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Application of Resilience Engineering on Safety in Offshore Helicopter Transportation

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Abstract— This paper is the result of a cognitive analysis performed on a helicopter system that provides transportation for a large petrochemical company in Brazil. This complex system was designed to be the link between the onshore base and the petroleum drillers located on offshore platforms. By analyzing the factors within the complex socio-technical system and focusing on the concepts of resilience engineering, various goal conflicts that stress the system were identified. Many of these system stressors resulted from various human, machine, organizational, and environmental factors that involve the helicopter companies' executives, pilots, and mechanics. While some codes and regulations define boundaries for the activities performed at the base, these codes and regulations do not cover all the issues. Pilots, mechanics, and managers create workarounds that may have harmful side effects on the entire system. The goal of this system analysis is to identify which points are critical and how they may be modified to provide a more resilient system.

I. Introduction

A. Overall Information

THIS document is the result of an exchange program between The Ohio State University, Columbus, OH and Universidade Federal do Rio de Janeiro, Rio de Janeiro, Brazil. The research developed throughout this one-year program focuses on the analysis of the offshore aviation system that provides transportation for Petrobrás' personnel.

Petrobrás is the largest oil exploration, drilling, production, and distribution company in Brazil, and oil and gas production are increasing each year. The daily average production in February 2006 set a new record reaching 1,758 barrels per day, and over 80% of the national oil production comes from the Campos Basin region, according to [1,2]. The company currently has 64 drilling platforms and ships in the Campos Basin area. On average, 40,000 people per month are transported via helicopters throughout this region.

These numbers illustrate the large load on the offshore aviation industry, the importance of helicopter transport to Petrobrás, and how maintaining safe operations is crucial if the whole system is to work as expected.

B. The Research Methodology

Petrobrás is responsible for hiring helicopter companies and setting contracts in which they define all the specifications of the services to be provided. In accordance with information collected during interviews, a total of 8 helicopters companies work for Petrobrás.

Findings for this research project were mainly based on interviews with helicopter pilots who actually fly in the Campos Basin region. In order to collect this data, all the

TABLE I
LIST OF INTERVIEWS

Date	Company	Person Interviewed	Position in the Company	Duration
10/27/05	Líder	**Julio**	FOQA Operator	1h
	Aeroleo	**Fabio**	Co-Pilot	3h40
	Líder	**Marisa**	Psychologist	0h40
01/09/06	Líder	**Julio**	FOQA Operator	2h20
	Líder	**Medina**	Co-Pilot	4h50
	Líder	**Imperatore**	Co-Pilot	4h35
01/23/06	Líder	**Fabrício**	Captain	5h15
	Líder	**Carine**	Co-Pilot	5h00
01/30/06	Líder	**Mariza**	Human Resources Analyst	3h15
	Aeroleo	**Filizolla**	Captain	1h45
	Aeroleo	**Hossein**	Co-Pilot	1h45
02/06/06	Líder	**Sakaue**	Co-Pilot	5h50
02/13/06	Líder	**Tizo**	Co-Pilot	6h10

All of the interviews were performed at Macaé airport. The other two interviews were done with helicopter pilots, but they do not fly in offshore aviation.

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interviews took place at Macaé airport, where most of the helicopter companies have their hangars. All the people interviewed are listed in Table 1.

The main purpose of these interviews was to collect more information about the pilot's activities. By analyzing the opinions of these practitioners, this methodology helps in identifying real system constraints. In addition, to better understand the mental model of the pilots and all the factors that influence their activities, a resilience engineering approach was chosen [3].

II. THE RESILIENCE ENGINEERING APPROACH

Macaé airport is a high risk complex system that copes daily with the pressure to be "faster, better, and cheaper" [3]. The demand for flights has increased tremendously in the last years and has brought and continues to bring new challenges of how to adapt and respond to the loads, while reducing the risk of incidents and accidents. It is natural for all systems to have the ability to adapt to handle disturbances, disruptions, and changes. The concept of resilience refers to a broader capability, the ability to adapt and absorb disruptions and disturbances when they fall outside the predictable or textbook cases the system was designed to handle.

