Impact of the Organizational Structure on Airline Operations

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Abstract—This paper introduces work practice modeling and simulation as a mean to assess and evolve the airline organizational structure performance. It departs from the empirical knowledge conveyed through interviews with airline operators and builds an analytical infrastructure geared towards evaluating the current and hypothetical organizational structures. To better reproduce the operational control challenges faced by airline companies it uses real pre and post operational data containing scheduled flights, delay codes and aircraft and crew rosters. By the end of the research study, the simulation of the same operational scenario across four distinct organizational structures demonstrated improvements up to 15% in disruption handling time and up to 21% in collaborator stress.

I. INTRODUCTION

An organizational structure might be regarded as a set of entities collectively collaborating and contributing toward one common goal. The employees working in an assembly line or a rescue team are examples of organizational structures. Nowadays, with the increasing complexity of goods and services, and competing in a globalized world, organizations require tuned work systems, involving human capital interwoven with the latest technological innovations.

Evolving an established organizational structure is often daunting when it is behind the core mission of a business or when it operates uninterruptedly. In these cases, software simulations are an invaluable tool to explore new work practices, information flows or even decision making processes. Modeling and simulating complete or small portions of critical workflows, makes it feasible to collect a set of metrics as well as introducing organizational transformations. Brought together, these factors allow for organizational performance assessment and evolution.

The work presented in this paper is founded on such observations and aimed at proposing improvements to the operational control within a real airline company. To accomplish such aim, we had to use a real airline company as case study. TAP, the major portuguese air carrier, agreed to participate on such project and provided useful information and data.

As any simulation-based research, this study involved three main stages that will be discussed in the following sections. First, we had to unveil the entities involved on airline operations such as facilities, supporting systems, human collaborators and their main activities. Next, we used Brahms, a multi-agent system featuring the BDI model and its own agent-oriented programming language to model and simulate the airline empirical concepts. Finally, we collected a set of metrics, introduced organizational structure modifications and established a quantitative comparison among the latter.

II. BACKGROUND

First and foremost we tried to get some background information or discover targeted literature about other initiatives regarding airline operations control simulation but at no avail. Following this, to the best of our knowledge we were the first to simulate the Airline Operational Control Centre (AOCC) organizational structure in order to study its impact in airline disruption handling. Because of that it is difficult to compare our approach with others. Nevertheless, in this section, we would like to provide some background regarding work systems modeling and simulation and, also, about AOCC organization and some work related with disruption management.

A. Work Systems Modeling and Simulation

A work system involves people engaging in activities over time. Human participants might not just interact with each other, but also with machines, tools, documents, and other artifacts [15].

The activities performed often produce goods, services or data. There are two different approaches when it comes to designing or improving systems: machine-centered and human-centered [16]. The former is usually accomplished through a business process reengineering approach [17] based on business process flow analysis focused on work products. The latter also takes into account how the people in the organization actually prefer to work [18]. Unlike the machine-centered approach, which neglects human communication, collaboration, workspaces, problem solving and learning; the human-centered approach analyze human activities, work processes or tasks, comprehensively and chronologically throughout the day [19].

The human-centered work system design approach is based on modeling and simulating work practices: what people
actually do, rather their outcomes. This way, it is possible to understand the effects of human behaviors in different places and times, details often omitted in a product-oriented task analysis. In the end, besides the traditional system workflow, human-centered approach might also propose some work system transformations, including different tools, resources, locations or scheduling.

Aiming at using a human-centered approach to model and simulate our organizational structures, Brahms [20] was adopted as modeling and simulating tool. It follows a holistic approach to systems modeling. By developing formal models of people’s behavior at the activity level, it is possible to determine the impact of these actions on the whole system.

Besides its own agent-oriented programing language, Brahms contains some pre-defined model components that make it straightforward to implement reality concepts:

- **Agent/Groups**: to model the human collaborator;
- **Objects**: for the computerized systems;
- **Geographies**: used to indicate the location of facilities;
- **Activity**: to express the agent behaviours;
- **Timing/Workframes**: used to model activity duration.

