

Flight disruptions can either cause almost negligible consequences or they can escalate very quickly, propagating across the flight network and impairing the airline's ability to operate scheduled flights on time and to maintain the continuity of operations (Kohl et al., 2007; Richters et al., 2016). Airlines operate in a dynamic and competitive environment, with narrow financial margins and reduced slack, balancing efficiency and the ability to recover from disruptions (Abdelghany et al., 2004; Castro & Oliveira, 2008). Factors such as adverse weather conditions, unplanned aircraft maintenance, crewing issues, air traffic control

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flow and congestion (Abdelghany et al., 2004; Bruce, 2016; Kohl et al., 2007) can delay, cancel or divert one or multiples flights. These resonate throughout the flight network, causing further cancelations due to the limited number of resources such as replacement aircraft, crews and other options to accommodate passengers (Clarke, 1998; Weide et al., 2010). Other than maintaining available resources flowing and being continuously available, maintaining high levels of punctuality and regularity are critical metrics for bidding for new viable routes and sustaining profitable ones (Kohl et al., 2007).

Many studies have advanced the understanding of the decision-making processes inside OCCs as naturalistic (Gore et al., 2015; Klein, 2008, 2015) rather than rational and are mainly based on the expertise of Operations Controllers, especially when troubleshooting flight disruptions (Bruce, 2011; Bruce & Gray, 2004, 2019; Feigh & Pritchett, 2007; Igbo, 2013; Richters et al., 2016). Some of these studies observe that these controllers rely heavily on their background experience and contextual situations, using scenarios experienced in previous disruptions and negotiating the rules to implement complex strategies rapidly. Despite the contributions, these studies are limited to Operations Controllers only, as these are formally responsible for integrating decisions within OCCs.

There is anecdotal evidence (Feigh & Pritchett, 2010; Igbo, 2013; Kohl et al., 2007) suggesting the decision-making process in the OCCs during flight disruptions may actually be distributed and take place before disruptions occur, as a continuous process of searching for and disarming potential problems before they can cause delays or greater issues. This process may continue even after the disruption has been managed, as a way to reduce the likelihood of future problems. However, the mechanisms that enable the decision-making to be distributed and to take place before, during and after a disruption remain unknown.

This study investigated the decision-making process during flight disruptions inside an OCC from the naturalistic decision-making perspective. In particular, we aimed to understand the mechanism that enables the OCC to anticipate and cope with a flight disruption and address post disruption consequences through the functional description of work-as-done. To achieve the objective, this study conducted a mini-ethnography case study inside a major Brazilian airline's OCC. We used the Functional Resonance Analysis Method (FRAM) to map the functions critical to flight disruption management and the everyday variability, and the Recognition-Primed Decision (RPD) model to analyse the decision-making process that occurs inside each function and how individuals cope with the variability. We expect the findings reported in this study can contribute to further comprehension on how the decision making occurs in the OCC. Also, the findings here can inform the design of the next generation of OCCs, decision-support systems and the training of different actors involved in airline operations.

THE OCC AND THE FLIGHT DISRUPTION MANAGEMENT

There are basically three main models of Airline OCCs (Castro & Oliveira, 2008; Jimenez Serrano & Kazda, 2017). The traditional one (used by most airlines and modelled in this study), is composed of functional specialised groups responsible for each of the main elements which are important in the execution of each day of operations, such as flight dispatch, maintenance control and response, crew schedule/tracking, customer service and communication with air traffic control. These are normally centred around one or more Operation Controllers, who act as central decision-makers that rely on other functional groups to converge on complex solutions that are then implemented in the flight network (Clarke, 1998; Kohl et al., 2007; Ball, et al., 2007; Bruce, 2016). The second model, implemented by China Eastern and Air France, has a two-level structure. In addition to the OCC, these companies have a Hub Control Centre, which manages more local disruptions to hub airports. The third model, mostly used by American Airlines and Qatar Airways, is the Integrated Operations Centre that encompasses the functions which are normally part of the OCC in addition to catering, ground handlers, maintenance, social media, data analysis, revenue management and others (Jimenez Serrano & Kazda, 2017).

Managing and adjusting for unplanned and unexpected events is the main objective of an Operational Control Centre, as well as exchanging information and coordinating with organisations responsible for managing the air traffic flow and reporting metrics (Clarke, 1998; Bratu & Barnhart, 2006; Machado, 2010; Jimenez Serrano & Kazda, 2017; For a deep understanding of how flight dispatchers interact with air traffic control systems, see Smith et al., 2007). These processes are continuous and even though much effort is put into flight network planning, disruptions are part of the normal operation: there is a constant need to reconcile elements that cannot be completely controlled, such as weather, airport constraints (congestion, runway closure), flight delays, unscheduled aircraft maintenance, crew and industrial action, which add complexity to the operation of passenger and cargo flights (Filar et al., 2001; Ball et al., 2007; Mota et al., 2009).

Flight disruptions are defined as situations that negatively impact a scheduled flight, such as cancellations, delays of over two hours, or even aircraft type change or unavailability, within two days of the original departure time. Additionally, a flight disruption impacts on the operation of the airline over the rest of the day, or following days (Clarke, 1998; Jimenez Serrano & Kazda, 2017). Therefore, the process of monitoring the flight network for such events and rearranging resources to disarm or mitigate them is called disruption management (Kohl et al., 2007). Timing is also an important variable for the magnitude of the disruptions. As argued by Clarke (1998), delays early in the day may cause a cascade of delays and disruptions, impacting the whole network if not stopped in time. Consequently, understanding these events in terms of time, predictability, duration and impact is important for the disruption management process (Jimenez Serrano & Kazda, 2017).

According to Rosenberger et al. (2003), most flight disruption management processes are dealt with as soon as they are detected by the OCC, which immediately intervenes to avoid escalation as much as possible. This process is heavily influenced by the decision makers, especially in the figure of operational controllers who are tasked to integrate available information, empirically qualifying the disruption in terms of resolution time, increased costs (such as fuel burn and hotel or meal expenses for passengers), passengers affected and delay propagation through the network. Once the passengers are cared for and the element that initially caused the disruption is removed (or mitigated), the OCC can start a recovery phase, in which the impact on other flights is adjusted in the schedule, seeking a return to regular operations.

Disruption response itself depends on the airline's network structure, whether it is point-to-point, hub-and-spoke or a mix, the slack between flights, the resources and the recovery strategies available. Once identified, containing the disruption locally by employing mainly resources directly related to the event within a suitable timeframe is normally a first option, as suggested by Kohl et al. (2007). As scenarios evolve, different recovery strategies begin to unfold, focussing on aircraft recovery (flight leg cancellation or delay, aircraft re-routing; Rosenberger et al., 2003); crew recovery (deadheading, reserve crew or reassigning); and passenger recovery (protecting the passengers not directly affected and reassigning those disrupted to alternative itineraries), whether commencing and terminating at the same or nearby location (Ball et al., 2007).

These recovery strategies must satisfy many contextual constraints, including legal ones. Any change to an aircraft schedule must meet the maintenance requirements, airport curfews and slot restrictions; and position the aircraft to resume the operations as planned. Crew scheduling must respect the union agreements (sometimes the company must pay the higher between the planned and alternate schedules), work rule regulations (maximum crew work time, maximum rest time, etc.) and, more recently fatigue management systems in some cases (Jimenez Serrano & Kazda, 2017). Lastly, in some countries, passengers not disrupted cannot be displaced to accommodate disrupted passengers and any change in the itinerary must comply with the local consumer legislation, which commonly require the company to provide meal, accommodations and other modes of transportation in case of long delays (Ball et al., 2007; Jimenez Serrano & Kazda, 2017).

Decision Making Inside the OCC: A Naturalistic Perspective

The need to work with dynamic resources, unstructured problems, sometimes creating novel solutions and rearrangements in a tight timeframe while keeping the continuity of flight network operations, makes airline disruption management something that cannot be performed simply and blindly following written procedures or through a rigid structured process. Rather, good solutions rely heavily on the expertise of a human decision maker. Given these characteristics, Kohl et al. (2007) state that 'there is little reason to believe disruption management can in the foreseeable future be automated to the same extent as crew and fleet scheduling'. Moreover, 'humans must be involved in the actual decision-making and determination of when decisions must be taken' (p. 153).

In a broad perspective, Kohl et al. (2007) describe OCC's disruption management as an ongoing process, rather than finite, which looks for ways to avoid the disruptions instead of waiting to act. By continuously looking for discrepancies between planned and the actual events or potential threats, in real time cues are evaluated to decide if an intervention is required or not. Some minor delays or variability do not prompt any change unless greater inconvenience for passengers or impact is expected to follow somewhere else in the network. If the OCC does act, some actions are very limited to local problems, such as replacing a no-show crew or a faulty aircraft. A major intervention is only required when it may not be possible to do anything about a disruption in time or if something passes through undetected. Rather than a sequence of steps, the OCC evaluates the problem and the actions in an interwoven way because the objectives and context keep changing. This is done from different angles, including passenger, crew and aircraft, legal and economical perspectives, until a final solution satisfies all perspectives. Even after reaching a solution, the implementation may be postponed, reserved for a specific window of opportunity, or to avoid losing momentum.