In our object of study, Macaé airport, the blunt end is comprised of Petrobrás managers and helicopter companies. The sharp end is represented by the pilots. When the ability to respond to a sudden, unanticipated demand and return to the normal operations quickly (with a minimum decrement in their performance) fails, an accident occurs.

Resilience approaches analyze incidents, not to count errors, to identify where and why the system is resilient or brittle. When a failure occurs and we label the cause as human error, the analysis end and no relevant information about the brittleness of the system is gathered. Therefore we are missing the most important part of the history behind the failure and consequently the chance to improve the ability of the system to adapt and respond effectively to unanticipated events.

The purpose of Resilience Engineering is to anticipate the changing potential for failure considering that plans and procedures always have limits or gaps and that the environment constantly changes [3]. Our first step to a resilient approach is to identify the disturbances that affect the system and how it adapts to those unforeseen events, and then study how organizational context creates and cope with multiple pressures, goal conflicts, and dilemmas.

III. OVERVIEW OF THE HELICOPTER ISSUE

The following story describes facts collected during interviews and is designed to help the reader understand the system and its brittleness in a general sense. The story relates a pilot's point of view and some of the issues related to his activity.

Captain John Smith went to work at 6:00 AM, as he usually does when flying early in the morning. He was especially concerned about his flight that morning. The vibration on the helicopter he had been flying had worried him for more than a week and he expected to find it fixed by that morning. If not, his last option would be to officially report it, in the case that maintenance has not fixed it yet. That would leave the helicopter automatically unavailable until it gets repaired and inspected, which can take several days.

Upon arriving at the company's office, Captain Smith checks his flight plan, calculates the fuel, checks the platforms position, and all the procedures he must follow. His responsibilities include finding his own map of the Campos Basin, since the one provided by the company does not contains all information necessary for the flight.

Time to go. Fuel is ok, passengers are ready. He then walks 13 minutes to get to the helicopter and starts the Minimum Equipment List (MEL) check-up. Instead of reporting in the official book – also known as the Boarding Diary – when there is a malfunction, pilots report it internally to maintenance if it passes the MEL.

Captain Smith reported the problem with his helicopter personally to maintenance three times in the last 12 days, but the vibration remains. The company discourages the use of the official book in order to not leave the helicopter unavailable. This is due to the fact that the contractor (Petrobrás) pays the companies according to the amount of hours flown. An unavailable helicopter will affect the company's profits. In addition, from Captain Smith's point view, not flying represents a considerable part of his salary which is attached to the amount of hours flown.

Everything seemed to be alright with the helicopter so, after the safety briefing and communicating with the tower, the helicopter departs Macaé's airport. While going to the first of the 7 locations (5 platforms and 2 ships), all communications with the different controls and radios are made according to procedures.

Once the pilot starts to approach the first platform and flies below 2000 feet, there no longer is any control or radar to orientate them, but only radio communication with all information given from helicopters flying in the area. At this point, Captain Smith receives directions to change his schedule. The difference does not change the flight plan considerably, but includes another ship instead of a platform. Fuel and the estimated time of all stops must be re-calculated and communicated to each platform and ship they are going to. All of these calculations must be performed while flying. This new requirement gives the pilot an extra load of work and stress in addition to the continuous stress and work of flying and monitoring equipment and conditions. During each stop they must also write down the time of landing, time of departure, number of passengers exiting and entering the helicopter, and loads that may have been picked up or dropped off. Despite all these factors, the pilot and the co-pilot manage to do all jobs.

The last stop in this story is a ship. They check the ship's position given by the map, but it is not the same position as the helicopter's GPS. Nine out of 10 times this discrepancy *happens because the GPS is out-of-date. So prior to departure, all pilots must check the company's main office board and look for any changes in ship or platform positions. As Captain Smith had not seen any warning of changes, he assumes that the GPS is out of date, which was confirmed via radio. When approaching the ship, his assumption becomes a doubt. The sign that indicates the code of the ship is too small to read. Both pilot and co-pilot try to read the code before staring to land, but it is necessary to get closer to be 100% sure. Once he is close enough to see, he confirms information and lands safely on the ship. However, the vibration in the wheel comes back, raising the pressure while landing.*

Captain Smith knows that vibration is the number one reason for helicopters stress and wear. Not fixing it correctly may result in the aircraft flying for more hours now, but can impact safety. This time Captain Smith will not give maintenance the chance of not repairing it. Maintenance might blame him for the fact that the helicopter will not be able to fly, but it is his responsibility as a pilot to make sure that safety is guaranteed. However, he truly believes it is the company's responsibility as well.