Brahms does not provide real-time visual feedback of a running simulation. Therefore this deficiency had to be address through the development of a visualization of the simulated airline.

### B. Airline Operational Control Centre Organization

The main role of the AOCC is to monitor the conformance of flight activity according to the previously defined schedule. The occurrence of some unexpected events might prevent operations to take place as planned, such as aircraft malfunction, crew delays, crew members absence, etc.

Following this, the AOCC is a human decision system composed by teams of experts specialized in solving the described problems. Teams act under the supervision of an operational control manager and their goal is to restore airline operations in the minimum frame and at a minimum cost.

According to Castro [1], there are three main AOCC organizations:

- **Decision Centre**: the aircraft controllers share the same physical space. The other roles or support functions (crew control, maintenance service, etc.) are in a different physical space. In this type of Collective Organization all roles need to cooperate to achieve the common goal.
- **Integrated Centre**: all roles share the same physical space and are hierarchically dependent of a supervisor. For small companies we have a Simple Hierarchy Organization. For bigger companies we have a Multidimensional Hierarchy Organization. Figure 1 shows an example of this kind of AOCC organization.
- **Hub Control Centre**: most of the roles are physically separated at the airports where the airline companies operate an hub. In this case, if the aircraft controller role stays physically outside the hub we have an organization called Decision Centre with an hub. If both the aircraft controller and crew controller roles are physically outside the hub we have an organization called Integrated Centre with an hub. The main advantage of this kind of organization is to have the roles that are related with airport operations (customer service, catering, cleaning, passengers transfer, etc.) physically closer to the operation.

As mentioned, figure 1 shows the traditional Integrated Operational Control Centre. As previously stated, the AOCC is composed by groups of workers, each one with its own responsibilities. They must report their activity to a Supervisor, translating a two-level hierarchical system. Figure 1 also represents the activity time-window of the AOCC, it starts 72 to 24 hours before the day of operations and ends 12 to 24 hours after.

The roles more common in an AOCC are, according to Kohl [3] and Castro [1]:

- **Flight Dispatch**: prepares the flight plans and requests new flight slots to the Air Traffic Control (ATC) entities (FAA in North America and EUROCONTROL in Europe, for example).
- **Aircraft Control**: manages the resource aircraft. It is the central coordination role in the operational control.
- **Crew Control**: manages the resource crew. Monitors the crew check-in and checkout, updates and changes the crew roster according to the arisen disruptions.
- **Maintenance Services**: responsible for the unplanned services and for the short-term maintenance scheduling. Changes on aircraft rotations may impact the short-term maintenance (maintenance cannot be done at all stations).
- **Passenger Services**: decisions taken on the AOCC will have an impact on passengers. The responsibility of this role is to consider and minimize the impact of the decisions on passengers. Typical this role is performed on the airports and for bigger companies is part of the HCC organization.

![Fig. 1. Integrated airline operational control centre (adapted from [2]).](image-url)
C. Disruption Management

Disruption Management [3], also known as Operations Recovery, is the process carried out by the AOCC when an unexpected problem prevents a flight to operate as planned.

The first overview of the state-of-the-practice in operations control centers in the aftermath of irregular operations was provided by Clarke [4]. In his study, besides an extensive review over the subject, he proposes a decision framework that addresses how airlines can re-assign aircraft to scheduled flights after a disruptive situation.

Currently, the most thoroughly analysis of the discipline is presented by Kohl et al. [5] where their conclusions are supported by the DESCARTES project, a large-scale airline disruption management research and development study supported by European Union.

Other authors propose more general perspectives regarding disruption management. Yu and Qi [6] analyze airline disruption management from different angles: crew and aircraft recovery; and applied to other fields as well: machine scheduling and supply chain coordination. Given the large scope of their work, airline operations recovery are not particularly detailed.

On the other hand, Ball et al. [7] give insight into the infrastructure and constraints of airline operations, as well as the air traffic flow management methods and actions. Simulation and optimization models for aircraft, crew and passenger recovery are also discussed. Furthermore, the authors give an excellent survey of the airline schedule robustness as a proactive alternative to recovery, including model descriptions and a literature review.

