INFORMATION SYSTEM AND AERIAL WARFARE: ENHANCING DECISION MAKING IN EXTREME CIRCUMSTANCES

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Abstract

This article investigates the potential offered by information system to improve the quality of decision making in extreme circumstances. The literature commonly mentions models of fit to explore technology-to-performance issues, reckoning users' evaluations as a relevant measurement technique for information system success. Drawing on such approaches, this article aims at providing some valuable insights to assess the benefits of a networked decision support system for decision makers, and offering a better understanding of how and why these improvements arise. An original case study considering usages of a networked decision support system called Link 16 during aerial missions has been conducted. It led to suggest an appropriate decisional model, the decisional fit model, which provides new perspectives to explore the effects of networked technologies on decision performance.

1. Introduction

2010 – Kandahar – Afghanistan, French fighter pilots are deployed on a daily basis to support friendly forces on the battlefield. As the mass media often reminds us, such air operations are quite dangerous and pilots have to make decisions under stressing circumstances. To achieve their goals, some of them are provided with a specific decision support system, called Link 16. It is a tactical up-gradable data link built upon a network made by all other military information systems and aimed to deliver shared information and shared intent to all the users.

This article investigates the potential offered by such a networked decision support system to improve the quality of decision making in extreme conditions, which can be characterised by contextual uncertainty, imprecise information, time-sensitivity as well as rapid, discontinuous, and simultaneous changes [2]. More precisely, the research question can be stated as follows: *How does a networked decision support system affect individual decision making performance in extreme environments?* Although the relationships between decision support system and performance have been largely explored by literature, analysis of networked decision support system and its effects on decision made within extreme conditions has been neglected until today. Literature commonly mentions models of fit to explore technology-to-performance issues [4], reckoning users' evaluations as a relevant measurement technique for information system success [5]. This paper draws on these fit approaches to provide a comprehensive understanding of the potential offered by a specific kind of information system, a networked decision support system, to enhance individual decision making. In doing so, we add to this line of work in addressing the particular area of decision making in extreme environments and outlining how decision support system affects decision performance. The measurement of performance relies on users' evaluations of decision quality when they use a networked decision support system, in comparison with decision quality without using such a system.

We conducted a qualitative study based on a research contract funded by the French Air Force and which especially highlighted the issue of acquiring new capabilities with regards to the multi-role fighter aircraft Rafale outfitted with the Link 16 system. It has been the opportunity to collect pilots and navigators' perceptions on decision making performance when the airplane is equipped with Link 16 and when it is only equipped with voice communications. This case study stood as a pertinent field since (1) decision makers deal with a highly complex environment, constantly facing new conditions and making real time decisions and (2) Link 16 is viewed as critical for supporting decision making, providing users with accurate and up-graded tactical information to make appropriate decisions.

This paper proceeds as follows. The first section describes the prior literature on fit models and suggests a definition of a networked decision support system. It is followed by the detailed case background, the research methodology and the case results. The third section discusses these results and displays a preliminary conceptual model which aims at enhancing the understanding of the effects of a networked decision support system on decision making performance. The last section concludes with implications for both research and practice.

2. Conceptual background

2.1. Decision Making in Natural Settings

Decision making has been studied extensively by management researchers as well as cognitive scientists and many others. The literature commonly addresses two key approaches to explore decision making process [9]. The first one, based on the rationalist thinking, focuses on the entire process of decision, seeking to conceptualize it. Decision is the result of a rational choice between alternatives, and supports a broad search for many options. Given these circumstances, people systematically made optimal decision or, when rationality is considered as bounded, made the more satisfying one. Rational approach is useful to explain problem resolution, especially when decision makers are novices and do not have sufficient experience base to refer to typical courses of action. In that way, rational models can provide novices with appropriate decision making guidelines.

The second model of decision has been developed at the end of the 80's by a team of researchers led by G. Klein. They decided to follow an original path to study decision makers [18] in examining the way they behave in natural settings. This naturalistic or observational methodology, which contrasts with experimental and quasi-experimental ones [10], has led to a relevant result: in context, an expert decision maker facing a complex, urgent and risky situation does not choose between many options to decide. He refers to typical ways of responding and his decision results from a recognition primed process. As we understand, naturalistic decision making approach mainly focuses on expert decision makers who have experience of past cases and the ability to link previous and current situations. Moreover, naturalistic decision making approach is usually applied to understand decision making under changing and time-pressure environments, such as healthcare, fire departments or military operations [9]. As a result, the naturalistic decision making approach appears to be in line with our research objectives and context.