IV. Analysis of the Helicopter Issue

A. General Issues

Reference [4] states: "To illustrate a safety culture, leaders tell stories about an individual making tough decisions when goals conflict. The stories always have the same basic form even though the details may come from a personal experience or from re-telling of a story gathered from another domain with a high reputation." Understanding how people bridge gaps, balance tradeoffs, handle goal conflicts reveals a great deal about how a system is brittle or resilient. The sample story consists of specifics extracted in one or several interviews integrated together to reveal general patterns about the complexities of offshore helicopter operations and system constraints that influence pilots' activities.

Looking for general factors on the system, and using the interviews as a basis for the initial premises, the main stressors on pilots' activities were identified and can be seen in Figure 1. Some stressors are very specific and could only be discovered by small details mentioned in the interviews. For example, some pilots mentioned that changes in their flight plans are common and it demands decision making and re-work which increases the stress level and the cognitive workload. Some of the issues that arose from the interviews can be seen in Captain Smith's story and are listed below:

- *Flight Plan sheet is inadequate* – Some pilots complained about the excessive amount of information on this sheet and the size of the paper used. So, they re-write the whole plan on another sheet to make it more user-friendly.

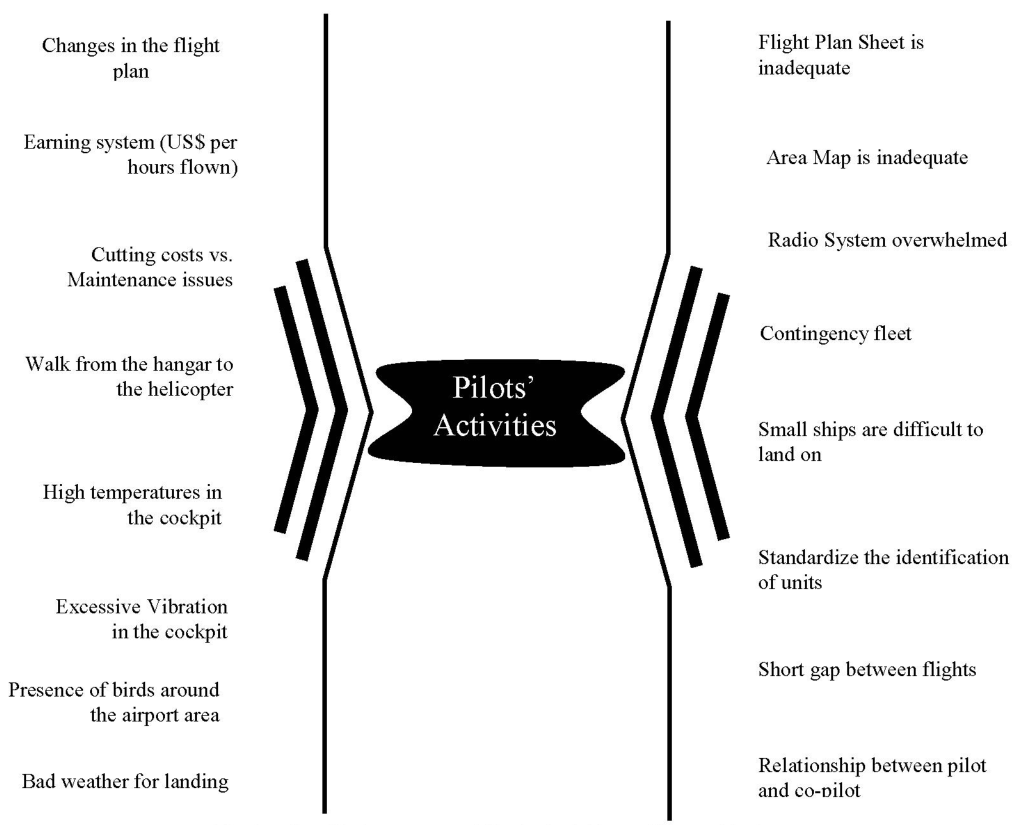

Fig. 1 – Identified stressors on Pilot's Activities at Campos Basin.