Generating novel solutions for complex problems in real time and under pressure by a team of experts in specific areas is what makes the study of an OCC an excellent case for Naturalistic Decision Making (Klein, 1999) approaches. The Recognition Primed Decision Model (RPD; Klein, 2008; Klein et al., 2010) offers a useful description on how experts make sense of the world and make decisions during challenging and unstructured real-world scenarios (Klein, 1993; Klein et al., 2010; Klein & Moon, 2006). The model states that experts use repertories built from previous experiences to deal with problems, set expectations, define priorities and objectives, and develop a reasonable course of action. The use of elements from the repertory tailored from both good and bad past decisions and experience are the main reason why experts can quickly respond to complex problems while novices struggle (Gore et al., 2015; Harteis & Billett, 2013; Kahneman & Klein, 2009; Klein, 2015; Newell & Shanks, 2014).

The RPD model is comprised of the following categories (Klein, 1999, 2008; Figure 1):

- *Indications* are the signals or elements that define a particular case or situation. These indications allow the decision maker to associate the present context to a pattern experienced in the past, determining the other relevant aspects that should be present.
- *Objectives* are plausible goals that may be achieved in the identified scenario but constantly revised as new information becomes available.
- *Expectancies* are predictions of how events will turn out or how a scenario is supposed to evolve. It works as a gate to a continuous feedback loop and keeps the other five aspects of the model in constant check for possible misinterpretation or false positive.
- *Relevant cues* are related to the capacity of the decision-maker to separate important cues from noise, since not all signs available in the context are relevant or important.
- *Actions* that should be taken and the priority in which they should occur to propose a solution.
- *Mental simulation of Action* takes place before implementing the action to assess its effectiveness.

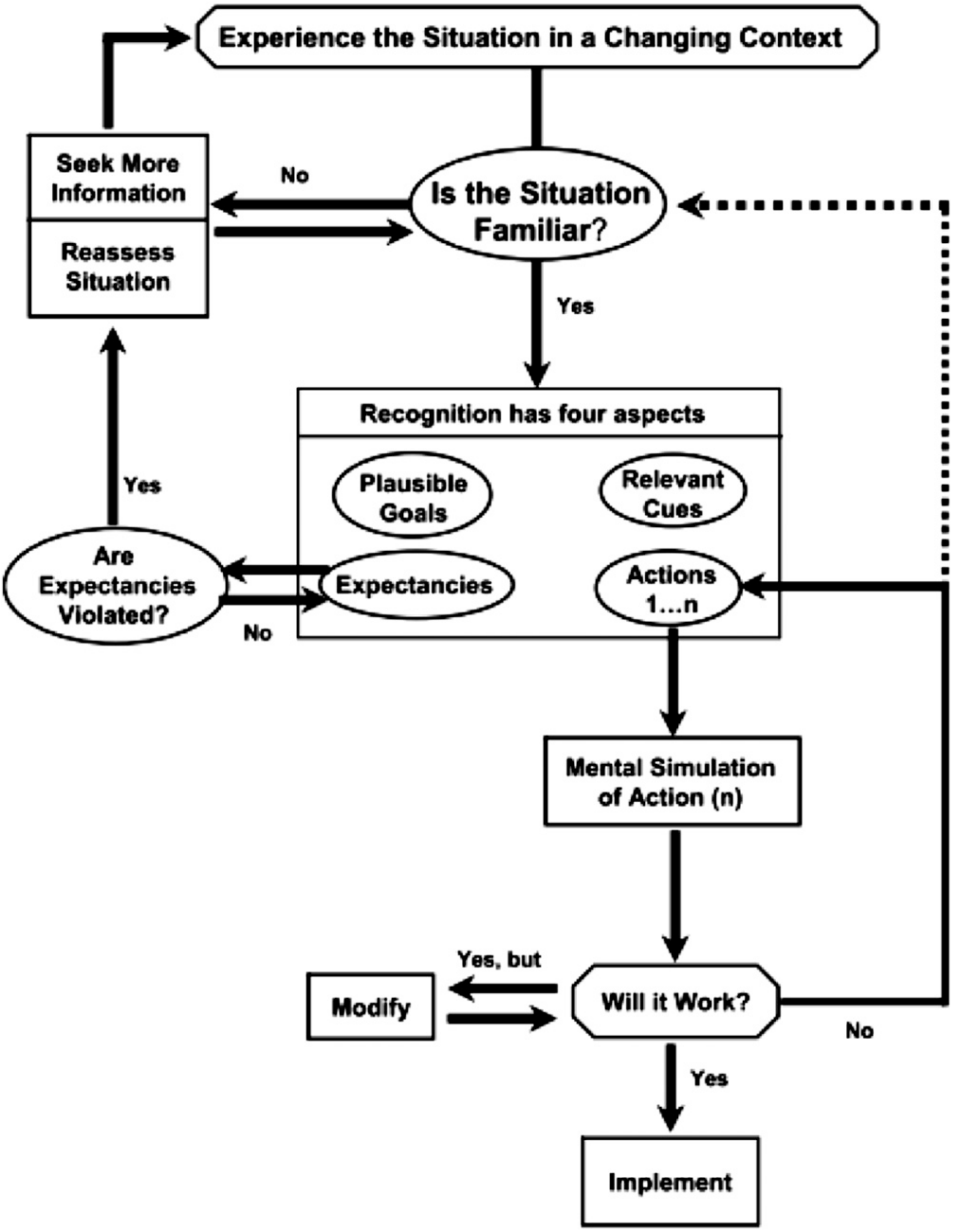

Figure 1. (ref. page 7) – Recognition primed decision model. Source: Klein (2008, p. 459).

When applied to the OCC, the naturalistic decision-making framework reveals nuances of the decision-making of airline operations controllers often overlooked by rationalist studies. One such example is the repertory bias. In a series of experiments conducted by Bruce (2011) and Bruce and Gray (2004, 2019), they found that operational controllers might favour solutions that relate to their backgrounds in the first instance when troubleshooting flight disruptions. Controllers that used to work in crew-related functions, for example, tend to start the flight disruption management by crew relocation rather than other factors because of their familiarity with the area, resources and strategies commonly used.

Another good example is provided by Richters et al. (2016) who identified that despite being presented with novel situations in a simulated environment, operational controllers sometimes segmented the problem into smaller disruptions where they could make use of smaller familiar situations. By starting from familiar small disruptions, they were able to better use their expertise to save time and make rapid and better decisions.

Lastly, other situations highlight how operational controllers need to develop solutions dynamically, manage resource and time, and make sacrificial decisions when severe disruptions happen (Feigh & Pritchett, 2007, 2010). Furthermore, Igbo (2013) explains that the demand scope and severity of a disruption influence the operations controllers' perception of the rules, renegotiating them as they face local contingences and avoid further consequences along the network.

IDENTIFYING FUNCTIONS AND VARIABILITY IN NATURAL SETTINGS

The Functional Resonance Analysis Method (FRAM) is a method used to capture the variability of everyday work and depict how a socio-technical system works in practice (Hollnagel, 2012). It produces a graphical representation of the interactions and couplings between functions inside a socio-technical system, the performance variability that exists in the system, and how they may resonate and lead to loss of control or unwanted outcomes (Hollnagel, 2018; Hollnagel & Goteman, 2004).

Originally conceived as an accident model (Hollnagel & Goteman, 2004), many of the early uses of FRAM were in retrospective accident analyses (Patriarca et al., 2020), as a way to understand how actions resonated and tipped otherwise safe systems towards failure (Woltjer & Hollnagel, 2008; Herrera & Woltjer, 2010; De Carvalho, 2011). More recent works expanded the methodology and have used it prospectively for a suite of applications, including the analysis of coupling, interdependency, variability, adaptability, understanding the difference between work-as-imagined and work-as-done, for risk and resilience management, improving training and redesign processes and procedures, to name a few (Patriarca & Bergström, 2017; Saurin & Patriarca, 2020; Patriarca et al., 2020). The method can also be used for system design or redesign (Hollnagel, 2012).

The FRAM is based on four principles about how complex socio-technical systems work (Cabrera et al., 2014; Herrera & Woltjer, 2010; Hollnagel et al., 2011; Hollnagel & Goteman, 2004; Nemeth & Hollnagel, 2014; Praetorius et al., 2015). The first is acknowledging that success and failures are the result of the same processes. The second is that performance variability is part of normal work since individuals, groups and the organisation constantly adjust their performance to meet the conditions not previously considered in the original design. Thirdly, the variability itself is not enough to lead to a bad or good outcome. However, the performance variability in different parts of the system can combine in unexpected and unanticipated ways, leading to a much larger outcome. Therefore, it is recognised that failure and success, and normal work, are emergent properties that cannot be traced back to a single variability or a performance of a single function. Lastly, the principle of functional resonance proposes that the increased performance variability may spread to other functions because of tight couplings and dependencies between functions.

As opposed to a structural description of the organisation or a sequence of events, the FRAM involves identifying functions concerning a specific objective. A function represents an act task or activity required to produce a certain result, but not necessarily how. It can be performed by a person, organisation or technology (with or without human input). For this reason, a function is normally described as a verb or verb phrase (Hollnagel, 2018). Each function is then defined according to six aspects (input, time, control, precondition, resources and output; Figure 2) generally represented by the vertices of a hexagon, which are interrelated to other functions elsewhere (Hollnagel, 2012).

