Flight Operations as a System of Networks: A Sociotechnical Approach

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Abstract. The study reported in this paper used the Event Analysis of Systemic Teamwork (EAST) method to examine aviation operations from multiple perspectives (Dispatch, ATC/ATM, Maintenance, Loading, and the Cockpit). These networks were created for five key phases of flight: (i) crew briefing, (ii) preflight checks and engines start (iii) taxi and take-off, (iv) descent and landing, and (v) taxi, park and shutdown. The networks have been produced as an 'information audit' in order to understand the interactions and connections within the current system.

Keywords. Aviation, Networks, STS, EAST

1. Introduction

Aviation is a sociotechnical 'system of systems', encompassing technical, human, and organisational aspects (Harris and Stanton, 2010). Within these systems there are distinct operational independencies (aircraft operations; maintenance; air traffic management/control) and each of these aspects has managerial independence (they are run by independent companies or national providers). However, they are bound by a set of common operating principles and international regulations for design and operation. The inherent complexity of these operations is difficult to capture in their entirety, as they are distributed both in time and space. To overcome the challenges of modelling distributed cognition, Stanton and colleagues devised the EAST method (Stanton et al., 2008). EAST is underpinned by the notion that complex collaborative systems can be meaningfully understood through a network-of-networks approach. The EAST methodology is a contemporary approach for analyzing and modelling distributed cognition. EAST is underpinned by the notion that complex collaborative systems can be meaningfully understood through a network-of-network approach. The networks show multiple perspectives on the activities in the system that is a necessary requirement for sociotechnical analysis. It has been argued that the multifaceted nature of the different networks (i.e., social, task and information networks) have revealed the aggregated behaviours that emerge in complex sociotechnical systems (Stanton et al, 2008). This representation was proposed as an alternative to the reductionist approaches often used to understand systems, which presented systems in their constituent parts but failed to capture the system as a whole. Specifically, three networks are included (as illustrated in Figure 1):

- Task networks describe the relationship between tasks and their sequences;
- Social networks analyse the communication structure (relationships) and the communications (activity) that occur between the different agents (both human and non-human) in a team; and

• Information networks describe the information that different agents use and communicate during task performance.



Figure 1. The network of networks approach in EAST

Since its development the method has been employed in a number of areas, including aviation accident analysis (Griffin et al., 2010), air traffic control (Walker et al., 2010), naval operations (Stanton et al., 2006; Stanton, 2014) and military command and control (Walker et al., 2006; Stewart et al., 2008). It has been argued that the multifaceted nature of the different networks (i.e., social, task and information networks) have revealed the aggregated behaviours that emerge in complex sociotechnical systems (Stanton et al., 2008). The original version of EAST required input from a number of data sources, including Hierarchal Task Analysis, Critical Decision Method, Coordination Demand Analysis, Communications Usage Diagram and Operation Sequence Diagrams (Stanton et al., 2008; Stanton et al., 2013). Stanton (2014) presented a shortened version of EAST in which networks are developed directly from raw data (removing the need for all intermediate analysis), which is why it was chosen for this study (as is explained in Stanton, 2014). The EAST framework lends itself to in-depth evaluations of complex system performance, examination of specific constructs within complex socio-technical systems (e.g. situation awareness, decision making, teamwork), and also system, training, procedure, and technology design. Whilst not providing direct recommendations, the analyses produced are often highly useful in identifying specific issues limiting performance or highlighting areas where system redesign could be beneficial. Walker et al., (2010) suggested that the insights gained by network modelling were superior to the traditional ethnographic narrative that has previously been used to describe distributed cognition because they present graphical models of systems. 2. Methods

Data for this study were collected over a week-long observational field trial at an international air cargo operator in the Middle East. Ethical permission to conduct the study was granted by the Research Ethics Committee at the University of Southampton (RGO number 16250). All employees were aware of the nature of the study and signed a consent form prior to the observations. During the study period, six researchers were assigned to key operational areas within the cargo company and simultaneously observed and recorded the associated activities within the areas of: Crew Briefing Room (Dispatcher, First Officer and Captain), Loading (Supervisor, Team leader, Heavy Load Operator and Loaders) Maintenance (Engineers and

Bowserman), Flight Deck (Captain, First Officer and Engineer), Air Traffic Control (ATC) Tower (Ground Controller, Air Controller and Assistant) and Air Traffic Management (ATM) (Sector Controller).

Audio and video recordings captured the work being undertaken in each area. Each researcher also captured additional observations using pen and paper. An outbound flight was observed from the time the pilots entered the crew briefing room until it left the airspace. An inbound flight was observed from when the flight re-entered the airspace until it was shut down at the stand. Three outbound flights and two inbound flights were observed. Each flight resulted in approximately ten hours of recordings, which were transcribed, and supplemented with the additional observations, into excel files. The excel data transcripts were used to populate the three EAST networks for each phase of flight (i.e., (i) crew briefing, (ii) pre-taxi, taxi and take-off, (iii) descent, landing and (iv) taxi, park and shutdown), Task networks were generated from specific actions in the transcripts and key phases of work. These were arranged in chronological order to create a task network with colour coded nodes to represent the tasks and responsible actors. Social networks involved summing the frequency of from/to communications between actors and agents, i.e. noting which actors and agents the exchange went to and from. The social network details direction of information flow and strength of relationships between agents is represented by arrow thickness. Information networks were produced from key words within the transcripts to inform the nodes. These were typically were nouns as they represented the information content being transmitted by actors and agents. Key words that appeared together in the transcripts were linked to produce the network.

