Applying Pretopological Concepts & Negotiation Analysis to Study Cockpit's Perspective to Collaborative Decision Making

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Abstract

Objective: This research is designed to present a methodological approach for problems encountered with cockpits perspective to collaborate decision making in order to support the Air Transport Management (ATM) with simulation software development and system behaviour simulation.
Background: Collaborative decision making (CDM) is a means to challenge punctuality and reliability issues at congested airports in order to raise operational capacity at the airport and air space structure, not by sophisticated optimization algorithms rather than just information sharing and common situational awareness. Initial concepts of CDM emphasize the importance of global collaboration among interactions between airport operators, air traffic control (ATC), airlines, ground handling service providers and the central flow management unit (CFMU). From cockpits perspective, CDM should be considered as a means to allow participation of flight crews in air-traffic decision making that affects them. This applies to all decisions ranging from operational to safety issues during all phases of flight/ ground operation. From cockpits perspective, two main issues should be addressed:

- How can information sharing/ common situational awareness between flight crews and ground parties be accomplished in order to achieve a high level of punctuality and predictability during flight/ground operation.
- Is it possible to improve operation by cooperation of all parties.

Method: This approach is based upon mathematical tools like pretopological and decision making concepts. Negotiation Analysis approaches decision making in order to identify prescriptive, normative and descriptive decision concepts. Distinctions are made among the prototypical and unitary perspective of an individual decision maker (pilot), and the dynamics between multiple decision entities (airline operator, ATC). In complex systems decision entities can also have a different structure. Pretopological concepts are used to identify groups of interdependent elements (for example pilot-controller relation) and elements which are related with each other within the Air Transport System (for example pilot-pilot relation).

Key Words: Collaborative Decision Making, Behavioral Game Theory, Multi-Agent Systems, Cognitive Engineering, Pretopological Concepts, Negotiation Analysis, Naturalistic Decision Making, Coalitions

1. Scientific Context: There are many definitions concerning complexity: complex systems can be for example abstract, natural or networks. A common property of complex systems is the difficulty of their representation as a formal model. The description of complex systems is both multifaceted and dynamic and can be found in numerous areas like Air Transport Sytems, Space Systems, Medical Systems, and Industrial Engineered Systems. However, complex systems may also have key commonalities and common underlying mechanisms, and can therefore be modelled to a certain extent. The objective of the research is to examine how the application of game theory and negotiation logic can enable the predictability of collaborative decision making results within the complex environment of an automated supervision system incorporating human interaction. The research will aim to generate real-data scenarios and simulation tools to provide a scientific basis for optimizing the complex systems decision making.

2. Theoretical Approach: Decision Making has often been analysed as isolated decisions made by individuals. In a complex system environment, decision making is a continuous, interpersonal process with usually multiple decision makers[16,17]. Distributed decision making provides a theoretical framework to study automated supervision systems in interaction with humans in complex networks[1]. Game Theory as a special branch of mathematics, has been developed to study such decision making within complex circumstances and tries to predict outcomes based on interactive models in which the decisions of each stakeholder may affect those of the other stakeholders. These models are simplified abstractions of the real-world interaction. They can be used to abstract many serious situations and offer a basis for the design of a decision support system in complex and collective environments. The Decision Making process is as a basic cognitive mechanism having distinctive characteristics of dynamical behaviour[2]. Conceptually located between decision analysis and game theory, the logic of the Negotiation Theory follows the neuro-cognitive process of decision making [3]. It emphasizes the assessment of the parties underlying interest, seeking to manage the inherent tensions between corporate and individual interest to create value jointly (including for example non determined, but emergent behaviour, certain degree of concurrency/ compromising, and reactive information-driven behaviour).
While negotiation analysts often draw on experimental and scientific behavioural findings, the game-theoretic rationality can thereby not necessarily be presumed. The application of pretopological concepts aims to define a clustering algorithm in order to gain a view of relations between groups in its structure and offers a new clustering method in two stages: first structuring the population by minimal closed subsets, then extracting clusters number and cluster centroids. The advantage of this approach is, not to be cluster number constrained a priori or restricted by random choice of centroids. It also provides a framework for modelling and formulating different types of connections that exist between elements of a population[4].