- *Area Map is inadequate* – Maps provided by companies do not help in identifying the platforms around Campos Basin. Pilots buy better ones from a colleague.
- *Radio System Overwhelmed* – All the people interviewed complained about the radio system. Many of them have stories of incidents that happened because of miscommunications.
- *Contingency fleet* – Some pilots believe that Petrobrás should have an extra helicopter on hand, as a faster mean of rescuing people after an incident or accident.
- *Short gap between flights* – Usually pilots do not have time to rest between flights.
- *Relationship between pilots and co-pilots* – Since many of the pilots come from military schools, the methodology of dealing with people is/may be different from civilians, which may cause problems in the pilot, co-pilot relationship.
- *Earning System* – both pilots and co-pilots earn income per hours flown each month. This variable amount accounts for more than 40% of their total income. During the interviews, some pilots affirmed that this is a way to force pilots to fly as much as they can.
- *Walk from the hangar to the helicopter* – Generally the helicopter is requested to land one kilometer away from the hangar. In these cases, the crew has to walk about 15 minutes from the company's office, sometimes facing high temperatures and humidity.

These issues identified from the interviews are interesting and challenging. Some of them may be solved by adding equipment in the aircraft (e.g. for excessive vibration and heat issues) or by working on some of the resources, e.g. providing better maps, carts to move along the runway, or changing the radio devices. Resilience is more than simply trying to correct each specific problem identified [5]. The limits of plans/procedures, pressure to be "faster, better, cheaper," the inherent variability of physical systems, and ongoing change in the world mean that some gaps will always be present in complex systems. Adding resilience means that the system can adapt effectively when events in the world challenge the basic model of successful operations.

The gaps illustrated by the issues shown in Figure 1 happen because in some cases the planned task is not similar to the real task. For some reason the system is not adapted to the full reality of the activity. For example, the air traffic industry and airports layouts have been increasing in size the past years, leading pilots and passengers to walk about 15 minutes from the company's offices to the helicopters which adds to physical and schedule pressures (does one go back if something relevant should be left behind or is missing?). In effect, the system has not adapted to these environmental changes, which creates a demand for a redesign in the airport layout or some kind of ground transportation.

Another example where we see a lack of adaptation in the system is the Flight Plan and the Area Map provided by the company. The first one contains information about the schedule. It is provided everyday on a sheet of paper that is sized larger than the clipboard used by the pilots during the flight. The information is provided in a table. Pilots complain about the amount of unnecessary information and how it is displayed. The table layout raises the cognitive workload during the flight because it is necessary to look for the relevant data across the lines and it does not follow the natural order of the flight. This typically forces pilots to write down information about the flight on a blank sheet of paper and copy information in their own way.

The Area Map is provided every 15 days by the company and contains information about the position of the platforms, ships, radio frequencies, and main routes. Most companies provide a black and white map with little distinction between different information. To make the task easier and safer, the pilots buy a map from a colleague which contains some extra information useful to the flights and it is easier to read (e.g. radio frequencies of different areas are in different colors). This is another example that reveals resilience in one way—how the pilots have adapted; and reveals brittleness sin another way as the system as a whole does not provide information tools designed to fit the conditions. Plus the pilots' adaptations may hide the underlying gaps from the blunt end's view unless and until there is an accident where these displays and maps contributed to the misactions or misjudgments.

B. Incentive Structure

One of the problems discussed in the interviews is the pay/incentive structure. Both the company and the crew earn more money when the aircraft is flying. As it is defined in the contract, Petrobrás just pays the company for the hours that the helicopter was flying or, at least, eligible to fly. If it is under maintenance, the helicopter companies do not earn the amount related to the days that the aircraft was not available to provide the service requested. In the same respect, pilots also earn by flying. Some pilots affirm that this variable part in their salary usually represents more than 40% of the total wage.

This fact creates pressures to keep the helicopters flying under almost any circumstance. The managers want to maintain the financial health of the company and the pilots are interested in earning more at the end of the month. This incentive structure seems to make it more difficult to make tradeoff decisions about safety versus production as we tried to capture in the flight story at the beginning.