As a method, the FRAM is organised around four steps (Hollnagel, 2018). The first one aims

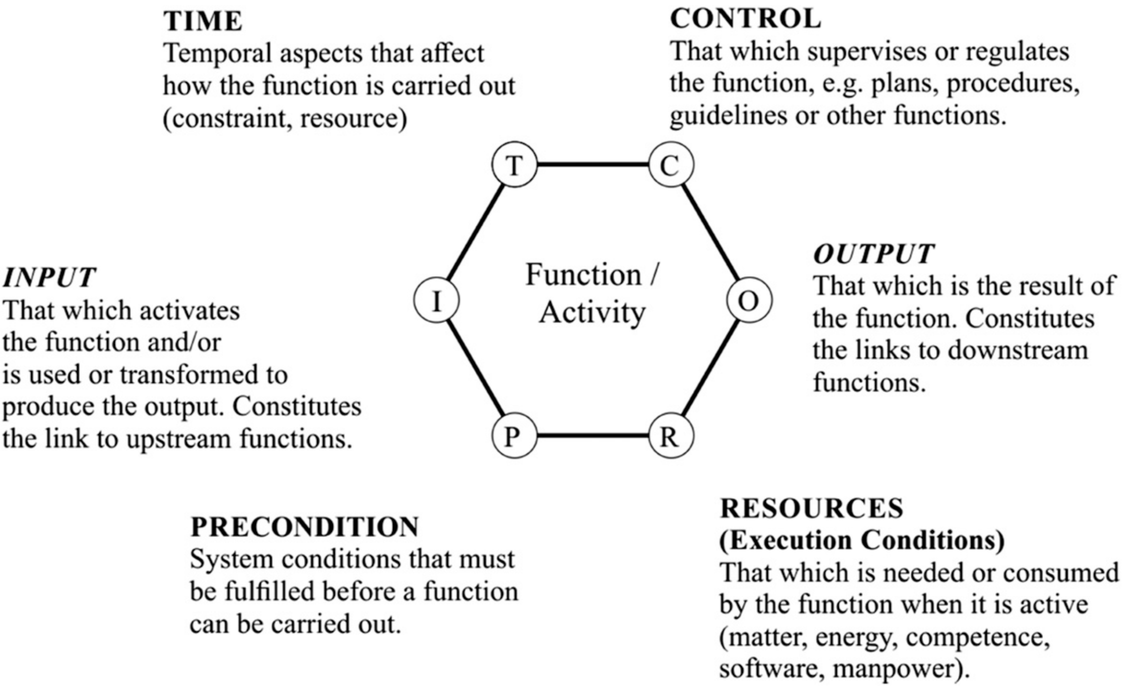

Figure 2. (ref. page 9) – FRAM Aspects for modelling. Source: adapted from Hollnagel et al. (2014).

to identify and describe the important functions critical to the system under analysis, without having any particular situation in mind. These functions are then characterised and connected to other functions through the six aspects (hexagon), with at least one input and one output. As a rule, the output from one function goes to other functions revealing couplings between them. Depending on the nature of the coupling, such as the output of one function being the resource of another function, it may be possible to highlight tight or loose couplings (Hollnagel, 2012). Once the functional model of the system has been completed, the model is then applied to generate instantiations. An instantiation represents a subset of actual couplings and dependencies given a particular condition, situation or scenario (Hollnagel et al., 2014).

The second step includes the identification and characterisation of the variability for each function (Patriarca & Bergström, 2017). Variability, whether potential or actual, is defined as the different possible states a function outcome can take, and hence, influence other functions. This can be of a different nature (endogenous or exogenous) and take different forms depending on the couplings between two functions. For example, if the output of one function is the time of another, the output can vary and deliver too early, on time, too late, or not deliver at all.

The third step involves aggregating the variability and looking for functional resonance. This step involves analysing how the variability across different functions may interact and resonate with each other, particularly where couplings and dependencies exist. The analysis brings insight to both the negative or positive effects of variability on the stability and functioning of the system (Herrera & Woltjer, 2010).

According to Hollnagel (2012), understanding why the variability exists, how it propagates and the impact on the functions help the organisation provide better resources for frontline operators, increasing the system resilience and response capability (Hollnagel et al., 2014). Therefore, the last step aims to manage the variability, either by damping, amplifying or just monitoring. The reason is that variability will always be present, and it may not be possible to be eliminated, especially when it exerts positive influence on the system (Hollnagel & Goteman, 2004).

METHOD

Mini-Ethnography Case Study

A mini-ethnography (Fusch et al., 2017; Yin, 2009) case study was conducted in this research. As suggested by Storesund and McMurray (2009), this type of blended design allows researchers to explore the nuances of the activity over weeks or months, instead of years as in traditional ethnographies. At the same time, this method establishes boundaries around the objective of research in time and space. This is possible because mini ethnographies are more focused on small social groups within well-defined boundaries. The methodology uses data collection techniques from both ethnography and case study, resulting in a comprehensive understanding of a complex phenomenon that may inform future interventions.

The research was conducted in the OCC of a major airline in South America. At the time of the data collection, the company operated around 900 flights a day to 130 destinations, using a fleet of just over 100 aircraft ranging from small turboprops to widebody jets, operating on regional, domestic and international routes. The OCC is located close to the airline's main hub, works continuously throughout the year, and is covered by fours shifts. At the time of this study, around 100 people were working in 13 different specialities. The centre also employs a diverse set of information technology systems to monitor the operation, ranging from a dedicated radio/VoIP, station which allows communication between the aircraft and remote bases, to software used in planning and managing maintenance, crew scheduling and pairings of aircraft and routes.

Rather than focussing on airline operations controllers or managers, as past studies have done, we focused our study on flight disruption management and not on structures or roles. Hence, we collected data from all available areas, roles and a diverse set of events involved with or impacted by flight disruptions. Knowing more closely what the OCC does in general helped to understand how different areas contribute to disruption management.

Data Collection

Our study included direct observation, field notes, interviews and document analysis. The direct observations occurred during four visits to the OCC, with a duration of five days each. The first and third authors took turns on consecutive shifts, covering both day and night to observe the full cycle of operation and disruption management. During the first two visits, the arrangement of different workspaces, the interaction and information flow in different areas, the pressures and negotiations involved in the activity helped to identify key decision makers in each area of expertise. The main objective was to understand normal operations inside the OCC and what each area was responsible for in general, not only during flight disruptions. In these two visits, but especially during the second, each workstation received a dedicated interaction, observing the contribution of each area to the management flight disruptions for at least one work shift. The third and fourth visits were dedicated to the mapping of integrated actions of the OCC towards disruption management. In total, over 240 hours were invested in direct field observations.

The researchers were granted access to manuals and documentation that regulate the activity of the OCC, among these, some deserve special mention, such as the coordination manual that contains the Centre's organogram and role description. This document also contains basic training content for new employees and was very useful as a starting point. The airport manual also provided the description of activities and processes carried out by the company's personnel at the airport, and policies for flight delays and cancellations. Alongside these manuals, 44 bulletins and 20 safety alerts were active during the time of the research and covered instructions, changes to procedures and activities performed by, or that impacted, the OCC. The document analysis provided a big picture of how managers and supervisors expect the work to be done and how these guidelines impact each area.

Table 1. (ref. page 12): Summary of the Participants in the CDM Interview.

Interviewee	Time in Airline (Years)	Experience Working in Airline OCCs (Years – Includes previous jobs)	Interview time (min)
E1	5	15	32
E2	3.5	6	40
E3	2	6	27
E4	0.75	7.5	24
E5	3.5	6.5	42
E6	5	12	29
E7	3	6	58
E8	3.5	19	28
AVG	3.3	9.8	35

The study conducted three types of interviews: informal, semi-structured and in-depth: all but the informal were recorded and later transcribed. The informal interviews were conducted spontaneously mainly during the first two visits to the OCC whenever the researchers had the opportunity to enquire about the employees' activity. These included 26 staff members from the OCC and safety department who provided an overview of the nature of the work in an OCC.

During the first and second visits, 18 semi-structured interviews with 17 OCC managers and employees and the safety department managers. The interviews averaged about 29 minutes each and focused on activities necessary to manage flight disruptions and how the participants balance production and protection goals.

Eight in-depth interviews were then conducted with eight highly experienced managers and specialists of the OCC about the most challenging flight disruption scenarios that they have faced in their careers (Table 1). We selected at least one representative from each area in the OCC aiming to cover as many different perspectives as possible during the decision-making. The interviews were structured based on the Critical Decision Method and followed four steps, as recommended by Klein et al. (1989) and Crandall et al. (2006): (i) selecting the incident together with the interviewee; (ii) building a timeline; (iii) deepening the event description; and (iv) exploring the event through 'what if' questions. Individually, these interviews revealed that the decision-making process occurred in specific events from the individual perspective. Collectively, the interviews provided insights on how different areas of the OCC cope with or avoid flight disruption, and the similarities and differences of the strategies employed.

Data Analysis

This study used the first five phases of the thematic analysis method proposed by Braun and Clark (2006): familiarisation with the data collected; coding; merging the codes into potential themes; refinement and explaining the themes. Applied to this study, the data collected from the document analysis, direct observation, field notes, informal, semi-structured and in-depth interviews were initially freely coded using the MAXQDA software.

The codes were then linked to pre-defined themes derived from the FRAM method (Hollnagel, 2012) and RPD model (Crandall & Getchell-Reiter, 1993; Klein et al., 1989). We were particularly interested in actions, activities, or tasks performed by different parts of the OCC that could represent a function. We then sought to identify codes that represented couplings between functions and characterised them according to the six aspects and their degree of dependency. Next, we reviewed the codes that could indicate endogenous as well as exogenous variability during specific events. Lastly, we merged codes that represented strategies carried out by the individuals and group of individuals given certain conditions. These strategies were then characterised according to the elements of the RPD model: Indications, objective, expectancies, relevant cues, actions and mental simulation of action.