3. Context of the Research Proposal: Air Traffic Management can be considered as an automated supervision system interacting with humans (controllers, pilots, ground airport). It has considerable network characteristics and can be seen as a complex system. Within this complex system are undefined interrelations, interfaces and information transfers between multiple subsystems, which themselves can be classified in society, technical, and human subsystems. A representative number of activities and interactions can be linked to the cockpits perspective as one component of different subsystems and part of the Air Transport System. The research encourages the analysis of this cognition and decision making and the application of this knowledge to design systems and processes by applying theoretical models. Within the future airport operation control centre all concerned stakeholders contribute to the airport operations plan with the idea of a human centred automation, since human actors are directly involved in control activities. This approach follows the concept of collaborative decision making with collaboration, interaction and communication as the centre aspect and needs airside and groundside human behavioural data in order to create virtual human and behavioural modelling[6]. The representation and simulation of virtual humans is an essential part of the distributed decision making environment [7]. Early use of virtual humans and behavioural modelling can provide realistic representations and simulations of the decision making process and prototypes of collaborative decision making models can be built faster and with increased quality[8,9]. The application of the different models and mathematical tools will be based on collected multi-modal behavioural data linked to cognitive activities, empirical study of weak points and information sharing needs identification. As a result, best/worst practise approaches, incorporating user behaviour are used to create simulation software development and contribute to the holistic idea of a human centred automation based on the multi-agent systems. As a consequence, this approach allows to establish structured methods for collaborative decision making to improve airport throughput.

4. Introduction to cockpits decision making environment: The environment of the aircraft specifies a special case of decision making: the commander of the aircraft has the topmost responsibility of all decision making on board the aircraft. This can be compared as decision making with an individual decision maker (commander) and a group of advisers. He can either use his position to listen to his various advocates different positions or actions, or execute his own analysis by the use of help from experts or advisers (airline company, ATC, ground handlers.). It is his final responsibility to identify key uncertainties in decision making and he either adheres to objectives for the organisation or his personal goal. (It seems unlikely that the commander puts his personal goals too far from advisors position but will be taken into account to gain a more realistic view of decision making). Further losses of efficiency in this kind of decision making may result from other players interactions, lack of information or limited ability of decision making. The advantage from this individual decision making is that a group of advocates is involved and therefore has more resources available [2]. Decision making seen from cockpits perspective is also distributed since a number of decisions necessary for the flight operation remain in responsibility of the advisors (ATC, airline company, airport.).

5. Behavioral realities in decision making: For better understanding of the decision making process in air transport management systems (ATMS), the variation of behaviour between the fact how decision making is assumed to take place and how it really is, will be taken into account. While single decision makers try to maximise own value (e.g. flight crew adjusts speed or cruising altitude to individual interest versus prefered speed and altitude by airline company), collaborative decision making emphasizes a full, open, truthful exchange in order to maximise joint gains (conflicting of interests within decision making may be possible)[2]. But payoffs for one cannot be dissociated from choices of the other. This interdependence of payoffs is a feature of the game theory and joint decision making is assumed to determine the payoffs for each party[10]. As communication can be used to share interests, expectations, visions, etc, it can also be used for bluffing, threats, trickery, and half-truths. [2].

Decision making needs to take different perspectives into account: a particular problem can be viewed by an individual decision making perspective (e.g. single pilot, single controller) or an interactive decision making perspective where behaviours and interests of the other side are considered. The joint decision making perspective emphasizes the opportunities for cooperation between parties for iden-

tification and drafting of joint agreements to benefit both sides. Sophisticated decision makers can switch between the different perspectives[11].
Analysed by means of the game theory, number of behavioural realities for decision making should be taken into account [12, 13, 14]:

- Are there linkage effects on the decision
- Is the decision repetitive and how many issues does the decision have
- Is an agreement required or are there possible threats
- Are all partners fully cooperative: (e.g. fully cooperative partners might have different needs, values and opinions expecting total honest, full disclosure and no strategic posturing)
- The difficulty to balance joint value creating tactics with tactics designed to claim individual value

The analysis intends to capture this behavioural complexity of human decision-making in ATM operation. Further complexity arises from the way in which prior actions affect later decisions as decision-maker struggle to adapt to a changing environment[2].