2.2. Positioning our study among the world of fit-based models

Two models of fit are commonly mentioned and used to explore technology-to-performance questions: the task-technology fit and the cognitive fit models. First theorised by Goodhue and Thompson [4], task-technology fit mainly focuses on the relationship between task and technology, and its impact on performance. In that view, technology is considered as a means to allowing an individual to carry out a task. Measurement of performance is based on user evaluations of differences in fit before and after technology implementation. According to Goodhue [3], user evaluations are "*elicited beliefs or attitudes about something and [can be] used to measure many different 'somethings' about systems*" (p. 1828). Consequently, they must be thought of as a measurement technique (rather than as a single theoretical construct) which allows identifying some theoretical perspectives to examine system success.

Many contributions rely on task-technology fit model to analyze the interplay between decision making performance and technology. For instance, Todd and Benbasat [14] investigate the relationship between a decisional task and a decision support system to evaluate its impact on decision performance. The model they display is one of the first which clearly focuses on decision making performance. Recently, Junglas *et al.* [8] built their studies on the healthcare industry upon the task-technology perspective. Combining seven notions of fit and four human drives into two original research models, they examined the determinants of decision to utilise or not mobile technologies.

However, task-technology fit models have some limitations to explore technology-to performance issues, especially due to the fact that they mostly ignore the influence of individual characteristics [8]. In that way, the cognitive fit model is interesting to consider since it takes into consideration the influence of individual minds and cognitive factors. As Vessey [15] states, it is necessary to look beyond task-technology fit model and to view "*problem solving as an outcome of the relationship between problem representation and problem solving task*" (p. 220). As a result, the cognitive fit model focuses on the relationship between information and cognition as essential components to understand the effect of decision support system on decision performance. It reckons that decision quality highly depends on the ability of technology to provide decision maker with the appropriate problem representation.

Shaft and Vessey [13] refine the cognitive fit perspective and detail the question of problem representation in a model they call extended cognitive fit. The authors distinguish the internal and the external representations of the problem domain to provide a more complete understanding of the relationship between software comprehension and modification. Based on Zhang and Norman [17] contribution, internal representation refers to the pre-existing knowledge concerning the problem category. The external representation is the formalised image of the problem perceived by a decision maker.

As an articulation of task-technology fit and cognitive fit approaches, the extended cognitive fit model refines the micro-level analysis of the relationship between technology, user and task characteristics, especially in considering the problem of internal and external representation as critical to investigate technology-to-performance issues. This article relies on these refinements to explore the research question, suggesting that when individual decisions are made under time-sensitive and changing circumstances, the systems ability to provide the decision maker with an appropriate representation of the problem becomes central.

2.3. What a networked decision support system is?

The article is interested in exploring the effect of a specific information system on decision performance: networked decision support system. The decision support system has evolved to accommodate many forms [1]. With regards to the five main categories of decision support systems listed by literature [11], networked decision support system matches with the data-driven system category. Indeed, it aims at organising, retrieving and analyzing data in order to provide the decision maker with an accurate representation of the problem he addresses, and to support him to picture his environment.

When a data-driven decision support system is structured into networks, it becomes what we call a networked decision support system. In gathering large amount of information from all available networked sources, such a system provides decision makers with (1) visualisation of all elements of interest in layered form and (2) representation of links between these elements. As a result, an individual decision is made from an overall vision of the environment and its components (human, technological, physical, etc.).

3. Research method

To investigate our research question, we conducted an explanatory case study [16] in which decision makers use a networked decision support system to achieve time speed tasks.

We selected an extreme single-case study to explore the significant phenomenon of decision making under extreme circumstances. More precisely, we focused on fighter pilots and/or navigators' decision making in a warfare context, using a networked decision support system called Link 16.