Following the three out of four steps of the FRAM, we were able to first to build the functional description of work-as-done by the OCC in general, without focussing on any flight disruption. To this end, we mostly used the themes to construct a graphical representation of the key functions and their couplings using the FRAM Model Visualiser (FMV). The final assembly was done using Corel Draw to add colour coding and more detail. Once the functional description was complete, it was presented individually to eight of the CCO's operational managers and specialists for accuracy check, validation and adjustments which were implemented.

Based on the initial functional representation of the OCC, and still following the first step of the FRAM, we also used the FMV and Corel Draw to build instantiations of five prototypical flight disruptions identified during the study. For each instantiation, we identified and described the individual and aggregated variability during each prototypical event, according to the second and third steps of the method. We were able to reveal how the output of some functions varied during a particular event and how the initial variability spread across the OCC and the company, both functionally, geographically and in time. The result was presented to the OCC and safety department managers for validation.

Rather than proposing recommendations for the organisation to manage the variability, step four was replaced by the analysis of how different individuals in the OCC cope with the variability using the RPD model. The aim was to understand how people manage variability in their natural setting, which is not clear only through a FRAM instantiation. We used the RPD to demonstrate what happens inside a function, revealing how it processes the five aspects and produces the outcome (Figure 3 brings an example of the analysis using the RPD). We identified the knowledge used to assess the event described, the objectives established or changed during the event, the expectations created during the problem-solving process and the course of action used to avoid or resolve the problem. As a result, we identified a decision inventory of the most common strategies and solutions employed by different actors of the OCC to manage the variability and the flight disruption (Crandall & Getchell-Reiter, 1993; Klein et al., 1989). The company representatives validated the description of the decision-making process and the decision inventory.

FUNCTIONAL REPRESENTATION OF AN OCC: WORK-AS-DONE DURING FLIGHT DISRUPTIONS

Mapping the OCC work revealed 17 critical functions that compose the core of flight disruptions detection, avoidance and mitigation. These were grouped into seven categories according to their nature: Flight Dispatch, Maintenance-related, Crew-related, Client Support, Operations Controller, External Functions and Supervision. Figure 4 provides the graphical representation of these functions and couplings.

Flight Dispatch Function

Flight dispatchers, main elements of the yellow function in Figure 4, provide the OCC with flight data for aircraft performance and loading, enroute weather, airspace restrictions and airport conditions required for every flight. Airworthiness is also important for this function since some aircraft may legally operate with some systems or components inoperative for a limited time frame. This is regulated by the aircraft manufacturer through a document known as Minimum Equipment List (MEL). Some of these conditions impact the aircraft performance or capabilities, which may hinder the capacity to operate in some airports and routes.

Once complete, these plans and calculations are fed into a system, making it available online to all hubs and spokes of the airline flight network. Most of the information is automatically gathered by the systems, which also perform some of the calculations autonomously. The variability involved is sufficiently small to allow each technician to dispatch 5–6 flights per hour, but it is still relevant enough as to require human

Assessment 1 (*start*)

Indications: Aircraft with landing gear malfunction indication during regular flight; Needs to land soon, fuel is being burned. Checklists and procedures onboard failed to solve the issue. Hubs and other main airports with good infrastructure available

Expectancies: Good infrastructure to compensate for probable landing gear collapse with belly landing with further complications (fire and injured people); Accident on Main Hub or other main airport will compromise landings and departure, affecting other flights; Media exposition may rapidly escalate.

Objectives: find airport with infrastructure to aid the aircraft, but away from main nodes of flight network; company personnel must be available to tend to passengers and crew; assess malfunction details (flight dispatch and Maintenance functions).

Actions: Airport with heavy maintenance base selected, away from main nodes and hub, but within 2 hrs round trip; experienced personnel available. Additional teams dispatched (maintenance, clients and management) to oversee operation from site.

Assessment 2 (*development*)

Indications: Aircraft already overhead selected destination airport, holding; Maintenance analysis suggests false alarm: aircraft may land safely despite malfunction indications still present in cockpit).

Expectancies: favourable report does not rule out possibility of a real accident; possibility of panic on board; support teams must be available.

Objectives: advise pilots; make additional structure and teams available in case of emergency. Use up as much fuel as possible in the air to avoid fires in case of emergency.

Actions: activate and brief destination airport emergency response teams with available info; Standby for the arrival of company teams that were dispatched.

Assessment 3 (*conclusion*)

Indications: Aircraft managed to land safely. Malfunction was indeed an indication error. No passenger is reported harmed.

Expectancies: Clients need to be tended to (client support); Aircraft needs to be serviced (maintenance functions).

Objectives: Get clients to a Hub on flights to their destinations; Find available Crew (crew schedule) and Aircraft (maintenance scheduling) for new flight and extract crew involved in accident for rest and debriefing (crew logistics)

Actions: Client support overseeing bus transport for clients to main hub (already available). Get clearance from Airport admin to ferry passengers directly to boarding second aircraft **(airport front-line office)**; select experienced crew to receive passengers on second aircraft **(crew schedule)**.

Figure 3. (ref. page 14) Situation assessment record: example of troubleshooting done by the OCC according to the Recognition Primed Decision Model (RPD-elicited from Operations Controllers).

operators to accommodate for specific combinations of factors, such as MEL items effect over special use airspace or specific airports. The need to reconcile different limitations and adapt to dynamic conditions requires human expertise to oversee, making human decision makers important to achieve optimised and safe results.

The *Dispatchers Supervision* is responsible for in depth analysis of meteorological conditions to anticipate potential limitations of the aircraft model to be used on certain routes. One such example from our observations involved the creation of an alternate route for an aircraft that needed to be dispatched with limited capability to deal with icing conditions. Despite being legal to fly with the anti-ice system inoperative, the flight had to be rerouted through regions that have no icing phenomena forecasted or conducted at different (lower) flight levels (which also impact fuel consumption).

Maintenance-Related Functions

Presented in green in the model, these are responsible for the fleet airworthiness, working to minimise downtimes of unforeseen events

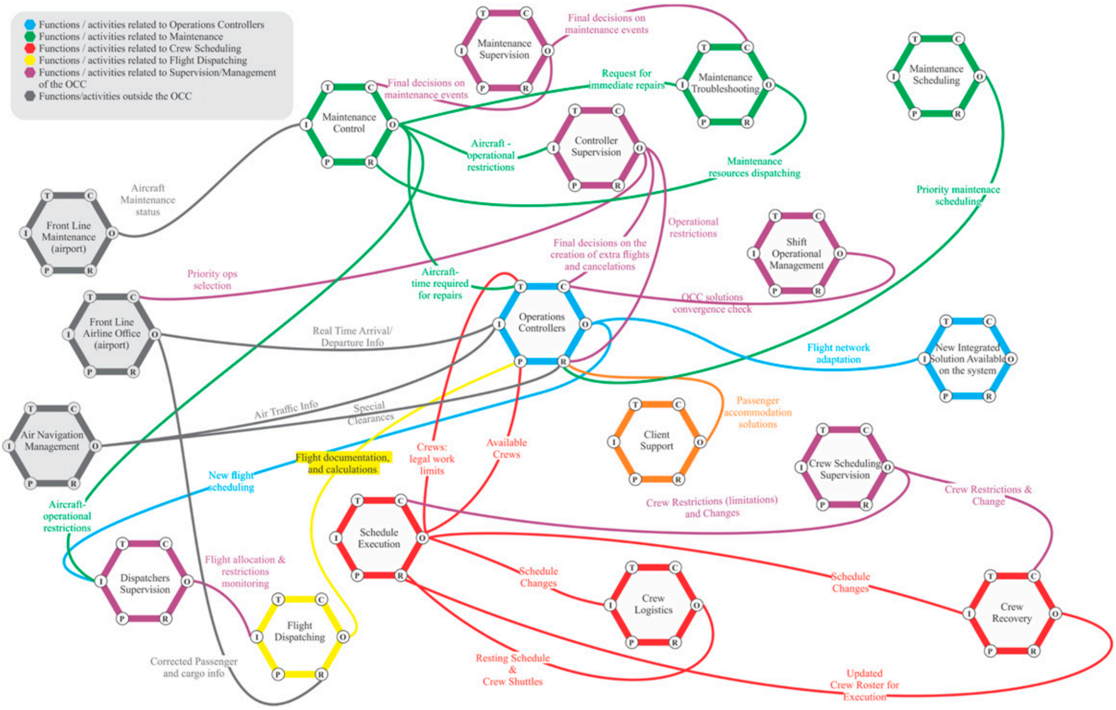

Figure 4. (ref. page 15) – FRAM modelling of the OCC during flight disruptions.

and making sure available time is spent in efficient ways: programming scheduled and non-scheduled repairs in a way that maximises fleet availability. Airline maintenance is well regulated and operates mainly with preventive cycles, making sure critical components are replaced before they expire (either by time or cycles of use), and especially before they can ground airplanes. Unscheduled events, such as punctured tyres, bird strikes, or even adverse equipment operation are common and should also be accommodated.

We identified five functions inside the OCC directly involved with aircraft maintenance: Maintenance Control, Troubleshooting, Maintenance Supervision, Maintenance Scheduling and Back-office. The first two are the main functions regarding technical problems with the fleet. We chose not to include the Back-office function in the model because it is not directly relevant for flight disruption management. Rather, it works by updating the system with data from the engineering department for long-term maintenance planning.