6. Research Concept

6.1. Literature Review

Game Theory: In order to effectively model and analyse decision making in multi-person situation where outcome depends on the choice made by every party, game theoretic situations relevant for decision making in the cockpits environment are used as a formal modelling approach to social situations in which decision makers (crew members, ATC, airport operator, ground handlers, CFMU) interact with others minds. **Behavioural Game Theory:** Behavioural observation of individual decision makers reveals that individuals act because of their own interests[15]. Behavioural analysis will therefore be applied to close the gap to ordinary game theoretic modelling by including aspects of players emotions ranging from how moral obligations and vengeance affect the way they bargain or trust each other. **The evolution of cooperation:** There is a broad division of game theory into two approaches: the cooperative and the non-cooperative approach. What are the individual (pilots, ATC, airport representative, ground handler) motives for cooperation and the consequences for the system? The aim of using the theory of cooperation[15] is to find factors necessary for a successful collaborative decision making environment, because if the conditions necessary for cooperation are understood, it is possible to find appropriate measures to advance the development of cooperation in certain situations. **Negotiation Analysis:** Collaborative decision making from cockpits perspective means also regular bargaining of cockpits crew members with different groups (ATC, airline company, airport, ground handler) having different demands and therefore different intensions. In ATMS context negotiation analysis implies mutual communication with the aim to converge the different positions of everybody concerned while all having mostly different interests and to find how the target group of individual cockpit crew members should and could make joint collaborative decisions. The advantage of using negotiation analysis for the research is that it is not as restrictive as game theory (individual perspective of decision maker) by combining the individual and the interactive perspective towards decision making by adding the third perspective of joint decision making. **Pretopological Concept Analysis:** Information sharing between flight crew members and other players within the ATMS takes place in various circumstances via established ways in order to increase common situational awareness. The aim of the research is to analyse the information sharing process within ATM to identify different types of information sharing among players and to model new types of connections by structuring the players into minimal closed subsets, then extracting clusters number and cluster centroids.

6.2. Data Collection

Sample Crew Members: There are 600 commanders (to be agreed) from different airlines in the study population for problem identification. Of that total, there are approximately 20 commanders chosen (to be justified) for identification of key issues in cockpits perspective towards CDM. The number 20 is misleading to be representative, but own perspective to the problem anticipates a straightaway agreement and identification of key issues.

Method: The data collection uses two types of methods (qualitative and quantitative) and consists of three stages:

1. In-depth interviews with senior commanders of different airlines in order to get a picture of the important issues which are likely to be encountered in the research.

2. A self-administered questionnaire will be developed with questions based on problems for CDM from aircrafts perspective mentioned above. Each problem will lead to a hypothesis (e.g. common situational awareness between cockpit and other players may not always be present due to spatial separation; cooperation among the players may not always be presumed due to different values of partners; one part of an operational information may stall the turnaround or flight punctuality; not all partners relevant for information sharing are integrated within current CDM approach). The questions in the questionnaire will seek to test these hypotheses. The questionnaire will be distributed to a sample (size to be agreed) of commanders from different airlines (to be agreed) across three major airline companies. Statistical tests will be run to ensure that the results are a function of cockpits perspective rather than situational coincidences. This survey strategy is used because it allows examination and explanation of cause-effect relationships, e.g. missing one particular part of information may stall turnaround punctuality and gives easy comparison of derived data.

3. Semi-structured in-depth individual interviews with further representative commanders to clarify the content of the expected questionnaire results. This will be necessary to get the meaning behind expected essential results and to understand the attitude.

Statistical Data Analysis: The hypotheses are tested first by determining the actual level of information sharing for decision making, failure or latency of information during each phase of flight and the mode of the decision in general (routine - non-routine/ collaborative - individual). Sample population are then asked to define a normative approach by arguing their actual information need in relation to actual information sharing and a definition of decisions which should be in position of cockpit or consigned to other decision maker. It is intended to identify thereby also dilemmas/ trade offs in the decision making process and information about the decision maker. Sample population will then be asked to evaluate present state of common situational awareness and identify opportunities for improvement. Subsequently it is evaluated how cooperation emerges from information exchange and decision making between crew members and third parties.

6.3. Agent-based approach for collaborative cockpit/ground decision making simulation

The results from statistical data analysis are extended in an existing large-scale simulation of ATMS to assess impact of aircrew behaviour, variance in information sharing/ common situational awareness, and relevance of cooperation on feasibility and scalability of cockpit integration within CDM. This effort is supported by application of software agents having consequences on punctuality caused by:

- Situational unawareness due to lacking information distributed from or into the cockpit by other party integrated in the complex ATMS (e.g. ATC, ground handler, airport).
- Poor cooperation among parties
- Unbalanced decision making or shifting decision-making responsibilities.
- Establishment of new forms of information sharing via minimal closed subsets within cockpit crews and ATM partners.

It is analysed how the interplay between complementary human-in-the-loop and agent-based simulations for decision support can be described and how obtained data can be used to leverage application of decision support tools and information sharing among flight crews and ATM parties to achieve efficiency and capacity gains while maintaining safe operations. The application of an agent-based approach is necessary because scalability investigations with multiple independent flight and ATC simulator operations are inherently complex and impose considerable staffing and logistical problems[18], but necessary to analyse sensitivity and robustness by systematically manipulating numerous independent variables.

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