3.1. Case settings

Implemented into Rafale aircraft at the beginning of 2006, Link 16 is a wireless decision support system, supported by a highly secured network. It provides users with a range of services such as communication devices enabling users to quickly share information on short notice (a kind of instant messaging), and up-gradable database delivering a real-time picture of the tactical situation. This general picture is built upon a line-of-sight data for aircraft-to aircraft, aircraft-to-command and control, and aircraft-to-sensor connectivity. For instance, a fighter aircraft equipped with Link 16 receives on its display screen information concerning friendly and enemy airplanes' positions, counter-battery sites, and location of ground forces. This information comes from other neighbouring fighters, the airborne control system aircraft AWACS, navy ships, and Special Forces units deployed on the battlefield. On the battlefield, Link 16 is used to achieve two kinds of aerial missions: air strike and air defence.

3.2. Data collection

In order to consider the effects of Link 16 on individual decision performance, we encouraged pilots and navigators to compare their way of operating when equipped with the Link 16 system and when equipped only with voice communications. We organised data gathering over a two-year period, from September 2007 to November 2009, in the course of which we visited Rafale squadrons two times (in January 2008 and November 2009). To achieve triangulation [2], we collected data from multiple sources of information, including individual and collective interviews, field observations, and archival records such as reports from the field, doctrinal documentation, and studies funded by the Department of Defence and the French Ministry of Defence.

Fourteen semi-structured interviews were conducted with pilots and navigators of Rafale, one with a Rafale experimental test pilot and one with an AWACS mission commander used to command and control the battle-space with Link 16. Each interview lasted on average one hour and a half and was tape-recorded and transcribed. We followed an interview guide focused on users' evaluations of differences in aerial operations conduct with and without Link 16: first, we questioned the Link 16 usages in achieving Close Air Support missions in Afghanistan and/or French airspace control and protection. In doing so, we wanted to understand how the system works and what pilots and navigators concretely do with it, and thanks to it, during the course of action. The second question concerned users' perceived values of Link 16 on decision making and, broadly, on mission achievement. Finally, the third question investigated unexpected effects of Link 16 usages and new issues it was able to instigate. We also re-used transcripts of two Rafale pilots to realise a new focus on users' evaluations of Link 16 [6]. We handled that secondary analysis of verbatim to complete our own investigations.

In order to yield our benchmarking approach and to better understand the nature of pilots operational work without Link 16, we interviewed 6 pilots of Mirage-5 (air defence aircraft) and 6 pilots and navigators of Mirage 2000D (strike aircraft) to understand the way they make decision and achieve missions without Link 16.

Further, we had the opportunity to observe how Link 16 runs by attending an air operation simulation. We also gathered French after-action reports from the field and NATO training exercises, as well as American institutional monographs and US Air Force after-action reports from Afghanistan and Iraq.

Finally, we collected data concerning the French doctrinal vision of Link 16, in studying internal archives and interviewing two high-ranking French Air force officers assigned to think the near-future evolutions of Link 16.

3.3. Data analysis

All of these data collection methods allowed us to gather an important amount of multifaceted data. In order to investigate the effect of Link 16 on individual decision performance, we had to document and analyse pilots and navigators' evaluations related to the ways Link 16 has modified the process of mission achievement and has affected decision making with regard to their previous way of doing. We transcribed data collected from tape-recorded and written interviews, and structured our observations and field notes. Coding of our data was conducted using N-Vivo7 software. We completed our analysis in a bottom-up perspective to foster the emergence of our categories.

4. Results

Recalling the research question presented previously, our goal was to gain clearer understanding of how and why Link 16 affects individual decision making performance in extreme circumstances. This section provides comprehensive insights from the interviews of reporting pilots and navigators, regarding the perceived usefulness of Link 16 when they make decisions in operational situations.

The first and general result is that all the interviewees agree that Link 16 has significantly improved the way they achieve air operations in comparison with voice communication: 100% of respondents spontaneously pointed out that Link 16 enhances mission capabilities, especially in increasing communication quality and sharing abilities. These two testimonies are good examples of what we have encountered:

"I can use a metaphor: before [Link 16], we used to run in a tunnel with only torchlight to guide us. Now, with Link 16, you'd switch the light on."

"With Link 16, it becomes simple to perform our tasks. Without Link 16, it's hell."

In addition to such general comments, line-by-line coding of the materials revealed that pilots and navigators evaluate Link 16 efficiency in a different way, whether they focus on the system ability to support air missions or respond to their requirements during the course of action. We assumed that the first issue concerns the interplay between technology and task whereas the second addresses the relationship between internal and external representations of the problem domain.