Maintenance Control receives and processes information from the maintenance technicians located in the airport and provides them with the correct maintenance procedures and technical data while helping to estimate how long these procedures will take. This information is critical to *Operations Controllers* and allows the OCC to consider different windows of opportunity regarding repairs, which are crucial for resource management as it interferes with fleet availability and the continuity of flights.

Depending on the impacts of unscheduled maintenance events, *Maintenance Control* may suggest changes to flight schedules, such as redirecting aircraft for landing at an airport with greater maintenance capability to perform repairs within an available window. If that is not the case, another function, *Maintenance Scheduling*, verifies if the selected aircraft is able to legally continue flying until the next maintenance window. Moreover, *Maintenance Control* is responsible for requesting *Maintenance Troubleshooting* for special materials and personnel to be made available for an overnight service in remote bases; and for locking an aircraft to a specific itinerary so that it ends in a maintenance capable base. If an aircraft is due for a routine engine inspection, it must be allocated to an itinerary that leads to a heavy maintenance facility that has the required parts, tools and specialists.

As mentioned above, *Maintenance Troubleshooting* ensures that the required parts, tools and personnel are where they need to be when unexpected or maintenance events take place. Whenever a scenario of unbalanced resources between bases develops, this function devises ways to efficiently relocate the resources needed. In the event of a malfunction that prevents the continuity of a flight in a location that is not capable of repairs, *Troubleshooting* is responsible for procuring materials and personnel and getting them to the affected aircraft. Options such as next company flights, flights from other carriers and even using smaller chartered planes are considered depending on the available time and the disruption impact, which is decided by *Maintenance Supervision*.

The *Maintenance Supervision* function manages data available in the system and information given by the other maintenance functions to help determine any limitations, such as the availability of maintenance teams and bases to accommodate unexpected events and rescheduling maintenance when necessary. This function is also responsible for two large screens positioned in the centre of the OCC room, providing the decision-makers a real-time general view of the fleet airworthiness levels and availability (aircraft that are currently unable to fly, those with technical restrictions, such as inoperative systems, and their operational limitations, – such as the anti-ice systems, mentioned above). The information is invaluable for decision-making as it updates awareness and expectations, both setting in motion warnings for future disruptions caused by the fleet while also changing possible objectives, given the updated limitations. During the time of data collection, *Maintenance Supervision* was perhaps the busiest function, rivalling with *Operations Controller*. This is mainly because of the criticality of maintenance-related information for other functions, that need constant updates on availability windows, resources and limitations.

Lastly, *Maintenance Scheduling* provides planning of maintenance tasks and some oversight to their execution, maximising fleet availability. These start with preventive maintenance tasks such as oil changes, cabin cleaning and engine overhauls, among other tasks. In this sense, larger repairs tend to be planned outside high demand periods such as holiday seasons or during weekdays. Unplanned maintenance must be, therefore, accommodated to avoid down times as much as possible. Maintenance technicians work together with *Troubleshooting* and *Maintenance Scheduling* to defer the interventions when needed, so they can be fixed in the next scheduled maintenance window or at night, when part of the fleet remains on the ground for periods of up to eight hours. Deferring maintenance is legal, as long as the due dates and limits prescribed by the manufacturer are observed by the carrier. *Maintenance Scheduling* can create both preconditions and resources in our functional description, when considering its interaction with Operations Controllers: it limits available aircraft, maintenance-wise, but also creates resources, freeing aircraft (by delaying scheduled maintenance) to solve open or potential flight disruptions (we therefore choose to model this function output as a resource due to its main use during observations).

Crew-Related Functions

Crew-related functions execute the monthly plan created by the Network Planning department, which is located outside the OCC and was not a part of this study. Of the many resources managed by the OCC, crews are particularly dynamic: their availability rapidly deteriorates and closes windows of opportunity since they work under union agreements, which, among other things, limits the daily, monthly and yearly maximum duty and flight time and the maximum of work days allowed before rest periods. This makes managing a crew roster even more demanding than fleet management. The mapped functions within this group are *Schedule Execution*, *Crew Logistics* and *Crew Recovery*.

Schedule Execution is responsible for overseeing crew allocation for all flights within the following 48 hours. The need for this monitoring happens in the wake of constant adjustments necessary for the operation, for example, if a crew from another flight is expected to arrive late, and there are crews available for a later flight, changing the assigned crew allows the next flight to depart on time and avoids lost connections further down. This function also monitors crews on reserve and standby duty, originally made available by the Network Planning: reserve pilots and flight attendants are sometimes scheduled to remain at the airport, ready as a replacement for any flight. On the other hand, standby crews can stay in a location of their preference, including their home, but must arrive at the airport normally within 90 minutes if called. Despite the availability of these crews, one of the most common strategies used by *Schedule Execution* was preserving crews on reserve and standby duty as much as possible. Operators of this function try to maximise the use of arriving crews with legal flight time still available whenever possible. This strategy preserves the resources and avoids leaving the system vulnerable to further disruptions from lack of available crews. *Crew Scheduling Supervision* is always available to validate changes that require extensive modifications in the schedule, also sharing its experience with *Schedule Execution* operators to help understand and solve complex crew events (such as sick leave).

We observed that crew-flight pairings change several times a day to accommodate constraints and solve immediate local problems. Sometimes, these rearrangements break the planned schedule, leaving the flights ‘open’, as referred by the member of the OCC. This means that crews that were supposed to be available in a specific time or place in the future were used elsewhere and would be unavailable for the original planned flights. Therefore, the *Crew Recovery* comes into play, reviewing the crew availability for the following days and rescheduling all pairings from two days ahead to the end of the published crew schedules (15 days to a month in advance). This ensures that all flights have crews assigned to, while continuously reorganising the available crew roster to optimise buffers in the system in terms of crew availability. This also includes looking for underused crews and replenishing reserves and standby crews as needed.

The last mapped function in this group is *Crew Logistics*. This function provides support for *Schedule Execution* and guarantees crews have a place to rest whenever and wherever their flight ends, especially if their itinerary was changed from what was originally planned. Procuring extra hotels rooms and transportation are important for the unplanned extra flights that emerged as solutions for disruptions along the day: At the end of their shift, crews become available again only after a 12-hour period of rest, which legally starts to count down as soon as accommodations are provided. Thus, *Crew Logistics* ensures that crews are optimally used, legally rested and available for the next shift on time.

Client Support Function

The orange function on the model works on two main roles. The first is finding adequate solutions for rearranging clients who may have been affected by delays, such as lost connections, cancelation, overbooking or lost luggage. Among the solutions, the function aims to accommodate passengers in hotels or to be placed on other available flights (company or not), to manage transfers to and from the airport, and to find and redirect lost or unclaimed luggage. All this effort aims to reduce the time required to strategically manage clients by the company representatives at the airport, since *Client Support* has access to much more information.

The second role is related to when clients contact the company with special health and medical demands, from post-surgery to food allergies, special mobility needs or even the transportation of vital organs for transplant. The *Client Support* not only assesses the paperwork but also the required infrastructure availability at the origin and destination. Both roles end up freeing other functions in the OCC while coordinating and converging decisions with the *Front-Line Airline Offices* that directly deal with clients.

Operations Controller Function

The *Operations Controller*, represented in blue in Figure 4, is the central function in the OCC, where all information and resources provided by the other functions converge. This function actively looks for potential problems that might end up in disruptions, valuing early detection and attempting to disarm any potential threats. When prevention cannot be achieved, the function works on de-escalation and mitigation as much as possible. This involves looking for and managing resources, such as available aircraft slots, both for extra flights or maintenance, and crews.

The main routine involves monitoring scheduled incoming flights and interrogating other functions, such as the *Crew Schedule*, *Maintenance Control* and *Maintenance Schedule*. The information normally arrives to the *Operations Controller* from other functions, therefore triggering the process to create, find and weigh options, but not necessarily in this order. The main objectives are minimising impacts on the flight network and restoring normal operations while making efficient use of available resources. These strategies preserve response capability and are vital as new complications always arise, and as one interviewee describes it 'managing flight disruptions is a never-ending process'.

During our study, a common arrangement of this function included a team of six operators alongside two supervisors for each one of the four shifts. This team would reconfigure itself in different ways according to the amount and severity of present disruptions: one or two operators could split and dedicate themselves to troubleshooting a severe event while the others would keep watch on the rest of the network. This configuration showed merits of its own, but the relocation of operators also meant scenarios of rapidly increasing workload.

The operations controllers have different mindsets, based on their own experience and systemic knowledge of the operation. Because of this, each one finds slightly different ways to cope with disruption scenarios. They share, however, a need for constant awareness of the system status which involves direct interactions with other functions that, after gathering information, verbally transmit the available options to the controllers. Empathy with other colleagues and functions also influence their ability to quickly assess what is happening throughout the flight network, raising awareness for the problems and solution development. However, the six-hour shifts that each operator works while maintaining focus on the information flow can create fatigue and degrade performance, particularly during high workload periods. One interviewee stated '[…] at the end of a six-hour shift, on an intense day [with many disruptions] coordinators coming in for the next shift arrive with a clear mind and are able to sometimes visualise solutions we are not able to'. This statement was followed by an explanation of the importance of a good briefing whenever the shift is being passed over to the next team.