The network analyses are further enhanced through the application of network analysis metrics via AgnaTM software (version 2.1.1). AgnaTM is a social network analysis tool but is becoming an increasingly popular method for general network analysis as a way to gain deeper, quantitative, insights on qualitatively derived networks (Houghton et al., 2006; Baber et al., 2013; Plant and Stanton, 2016). Stanton (2014) proposed that metrics should be selected based on the evaluation being performed and that not all metrics are relevant to all research questions. For this work, the metrics of density, cohesion, and diameter were calculated for the whole network and for individual nodes the metric of sociometric status was calculated.

The complexities of the data collection process are depicted in the 'rich picture' in Figure 2. The initials denote the member of the research team and the role they were observing.



Figure 2. Rich picture of data collection from multiple perspectives in flight operations

3. Results

Space limitations prevent all of the networks for all of the phases of flight being presented within this paper so just one phase is focused on, that of the Taxi and Take-Off Phase.

3.1. Task Networks

The task network for the taxi and take-off phase is shown in Figure 3. The flight deck tasks are linear, following a standardised pre-take off procedure, where one task cannot begin until completion of the previous one. The flight deck tasks are also dependent on ATC tasks, for example the aircraft cannot be taxied until ATC have provided permission to do so. Once the aircraft has taken off, ATC pass the flight to radar control in the Air Traffic Management (ATM) sector. ATM provide the flight deck crew with instructions (e.g. height, heading, flight level, route). Data collection ended once the aircraft had left the controlled airspace of the country the study was conducted in.



Figure 3. Task network for taxi and take-off phase

3.2 Social networks

The social network for the taxi phase is shown in Figure 4, where the frequency of communications determine the strength of the connection between agents, i.e. darker lines represent stronger links based on high frequencies (and vice versa). This phase consisted of 45 human and technical agents but for clarity the top 30 agents are depicted. Social network metrics were computed from the raw data. The network density value is 0.03, indicative of a relatively unconnected network, although this network is slightly more connected than the pre-taxi network (0.01). Network cohesion is 0.007, suggesting few reciprocal links within the network. Network diameter is 6 (i.e. 6 'hops' from one side of the network to the other). In relation to the individual nodes, sociometric status was calculated to determine the relative importance of each node. The Captain and First Officer are the most important agents in this network both being defined as primary concepts. The other key concepts were ATC agents and the ATC Tower in general. This is unsurprising given that the task network demonstrated how this phase is dominated by flight deck and ATC tasks. Clearly, this has implications for a distributed crewing environment where it will need to be decided who has primary communication responsibility with air traffic services. Currently, the pilot monitoring communicates with ATC (although this may or may not be appropriate when this pilot is remotely located in a ground station). Similarly, the social network diagram depicts how many reciprocal links there are between the Captain and First Officer, thus the challenge for the distributed crewing environment is to maintain this level of communication across a distributed situation.



Figure 4. Social network for taxi and take-off phase

3.3 Information networks

As part of this phase the emergency brief is conducted between the Captain and First Officer (the full information network would not fit into the space of this conference paper – but will be presented). The network for the emergency brief is shown in Figure 5. This is where the pilots discuss what they will do in an emergency and the network highlights the information elements the pilots work through to complete brief. For example, the 'problems fire/engine failure' node is connected to 'below 80 knots' which is connected to 'stop', i.e. if the fire occurs below 80 knots the crew will stop the aircraft. The role of the emergency brief is to provide the crew with an opportunity to cross-check safety critical information. It is also a planning activity to ensure that the initial checks are actually made in order to complete the brief. Figure 5 presents one example of a flight crew brief but many other briefs make up the pre-flight preparation phase. Careful consideration will have to be given to the nature of the crew brief in a distributed crewing environment.



Figure 5. Information network for the emergency brief.

4. Conclusions

The analysis of current operations used the EAST method to produce task, social, and information networks. The context of this analysis was in short-haul cargo operations as this is likely to be the initial context of distributed crewing environments (Harris et al., 2015; Stanton et al., 2016). This analysis supports an alternative crewing model because it serves as an 'information audit' of the interactions and connections within the current system. It is not possible to consider the differences within a future operating environment without having first understood the current situation. In addition to generating the three networks for each phase of flight, key network metrics were calculated to quantify some of the qualitative insights gained from the networks. In this analysis of current operations, the individual node metric of sociometric status has been of most relevance to the discussions. However, it is anticipated that the whole network metrics will be used as a comparison between the networks created for the future operations analysis.

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