The Brazilian Department of Civil Aviation (DAC) is responsible for the legislation and legal issues when it comes to aviation. Most of the limits on this activity are explicit in the Brazilian Code of Aviation, written by the DAC. One of the issues limited in this document is that the aircrafts are only eligible to fly if they were considered eligible to fly at their last inspection. If a helicopter goes under maintenance after one inspection, it must wait until the next inspection to be checked and then can start flying again. For this purpose, the DAC has hired a company to work on these inspections at Macaé Airport. Typically, it can take approximately two weeks from one inspection to the next. That means if a problem is identified and fixed on the helicopter, it may be forbidden to fly for up to 15 days. Crew shifts are set in a 15 days-on and 15 days-off manner. Maintenance issues may result in a whole crew being unable to fly during their 15 days on shift. The interface between in-company maintenance and government inspection system creates a gap that influences safety tradeoffs the wrong way [6].

Many pilots affirmed it is a common procedure to wait until the last days of their shift to report a problem with the aircraft. Although they insist that it only happens with "minor issues", they are not maintenance experts and their assessment of the problem may be wrong and increase the risk of an in-flight equipment failure.

Even though the helicopter companies know that an accident is a major economic loss as well as the worst safety issue, they adapted to cope with the gap. Reporting technical problems using the Boarding Diary—an official instrument in which the crew writes all the events during the flight—means that the aircraft stops flying, at least, until the next DAC inspection. Avoiding this, companies allowed pilots to report problems directly to maintenance. After analyzing the problem, if it demands replacement of the parts of the aircraft, the mechanics report it to the management. After