The *Coordination Supervision* validates plans devised by operational controllers, making sure they converge globally in the flight network. They also actively collect information from the supervision of other functions, to maintain awareness of available resources if a disruption occurs. Furthermore, they are responsible for initiating a process called 'priority operations': in case of a disruption in a remote airport (spoke), the *Coordination Supervision* remotely commands temporary relocation of most, if not all, staff available at that airport, in an attempt to turn around the flight in the shortest possible time. Therefore, staff that normally work selling tickets or checking luggage help focus all efforts to expedite disembarking, boarding and helping to reorganise the aircraft interior. Interviewees reported that on a regular 30 minute stop this effort can save up to 10 minutes of ground time and helps save connections down the road, minimising the rearrangement of the flight network.

The final function inside the OCC is the *Shift Operational Management***,** which is conducted by a single manager, usually with an operations controller background and with substantial knowledge of all functions inside and adjacent to the OCC, and the airline operations. This represents the highest operational authority in the OCC, commanding all other functions, they are also tasked with reporting to senior executives, managing data and indicators for reports (such as regularity and punctuality levels) and authorising extreme measures and sacrificial decisions such as multiple flight cancellations or severe delays.

Functions External to the OCC

The functional representation also reveals that some important functions revolving around flight disruption management are not physically located inside the OCC or even in the company's hierarchical structure. Nonetheless, these functions provide fundamental information and resources for the decision makers and are indissociable from the OCC operation. Represented in grey on Figure 4, *Frontline Airline Offices, Maintenance (Frontline/Airport)* and *Air Navigation Management* were included because of important interactions with other mapped functions.

The *Frontline Airline Offices* encompass the ground personnel located at the airports the company operates. Among other duties, this function is responsible for passenger and luggage check-in, boarding and disembarking passengers, providing the flight documentation to the crew (made available by the Flight Dispatch function), coordinating the aircraft refuelling, catering, water and sewage, and assisting passengers if and when problems arise.

During our research, we found that despite having relative autonomy to solve many problems locally, the function keeps constant communication with the OCC, feeding data and effectively working as the OCCs' 'eyes and ears' on the front line, as defined by one of the interviewees, providing details and estimations on developing situations. Sometimes, they serve as an early warning so the OCC can begin to work on potential disruptions. The function also reports to the OCC the flight status, special demands and other critical information such as updated estimates for arrival and official departure times, received directly from the pilots via radio, so the OCC can update subsequent flight schedules. This function is also under the influence of the Coordination Supervisor, to act when requested in the 'priority operations'.

We also found another strategy practiced by the *Frontline Airline Offices* function in conjunction with the OCC to prevent delays. Named as 'early start operation', this practice aims to prepare the aircraft to depart 10 min before the schedule time for all first flights of the day, those that normally start before 8 am. When it works, this strategy allows extra buffer in the operation and avoid the snowball effect of the delays.

Just as the previous function deals with passengers, *Maintenance (Frontline/Airport)* focuses on the aircraft and interacts with *Maintenance Control* in the OCC. They assess technical problems with arriving flights and conduct small repairs in the available time between scheduled flights if necessary. All these activities are performed in collaboration with the OCC, updating the *Maintenance Control* and *Troubleshooting* functions of all symptoms, steps taken and the time needed to fix problems. Based on the information they provide, the OCC organises resources and alternatives to avoid further disruption to the flight network.

The last function is called *Air Navigation Management*, which involves a team from the company that works directly in a remote government body called Air Navigation Management Centre. This centre manages departure and arrival slots, real-time information about airport status, and oversees all flights carried out in national airspace. They provide first-hand information on developing problems that may be yet unknown to the Airline, such as an airplane from another operator that is unable to leave the runway and is making an airport unserviceable, or the sudden closure of an airport due to meteorological conditions. This function also speeds up special clearances for extra flights, especially the ones to crowded airspaces and airports where specific time slots for departure and arrival are required.

VARIABILITY AND STRATEGY: SOME EXAMPLES OF DISRUPTION MANAGEMENT

In this section, we present five instantiations that represent prototypical flight disruptions (Figure 5). For each instantiation, we characterise the variability, describe how it propagates across functions, indicate points of resonance

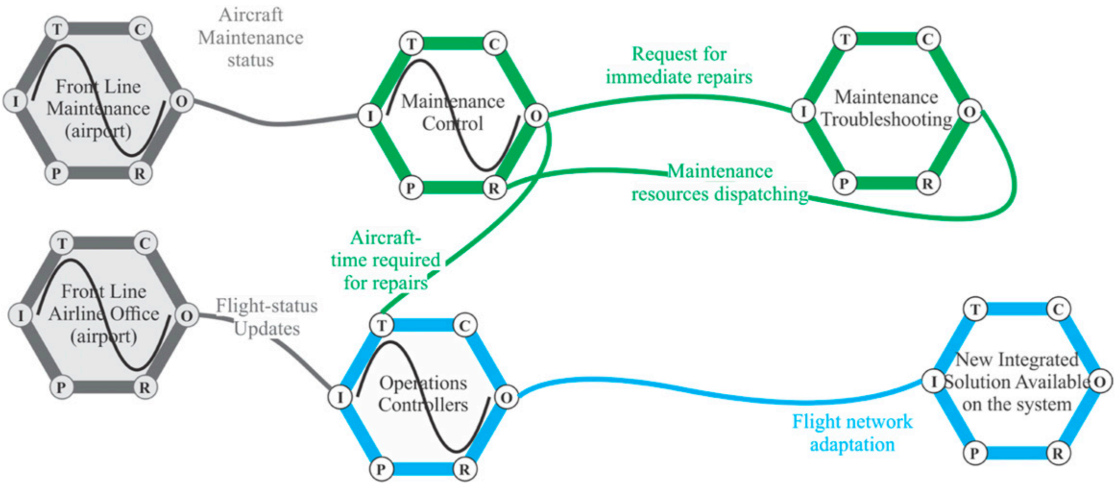

Figure 5. (ref. page 22) – Instantiation of variability and resonance on other functions.

and explain how different individuals manage it. These prototypical situations are not independent and many times overlap.

Information Flow Variability

Two types of events related to information flow were observed. The first is related to information update about the aircraft technical and flight status. Interviewees indicated that the *Maintenance Control* function occasionally passes incomplete information or incorrect diagnostics of airplane problems. Another issue is the imprecise estimation of the airplane downtime impacted by several factors, ranging from difficulties to understand system readings and manuals, to problems in diagnosing mechanical failures, particularly because manuals and reports are in English. Consequently, delays in providing an adequate estimation for the maintenance intervention impairs the operational controllers' expectations and objectives when troubleshooting disruptions.

Similar problems regarding critical information updates on the status of arriving and departing flights were also mentioned during the interviews and observed daily. Relevant updates included confirmations that the aircraft is on the ground or going around, any problems regarding refuelling or boarding routines, problems with the crew or passengers, or anything that can potentially delay the next departure. These updates are important as an early sign of future problems and as a trigger for the OCC to manage possible issues with passenger connections and delays of future flights. System-wise, multiple departure and arrival delays sometimes overlap and give the false impression that all is well, while smaller events resonate and end up affecting one or more strings of flights. This lack of information flow, whether related to quantity, quality or even timing in this case, is mainly due to the lack of experience of part of the workforce in remote bases, as revealed in the interviews. On some occasions, when problems arise during the aircraft turnaround, the airport team seems to focus on assessing the problems and forget to communicate with the OCC.

Not updating the flight status is further amplified during 'priority operations'; as a greater number of employees in an airport is momentarily reassigned to manage the aircraft turnaround, other duties, such as feeding the system with flight information and check-in for later flights, are put on hold or placed at a lower priority. The missing or delayed information can potentially reduce available data or indications for the OCC to make decisions. This trade-off increases the workload of *Front-Line Airport Offices*, and although it may ultimately help the network regain some normality, it comes at a cost of OCC's reduced capability to detect early signs. Some of the interviewees shared a perception that the ‘priority operations’ strategy is only effective while handling flights with a reduced number of passengers or when operating small aircraft models.

The variability of the information about the status of operations across the airports happens continuously throughout the operation. Because of this, different functions in the OCC constantly and actively seek information about the flight estimates and status updates to avoid unwanted surprises, particularly in airports known to have caused problems in the past. Integrated training helps frontline personnel to understand the bigger picture of operations and be more proactive in exchanging information with the OCC. However, high turnover rates among frontline workers were also pointed out as a challenging problem to make this function more efficient.

The second type of event relates to information overload scenarios. In an event that happened when the company was smaller, reported by one of the first employees of the OCC, the communication systems were partially out for a few hours. Information was able to get to the OCC but outbound data, such as flight plans and flight dispatch documentation, was unable to get to the airports or crews. The situation escalated rapidly, increasing the number of delayed flights, lost connections and last-minute changes. The increasing number of airports and personnel trying to contact the OCC to understand what had happened and trying to get information contributed to overloading the remaining communication channels. To add an extra level to the challenge, the main airline hub remained closed for two hours due to bad weather. As a result, the operations at the main hub came to a halt.

Even though the communication disruption lasted only a few hours, this scenario posed additional challenges to the flight dispatchers. During a normal workday, the *Flight Dispatcher* function completes a flight release every twelve minutes, on average, which does not leave much margin to accommodate changes and disruptions. While the flight plan modification and dispatch documentation were reasonably fast, the overflow quickly compromised the ability of the *Flight Dispatch* function to complete the documentation for upcoming flights in time while reworking the delayed ones. A supervisor mentioned that even now that the company has multiple hubs, such situations can still happen, mainly triggered by severe weather that closes multiple large airports in the same region. In his words ‘although rare, the inflow of traffic from all airlines quickly drains divert options and requires a lot of work to normalise the network’.