From the mentioned studies it is clear a tendency to consider the disruption management problem as twofold: aircraft recovery and crew recovery. For each type of recovery several solution approaches were proposed based on different methodologies.

An in-depth and comprehensive review over the most relevant studies and methodologies used in disruption management is presented by Clausen et al. [8]. They not only explain the most traditional approaches, such as Connection, Time Line and Time Band Networks, based on the scheduled aircraft and crew rosters but also mention newer and innovative research studies.

While the vast majority of the publications use integer programming solution methods to solve the aircraft recovery problem, the most recent works apply some metaheuristics to the problem, such as described by Andersson [9] and Liu et al. [10].

Moving to crew recovery, the majority of publications formulate the crew recovery problem under assumption that the flight schedule is recovered before the crew re-scheduling decisions are made, thereby following the hierarchical structure of the disruption recovery in practice. These publications include Wei et al. [11], Guo [12] and Nissen and Haase [13].

For instance, from the list of authors presented in the last paragraph, Wei et al. [11] model the crew pairing repair problem as an integer multicommodity network flow problem on a Connection Network. The challenge is to repair the pairings that are broken and the objective is to return the entire system to the original schedule as soon as possible while minimizing the operational cost.

Something interesting about Nissen and Haase [13] research is its founding on European reality. They propose a duty-based formulation for the crew recovery problem, which is especially well suited for solving the crew disruption for European airlines, as these, contrary to the North American airlines, employ fixed monthly crew rates, which should be taken into consideration when solving a crew disruption.

Finally, Castro and Oliveira [2] pioneer an approach that not only accounts for the aircraft and crew perspectives but also considers passengers. An implementation of an intelligent and distributed multi-agent system (MAS) represents the operations control center of an airline. MAS includes a crew recovery agent, an aircraft recovery agent and a passenger recovery agent. They use concepts of direct and qualitative cost to determine solutions for the disruption problem.

III. Empirical Airline Operations

The airline operations start way before the actual flight day as they require the scheduling of flights in advance. Then several stages emerge such as the revenue management, aircraft and crew rosters, and so on [2]. This is usually known as the Airline Scheduling Problem [14].

When the day of operations arrives, unexpected events may prevent flights to depart as planned and the airline specialists must address those situations. This is known as the disruption management problem.

Our study is about organizational structures of the AOCC on the context of the day of operations, not to the disruption management algorithms and/or processes that are used to solve the disruptions. For that, we need to know the workflows before and after that stage the disruption, i.e., which are the unexpected events, who detects such events, how the airline specialists know about them and who is notified of putative solutions.
In order to simulate such scenario we needed to know the entities involved on airline operations. Figure 2 clearly depicts those entities and their geo-location. Squares represent facilities and ellipses computerized systems. Table I describes each of the entities’ labels.

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<tr>
<th>Facilities</th>
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<td>ACT</td>
<td>Crew Terminal</td>
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<td>AP</td>
<td>Aircraft Parking</td>
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<td>CI</td>
<td>Passenger Check-In</td>
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<td>HCC</td>
<td>Hub Control Centre</td>
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<td>LIS</td>
<td>Lisbon Airport</td>
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<td>OCC</td>
<td>Operational Control Centre</td>
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<th>Computerized Systems</th>
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<td>AMS</td>
<td>Aircraft Movement System</td>
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<td>CTS</td>
<td>Crew Tracking System</td>
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<td>DOV</td>
<td>Flight Operations Portal</td>
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<th>Human Collaborators</th>
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<td>as</td>
<td>Aircraft Specialist</td>
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<td>cms</td>
<td>Crew Members</td>
</tr>
<tr>
<td>cs</td>
<td>Crew Specialist</td>
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<td>fd</td>
<td>Flight Dispatcher</td>
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<td>gs</td>
<td>Ground Supervisor</td>
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<td>hs</td>
<td>HCC Supervisor</td>
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<td>mss</td>
<td>Maintenance Services</td>
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<td>os</td>
<td>OCC Supervisor</td>
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<td>pss</td>
<td>Passenger Services</td>
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<td>Station Supervisor</td>
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With a big picture of the current TAP organizational structure and its components, an in-depth understanding about the workflows as well as related activities was essential. Eight workflows and activities were identified.