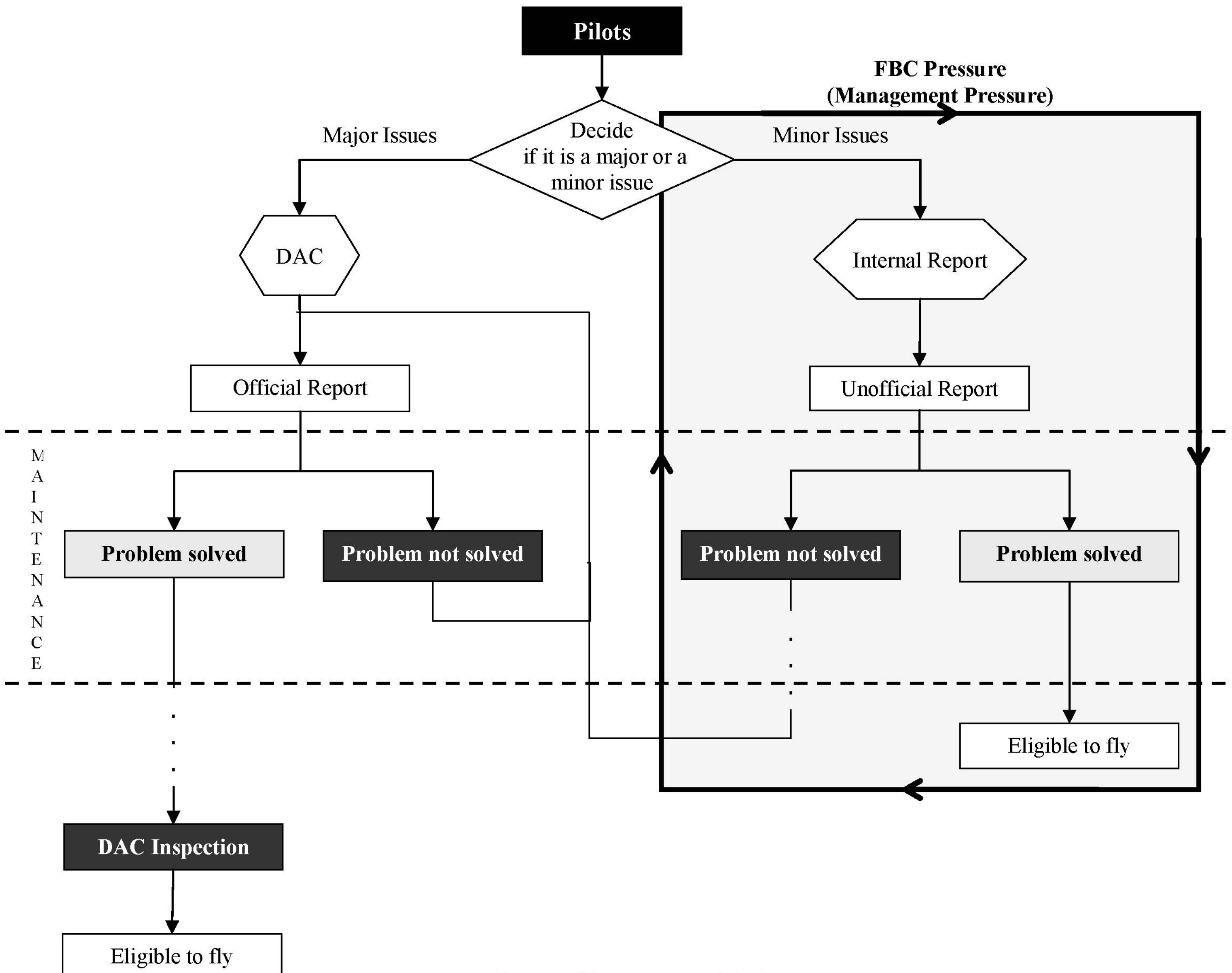

Fig. 2 – Decision processes made by the crew

that, the company's engineers and inspectors check and give their verdict, checking if it is really necessary to order the parts.

Helicopter companies have room to maneuver because they either can use either DAC or Minimum Equipment List (MEL) rules. MEL is an international list of items that are known as a regulation that must be followed in order to keep an aircraft eligible to fly. DAC rules are more severe. Because of that difference companies' managers can "minor" issues where if the MEL is ok, problems are reported directly to maintenance, avoiding the risks imposed by the DAC rules.

While this set of internal inspections is running, the aircraft remains in flight. Some pilots complained that usually small problems that are reported become recurrent and are not fixed after the internal inspection. This event can cause two main reactions. One is to stop reporting, which hinders effective maintenance and adds risk of in-flight problems, and the other is to induce the crew to report it officially. If they consider the issue as being a major problem, reporting to the DAC may be the only way to keep them safe. This kind of attitude may create conflicts between pilots and management.

Also, during interviews some people affirmed that if a mechanics diagnostic repeatedly found that an aircraft needs parts to be replaced and nothing happens, then they start to fix the problem themselves, which can create additional problems. In the interview with the psychologist from one of the helicopter companies, she emphasized that the system helps to create a strong rivalry between pilots and mechanics. This is exacerbated when reporting problems directly to maintenance personnel does not appear to lead to satisfactory resolution. Small details about their roles also lead to perceived differences in status. The general result of all of these factors is to create barriers to communication and team work that undermine resilience.

The whole sequence of possible events is summarized in Fig. 2. It is interesting to notice that the crew is in charge of deciding a problem on board the helicopter is a major or a minor one, but they have no training to make this kind of judgment. The issues identified in general and illustrated in the case reveal the many different trade-offs and conflicts that reduce system resilience.

V. Conclusion

In order to be safe, the system cannot only rely on trade-off decisions by individuals. To create a safety culture the essential ingredient is a general level of commitment to safety in the managerial ranks of the organization that means finding ways to balance production pressures with safety [6,7]. As mentioned in the 1st International Helicopter Safety Symposium, in Montreal (2005), the safety culture in a helicopter organization is fundamental to avoid shortcuts. But what is a safety culture? A safety culture is an organization committed to learning and improving [7]. A safety culture examines the gap between the official model of how work is done and how work is actually done in practice. But a safety culture is more than an attitude; this culture must provide the means to eliminate or reduce goal conflicts and to help people balance production pressure with safety goals. This is a difficult balance to achieve and resilience engineering promises to provide measures and mechanisms that support these tradeoff decisions [3,6].

This study is the beginning of the research on the complex evolving system of Macaé's airport. The work to date has identified many markers of brittleness in this system. The next steps are to develop and test ways to improve the resilience of the system given that production pressure and change will continue.

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