On the day of the communication disruption and the paralysation of the flights for few hours in the main hub, despite having passengers, crews on station, airplanes fuelled and the airport slots for departure and arrival available, multiple flights were cancelled in the wake of the lack of flight documentation. This led to more flight cancellations that prompted even more adjustments in the upcoming days. The variability that caused the disruption, unavailability of communication channels, was amplified by the overflow of required changes in a great number of flights, exceeding the available resources for an extended period.

The solution involved using the night shifts, when there are fewer flights scheduled, to reorganise the network and accommodate passengers. In this event, the *Operations Controllers* decided to make several changes across the network to reduce the impact over other flights, including grounding inbound flights to the main hub before they took off, rescheduling flights to avoiding stopping in the main hub and accommodating passengers in other and supplementary flights for the following days, so they could reach their destinations through different itineraries. These changes ultimately reduced the need to ferry empty aircraft and optimised the use of the available flights.

Crew-Related Variability

Crew variability happens mainly in three forms: legal work limits, differences between the pilot and the OCC’s decision, and flight continuity. We acknowledge that other forms, such as roster size and hiring policies, impact the variability directly, but these are not dealt with by the OCC, therefore, these factors have not been considered in the variability analysis.

When considering legal work limits, there is a cap on the number of hours pilots are allowed to fly annually, monthly and daily, with the latter being the most disruptive. Managing flights so that the crew work limits do not restrain the number of required flights or cause an aircraft to land at a location where there are no replacement crews, is paramount for disruption avoidance. The trade-off here involves using most of the crews' time while still being able to accommodate some variability and avoid locking down the aircraft because of unavailable crew. The *Schedule Execution* function monitors the system and feeds *Operation Controllers* with warnings and suggestions to maintain this balance. Crews are instructed to contact the OCC if they foresee any additional problems that might get them too close to, or over their duty limits.

One case of quasi-disruption was observed in a day where multiple airports closed due to bad weather. In this event, a crew, who were already enroute to an alternate airport, raised concerns to the OCC over approaching the limit of the daily working hours. Immediately after becoming aware of the problem raised by the *Schedule Execution*, the *Operations Controllers* requested the aircraft return to the airline hub, sacrificing the passengers of the destination but preserving the continuity of the flights. Had they landed at the alternative airport, they would have been required to rest for 12 hours before continuing the flight. The situation could have been worse since the location had no accommodations available and the airplane was needed in the hub to make another sequence of four flights with another crew on that same night.

The pilot's decision is also a source of variability, particularly when it disagrees with the solution or recommendation provided by the OCC. Some experienced captains still do not see that their decisions may have unexpected and unintended consequences and prefer to maintain their choices. This may result in a viable solution for the flight but certainly imposes additional burdens to the network. The case reported above is one such example: the captain had decided to divert to an airport geographically close to the original destination. In his mindset, the flight would land safely in a city close to the original destination, making it easy for the company to transport the passengers by land to their destination. However, while the solution was good for this flight, it was disastrous for the flight network, as both the crew and aircraft would have been locked down for 12 hours at least.

Flight continuity relates to a crew member becoming unavailable during a string of flights. As the minimum crew for airliners is two pilots, if one of them is not fit for duty, then further departures will not happen until there is a replacement available. For flight attendants, however, the minimum number required is related to the number of passengers on board: if one flight attendant becomes unavailable, the flight can still depart if the number of passengers is proportional. In any case, both *Crew Logistics* and *Schedule Execution* work to find reserve crews available, or preferably the ones arriving at the hub from their last scheduled flight who are still within the daily limit. Although reserve crews are available in most hubs, their use is often reserved for when other options are not available since they are regarded as a system buffer that is not always easily restored. After these adjustments are made, the *Crew Recovery* works as a 'mop up' team, rearranging reserves and optimising availability of crews that were used to fill in the gaps of previous disruptions. The ultimate goal is to recreate the buffer and make more crews and crew times available.

It is important to note that managing the legal work requirement is bound to become more intricate in the coming years, as there are new regulations on pilot fatigue in implementation worldwide. Work limits are becoming more dynamic and dependent on the check-in time, number of sectors, whether the crew is pilot or flight attendant, and other variables not previously considered. Consequently, functions like *Crew Logistics* and *Crew Recovery* will probably have to work extra to ensure the crews are available and properly managed in the coming years.

Passenger-Related Variability

Disrupted flights quickly generate a great number of demands related to passengers, particularly if they have lost a connection flight, had their flights cancelled or diverted to a different airport, or lost their luggage. These demands require a peculiar set of strategies, ranging from relocating passengers on own or other companies' flights, transporting them by land to their destination, creating new flights, providing overnight accommodation, vouchers and forwarding their luggage.

Strategies here are particularly time-sensitive; disruptions that take place earlier in the day involve searching for later flights that can accommodate the affected passengers. As operations get closer to the evening, the *Client Support* progressively begins looking at more expensive alternatives, such as hotel accommodation, flights from other companies and other forms of compensation. These options tend to be less desirable for the company, because of extra cost, and negative client experience relating to lost appointments and time. However, these strategies create a 'stasis', effectively pushing the problem to the next window of opportunity.

Especially during scenarios of multiple disruptions, with many connections lost, individual passenger needs can become both time and resource consuming. *Front Line Airline Offices* are tasked to be the main point of communication with passengers and keep in contact with *Operation Controllers* and *Client Support* to sort out the individual needs of each passenger. Most of the solutions emerge from the coordination between OCC and local ground personnel. Beyond reactive strategies, *Front Line Airline Offices*, *Operation Controllers* and *Client Support* constantly and actively anticipate passengers' reserves whenever possible. The strategy involves allocating passengers already in the airport, using available seats on earlier departing flights, which opens options to accommodate lost connections on what are usually the busiest flights at the end of the day. This is also encouraged by passenger actions on self-service terminals available at the airport.

Maintenance-Related Variability

During our research, we found that maintenance-related disruptions and variability were mainly connected with unscheduled events. These include bird strikes, which can range from harmless to engine failure or structural repairs, or a single failing electronics module, for example. Unscheduled maintenance affects fleet availability and, therefore, disruptions through delays and cancelations. Even though many malfunctions can be deferred to a later maintenance window, some problems reduce the aircraft ability to operate in certain conditions, such as bad weather, higher flight levels and short runways, which may themselves cause secondary disruptions.

The process usually starts with *Front line Maintenance* or pilots contacting the *Maintenance Control,* which then assesses the event and helps diagnose whether the malfunction can be deferred or requires an immediate stop for repairs according to aircraft manufacturer's protocols. If repairs are needed, *Maintenance Troubleshooting* activates a complex network of contacts and logistics to ferry parts, crews and maintenance specialists as needed. If ferrying the aircraft for heavier repairs or further maintenance is still needed, *Maintenance Scheduling* helps allocate the aircraft to a base capable of performing the needed services. If maintenance can be deferred, this function intervenes in the routes the aircraft will be flying in the following days and makes sure it will land at the required base with time available between flights for repairs.

The *Maintenance Scheduling's* decisions of postponing preventive and non-essential maintenance procedures affect *Operations Controllers* directly by adding or negating aircraft availability. There is an important trade-off here: postponing minor maintenance interventions frees the aircraft to continue flying but adds to downtime in the next scheduled maintenance task and may create situations where too many aircraft are in need of repairs simultaneously. The *Maintenance Scheduling* must keep in mind that services cannot be postponed indefinitely and new demands for repairs are always coming in. Therefore, deferring multiple maintenance interventions at the same time compromises the system's slack and ability to deal with variability.

Airline Hub Overwatch

There are two main factors observed when the OCC is monitoring the airline hub conditions: resource management and traffic overflow. The airline hubs concentrate the resources required to make the flight network efficient and reliable, and include crews, aircraft (and spare aircraft), parts and personnel to accommodate the variability throughout the operations. This, however, comes with a double bind: having many resources in one place can create vulnerabilities and impacts response capability if there is a problem with the hub, such as a closure due to bad weather conditions.

In one event recalled by some interviewees, a wide body freight aircraft landing gear collapsed during landing and made the only runway at the company's main hub unusable for days. Even aircraft that were parked or during turnaround were unable to take off for a few days. The event escalated quickly, affecting thousands of flights and passengers. To free the resources in the hub, the OCC relocated inbound flights, crews, parts, ground personnel and mechanics to smaller airports in the region. To connect these small airports to the hub, the company had to implement multiple shuttles with regular schedules in operation. This proved to be an effective strategy, albeit costly and difficult to operationalise. After the event, the company decided to formally recognise and implement this strategy to all hubs operated.

Carefully balancing the resources across different hubs is another key strategy used by the OCC to guarantee the capacity to respond to different disruptions. This does not mean an equal distribution at every airport, but rather having key airports in different regions able to buffer resources in case of problems. *Operations Controllers* alongside *Crew Scheduling Supervision* maintain overwatch of hub health and, although rarely required, move resources around. Therefore, the *Shift Operational Manager* together with the *Controller Supervision* and *Operations Controllers* constantly re-evaluate the current conditions and critical constraints while trying to optimise and free more resources to maintain OCC response capability.