Concerning the activities, across the organizational structure, information is conveyed by means of VHF radios or telephones. Since the computerized systems share the same network, information is instantaneously synchronized among them and it is visible at each other. Human collaborators interact with the systems by filling forms or reading data. Decisions are carried out at the Operational Control Centre by the specialists and supervisors are required to approve those decisions.

Triggering any of the eight identified workflows is a pre-flight anomaly, e.g., lack of fuel, aircraft malfunction, mandatory security, etc. If the anomaly causes a departure delay, then it is recorded on TAP databases accompanied with a delay code. Just to provide an idea about the number of potential anomalies, the proprietary delay code list of TAP has more than 200 entries, while the IATA, international delay code list has around 80 anomaly types. Each anomaly is usually detected by an airline operator or system, thus inquiries were made in order to classify each delay code according to concept.

In order to illustrate an operational workflow, an example follows. Imagine that 15 minutes before departure a ULD (Unit Load Device), inadvertently hits an aircraft during cargo loading. Assuming that this kind of anomaly has a delay code of 100 and TAP had classified such code as being detected by the Ground Supervisor then, at this point, the Ground Supervisor is the only agent knowing about the problem. The deciding agents on TAP organizational structure are the Aircraft and Crew Specialists, located at the OCC. They must be aware of the problem in order to reason and find the best solution, e.g. replace the aircraft, delay the flight, etc. Figure 3 illustrates the workflow behind the resolution of an aircraft anomaly detected by the Ground Supervisor.

In order to alert the Specialists, the Ground Supervisor first uses the VHF radio to communicate the problem to the HCC Supervisor. Next the latter fills a form into the Aircraft Movement System and the informations is propagated instantaneously to the OCC. There, the Aircraft Specialist is hopefully paying attention to the screen and becomes aware of the problem. He reasons about the problem and after reaching a conclusion inputs it into the AMS, being replicated to the CTS. Now it is the turn of the Crew Specialist. Mandating or not some crew assignment changes, the Crew Specialist is required to evaluate, take action and confirm the solution suggested by the Aircraft Specialist through the CTS terminal. His input will be readily synchronized, once again, with the Aircraft Movement System, making it available to both OCC Supervisor and HCC Supervisor. As the main character on the Operational Control Centre, the OCC Supervisor is required to ratify the decisions proposed by the Specialists, while the Hub Control Centre Supervisor uses the VHF radio again to communicate changes to the Ground Supervisor.

All the activities above require time to perform. TAP was questioned about the duration of such activities and, while a definite answer was impossible, it provided minimum and maximum time intervals for each activity. At this point we understood that communications by phone take, on average, more time than VHF radio transmissions as they are usually concerned with more complex anomalies.
IV. SCENARIO AND EXPERIMENTS

This section aims at presenting the underlying aspects of simulation input, transformation and output. It provides useful insights to understand the organizational results presented on the next section.

A. Simulation Input Data

As advertised, our simulations used real operational data from TAP. In the context of our research, a database service was purportedly implemented to collect pre as post flight activity. The pre operational records included the scheduled flights, assigned aircrafts and assigned crew members. On the other hand, post operational data exposed the flights that actually took off as well as aircraft and crew changes. We were also given a list with all the flights that suffered departure delays, the amount of minute, and the corresponding TAP and IATA delay codes.

Possessing such data allowed us to input the scheduled flights and treat the delays, recorded after operation, as anomalies occurred during flight handling, i.e., an actual flight that suffered a delay caused by unexpected late passenger check-in, would be simulated as suffering a late passenger check-in anomaly.