In one observed situation, a sequence of evening flights was cancelled to free up resources as a strategy to contain a developing disruption. An on-schedule flight, ready to depart from the company's main hub, was cancelled and the aircraft, together with a new crew, was ferried to another airport about an hour away to perform a sequence of flights that night. In this scenario, the sacrificial decision of sending over 100 passengers to a transit hotel on the company expenses enabled over 500 passengers in different airports to complete their journeys on schedule.

The problem of traffic overflow to main hubs may be caused by other airlines' traffic. Although different companies choose different airports as main bases of operation, they are mainly located in the central regions of the country, due to geographical advantages, infrastructure and economy. Therefore, even if the company's main hub is working flawlessly, the closure of other hubs impacts all infrastructure available, saturating parking positions and affecting the airline's operations. Managing air traffic overflow during episodes where multiple airports or large hubs are closed at once, is 'one of the hardest things to do', according to three interviewees. Another participant concludes that *'the country has limited infrastructure when it comes to airports and equipment. Outside of the main capitals and cities, few to none can accommodate rerouted traffic in numbers. This is a problem because other airlines will have the same disruption and direct their flights to the same airports at the same time'*. Despite the best efforts of the *Air Navigation Management*, flights tend to be rerouted to the same few airports with the capacity to receive passengers and refuel large aircraft. The need for early warnings and sometimes special clearances to execute flights with non-conventional routes makes it important for every major airline in the country to have representatives interacting in real-time with the *Air Navigation Management*, even though it is not part of any airline.

DISCUSSION

The Flight Disruption Management as a Functional and Active Search for Variability

As pointed out by Hollnagel (2012), the functional description of a system reveals work-as-done rather than hierarchical structures or how the system was designed. The functions identified in this study are similar to the ones described by Kohl et al. (2007) and Clarke (1998), corroborating the concept of functional groups. The functional representation of the OCC provided a rich description of the activity and a holistic view of the system, with each area, regardless of the hierarchical level, working organically to come up with convergent solutions.

Despite being designed as a central piece in the OCC and having the highest number of interactions among mapped functions, the *Operations Controller* is just one, although important, element in flight disruption management. Despite reconciling and converging information from different functions, the Operations Controller also relies deeply on other functions to manage variability and develop solutions. The graphical representation (Figure 4) revealed the peripheral interactions among the specialities that do not need to report back to the *Operations Controller* when working to avoid, manage and recover from a disruption in some instances. This finding may explain why one of the participants of the experiments ran by Bruce and Gray (2004) '[…] was unable to solve the scenario […] in the absence of co-workers' (p. 7).

The instantiations of five prototypical flight disruptions, represented graphically in Figure 5, showed how variability, either endogenous or exogenous, originates and propagates across the system since most of the function interactions showed evidence of tight coupling. The results also show that in some instances, the functional resonance of the variability aggravated the situation. The closure of the company's main hub is a typical example: an external factor closed the airport, locked resources in the hub (mostly aircraft and crew) creating a cascade of cancellation and delays across the network.

Distributed Decision-Making Before, During and After Flight Disruptions

Combining the RPD model and the FRAM revealed nuances not produced by any of them independently. While the FRAM helped us to represent the system and its variability more broadly, the RPD model was useful to understand how the decision-making is carried in the micro level, almost as the lens to understand how each function produces the output from the input and other aspects and copes with the variability. As a result, both approaches allowed us to arrive in 5 mechanisms involved in preventing, coping with and recover from flight disruptions.

The first mechanism is the decentralisation and distribution of the decision-making process. Despite being responsible for integrating information and contributions of other functions, *Operations Controllers*, *Supervisors* and *Managers* do not make all decisions. Differently from the results described by Igbo (2013) and Feigh and Pritchett (2007, 2010), we observed some peripheral functions making local decisions not validated or even reported to them. These activities and decisions are part of the organisation routine, considered as normal and based on trust that every function is performing as best as it can regarding its speciality. A further look into the functions revealed that the specialists rarely work alone. Occasional local validation with colleagues is enough most of the time, even for elaborate problems. The findings also suggest less experienced decision-makers 'borrow expertise' from more senior colleagues on some occasions regardless of their speciality. There is also evidence that a good relationship and empathy along interconnected functions leads to better use of resources and better integrated solutions.

The decision-making is even distributed and decentralised within the *Operations Controller* function. The studied team was comprised of six people, one working supervisor and one shift manager, there was enough background diversity to allow for the generation of solutions with minimal bias. Therefore, we could not corroborate the findings reported by Bruce (2011) and Bruce and Gray (2004, 2019) that suggest operation controllers are biased towards their background when it comes to managing an aspect of the flight disruption.

The second mechanism is the constant look for early indications of future problems while maintaining the normal operation. Rather than waiting for disruptions to take place, all functions actively look for developing situations or problems in their area of expertise, which corroborates Kohl et al. (2007). The objective is to detect early signs of disruptive variability and continuously monitor known sourced variability. For crews, changes made to their rosters are accommodated and rebalanced on subsequent days, in a constant process to maintain as much as possible the larger plan on course, ensuring crews are used but still available in case of future problems. For maintenance, constantly requiring updates on aircraft status and estimated time for a maintenance intervention avoids the OCC being surprised by unexpected but known variability. For hubs, the concentration of resources needs to be closely considered: these pockets of socio-technical resources are essential but vulnerable to airport closures. Therefore, as Hollnagel et al. (2014) argue, the same mechanisms that provide flexibility for the system can also reduce the organisation's ability to respond and, therefore, close monitoring and management is required.

The third mechanism is balancing resources. Our findings suggest that the OCC in general tries to maintain the flights on schedule as much as possible and different functions continuously balance resources. Strategies such as the 'priority operations' and 'early start operation' aim to keep the flight on schedule, avoid creating conditions for a flight disruption and maintain the operational indicators. Guaranteeing that the resources are available when needed is also a strategy deployed constantly. Examples of this strategy include the 'early start operation' that aims to create additional time buffer between flights to accommodate eventual delays, anticipating passengers' flights to create space to accommodate affected passengers, requesting crews to extend their duty time within the legal limits rather than using standby crews, and postponing maintenance intervention as much as possible. Lastly, accommodating changes to the flight, crew and maintenance schedules after recovering from a disruption is also a strategy to rebalance resources and avoid creating conditions for subsequent disruptions. These strategies further advance the findings from Jimenez Serrano and Kazda (2017).

The fourth mechanism is the generation of resources during a flight disruption. The evidence shows how sacrifice decisions and creating additional resources can reduce the consequence and even segregate flight disruptions. In one of the examples, the operations controller's sacrifice decision to return and cancel a flight to avoid stranding passengers, crew and aircraft in a small city created a small flight disruption, with only local consequences, but avoided a cascade of effects to the network.

The fifth mechanism is the application of the repertoire of strategies. As suggested by the findings, we rarely identified or observed completely new solutions being deployed. It seems that most of the strategies were previously tried, modified, or combined with others stored in a repertoire of strategies. The findings also suggest that rather than storing a big and complex solutions, the repertoire contains strategies for small problems, which corroborates Igbo's (2013) conclusion. As new solutions are needed to cope with new and challenging problems, what worked or what did not work are used to expand the repertoire of strategies in associations to specific situational conditions. This finding is in accordance with Klein's (1999, 2008).

In addition to these mechanisms, our findings suggest that disruption management will require human intervention and decision-making for the foreseeable future and provide further evidence to the arguments of Kohl et al. (2007), Bruce (2016), Richters et al. (2016) and Jimenez Serrano and Kazda (2017). Even though technology and decision-support systems constantly transform many of the functions, the complex nature of disruptions and the need to maintain the flight network continuity require dynamic strategies and negotiations to stabilise them and most of the time cannot be discretely defined. The limits between normal operations and disruptions are blurry and interwoven, with one becoming part of the other. The OCC continuously adapts and transforms existing plans, directing actions with dynamic objectives and expectancies entangled in a never-ending succession of events and solutions. This is the reason why it is so hard to individually evaluate and quantify the impacts of a decision in the operation and to determine when a flight disruption ends, and the normal operation begins.

CONCLUSION

This study investigated the decision-making during flight disruption management inside an OCC of a major South American airline. Through a mini-ethnography case study, we collected data using document analysis, field notes, observations and interviews. The FRAM was used as the method to functionally describe the work-as-done in the OCC, including the critical functions and their variability. The functional description revealed seventeen critical functions, grouped in seven categories that are directly involved in managing flight disruptions. We identified and instantiated five prototypical situations responsible for generating variability that may lead to or aggravate a flight disruption.

The FRAM instantiations display an integrated and distributed web of decisions which prevent, recover, and adapt to variability. Most of such decisions are performed naturalistically and depend on a network of resources. The findings suggest five mechanisms through which the decision-making process occurs. The first is the decision-making which is distributed and decentralised to many functions rather than centralised on the operational controller. The second, third and fourth mechanisms suggest that the decision-making before, during and after a flight disruption, in a constant and active effort to detect early signs, balance the resources and isolate a flight disruption when it occurs. The fifth mechanism indicates the strategies are ‘drawn’ or ‘saved’ in a repertoire of strategies, that expands as promising solutions derived from past experience, are recognised and validated.

Future studies should further explore the resource effects on the performance variability to provide theoretical and practical support for cooperative decision-making and resilience capability at a system level. In this sense, combinations of naturalistic decision-making models and FRAM should be further investigated since it may provide a way to engineer resilience at a system level based on the operators’ expertise deployed while dealing with complex and dynamic situations, such as large operational disruptions.

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