It worths emphasize the uttermost importance of using real data. In an organizational structure not all the business processes assume the same prevalence, e.g. there are workflows that take place a higher number of times than others. Since we will use anomalies to trigger workflow execution, using random data would not respect the uneven distribution of processes, compromising the final results.

Our simulation was fed with the flights operated by TAP from the 15th to the 21st February of 2010, a whole seven days week of activity. Although 7317 flights were scheduled to take place that week, due to data incompleteness, e.g. missing databases fields, table referential deficiency, inconsistent data, we were only able to input 1801 flights, 389 of which suffered abnormalities.

B. Operational Workflow Transformations

The major goal of our study was to assess distinct airline organizational structures. Based on the actual airline simulation, the control group, three organizational structures were incrementally changed and simulated. All the simulations were executed after the same operational scenario, comprising the scheduled flights and anomalies referred on the previous subsection. When proposing organizational structure modifications we were cautious not to alter the inputs and outputs of the business process, i.e. never change the triggering and deciding agents.

Our first proposal (I) suggested the removal of the HCC Supervisor. After analyzing the actual sequence diagrams, we observed that he usually plays as information distributor and only assumes a supervising position when facing anomalies related to Passenger Services. Removing the HCC Supervisor required three major changes in four (out of the eight) workflows. The Ground Personnel was now required to go to the Hub Control Centre to input data into the AMS; OCC Supervisor accumulated the role of notifying Ground Personnel about OCC Specialists decisions; and the Passenger Services started to report anomalies to the OCC Supervisor via phone.

Proposal II departed from proposal I and aimed at avoiding the Ground Personnel to go to the Hub Control Centre in order to reach the Aircraft Movement System. This way, we suggested to add mobility support to the existing AMS, making it manageable through a wireless smartphone or laptop. Conscious of certain security implications, we decided that at this stage, access would be solely granted to Ground Personnel. All the remaining operators kept interacting with AMS the same way they did previously.

In our last proposal, III, we removed the usage restrictions on the AMS found on proposal II and started to think of it as a web-based system accessible from everywhere. At this stage, the Flight Dispatcher and the Station Supervisor were now able to input and read data from the AMS, no matter their location.

C. Metrics

Two metrics were used to assess organizational structure performance: overall disruption handling time and average collaborator stress. While they are both based on the activity duration, they measure different concepts. Overall disruption handling time is the sum of the time consumed by all the workflows, i.e., when an anomaly disrupts a flight it also triggers a workflow composed of several activities, which durations will be summed up until a solution for the anomaly is found. Concerning collaborator stress, it is a metric associated with each collaborator and thus requires a statistical aggregation to be used, e.g. the average. It measures the number of hours spent by a collaborator on the course of a simulation.

There are activities that contribute only once to the overall disruption handling time but several times to the collaborator stress. For instance, a phone call duration is added once to the former, but contributes twice to the overall stress, once per agent involved in the communication.

V. RESULTS AND CONCLUSION

Considering the scenarios depicted in the previous section, figure 4 presents the comparison across proposals of the overall disruption handling time (left) and the average operator stress (right). The measurements are carried out in hours.

As expected, the metrics in analysis show a certain correlation, even tough the collaborator stress is more affected.
by organizational structure transformations. The proposal that performed better was the third, achieving an improvement of 15% in the overall disruption handling and 21% on collaborator stress.

Figure 5 compares stress across collaborator and proposal (chart column labels described on Table I).

As one may observe, the OCC specialists (“as” and “cs”) stress remained the same across all proposals since they are deciding agents at the center of the airline workflows.

In the first proposal “hs” was subtracted and “gs”, “mss” and “os” suffered the highest impact. On the second, the wireless intranet capabilities introduced in AMS, allowed the stress results to get back to the real values, except for “os”. The last proposal, transform the AMS into an internet-based system caused the highest general impact on stress.

The above results proved that is possible to assess different organizational structure according to different metrics. Beyond the analysis herein documented, the simulation of the real airline organizational structure makes it possible to evaluate other scenarios or introduce new metrics. As an abstract model from reality, there is always room for simulation evolution.

REFERENCES