4.1. Fit between aerial combat missions and Link 16 is enhanced

During interviews, pilots and navigators were very concerned about Link 16's characteristics and its ability to support their task needs during air combat. More specifically, data analysis shed light on the following results: pilots and navigators consider that the ways Link 16 provides information substantially reduces the risk of data misinterpretation.

In comparison with the way they used to conduct air operations without Link 16, pilots and navigators noticed two main technological improvements. They are related to the quality of (1) visual presentation of the tactical situation and (2) intra-flight (aircraft-to-aircraft and between aircrafts and AWACS) and extra-flight (between aircraft and ground forces) communications. To this extent, the system's characteristics appear to be in line with the pilots' task needs.

Concerning the presentation of the tactical information, Rafale pilots and navigators are provided with continuously updated tracks which visually display the precise location and velocity of detected aircraft, counter-battery sites and/or ground forces. Different icons appear on the screen to indicate the nature of the track (friend, enemy or unknown), warning the pilot of potential threats and helping him to change his flight path, for instance data characteristics are designed to be easily understandable and processed during the course of action: friendly forces are symbolised by green circles and enemy forces by red triangles. In addition, other coloured symbols appear to provide information related to the origin of detections. This way, pilots and navigators immediately know if tracks are transmitted by AWACS, their own radar systems, or some other sensors. Such extra information also indicates whether a track has been merged or not by the system. Merging operations are critical since they allow pilots and navigators to collect simplified information on their display. As a result, they don't have to manually differentiate between many tracks nor analyse each anymore. A pilot indicated:

"Before Link 16, you had to mentally create the situation by yourself. Now, you don't have to do this work anymore. With Link 16, it's really easy to see everything".

"The implementation of Link 16 is a means to improve considerably information gathering and to reduce manual tasks".

The second technological improvement perceived by interviewees concerns the quality of communication between aircraft and between aircraft and ground forces when necessary. Before Link 16, the main communication channel was radio transmission. Pilots and navigators had to continuously listen to voice communication describing air traffic, mentally convert each description into a location and develop an appropriate tactical response. As a navigator detailed:

"With Link 16, we quite limit talking".

"For example, the patrol leader can automatically check the fuel level of his wingmen. No voice communication is required anymore"

4.2. Fit between pilots and representation of the problem domain displayed by Link 16 is increased

During interviews, pilots and navigators responses often underlined that services (form and content) provided by Link 16 match adequately with their internal representations of the problem domain. In effect, material coding shows that the usages of Link 16 tend to enhance the fit between decision makers and the system.
Pilots and navigators' evaluations of Link 16 clearly indicate that their internal representation of the problem fits with the external representation proposed by the system. In other words, pilots' expectations of what the problem domain will be matches with the form and the nature of data transmitted by Link 16.
Especially, many of them stressed the reduction of cognitive workload they take advantage of. No mental calculation and compensation are required anymore and they can collect information much faster and accurately. To this extent, the pilots and navigators' perception of mental workload is positive since they feel delivered from information management tasks. When some duties are assigned to the system, they gain time for higher level decision-making. The results of such compression on time and cognitive workload are extra time saving. This extra time can be used to reckon more alternative courses of action and to make more decisions in a given period of time. Moreover, instead of spending their time to gather and monitor data, they can focus on the essential steps of their mission, which means refining plans and developing sense-making. A navigator stated:
"Tasks related to information management are pretty reduced now; Link 16 handles much of them".
A pilot detailed:
"With Link 16, you don't feel overloaded anymore." As a result, *"You can dedicate your capacities to tactics"*.
Some pilots also underline the ability of Link 16 to support what they called "*instinctive fights*." That means that Link 16 has significantly enhanced situational awareness; it efficiently supports tactics and mission steering by providing an integrated and real-time interpretation of the tactical situation. That way, pilots are "guided" within the combat environment. As one of them noticed:
"*With Link 16, you can see everything and share everything you see; you have a common visualisation in real time*".

5. Discussion

In examining how networked decision support system affects decision making performance, we provided a classical answer: in improving fitness. However, case study findings allow refining our understanding of this fitness, especially in entering deeper into fit relationships.
Indeed, the case study highlights two main results: the enhancement of fitness between (1) aerial missions' characteristics and Link 16 and (2) pilots' internal representations of the problem domain and representations displayed by Link 16. In this article, we consider these relationships as fit criteria to examine networked decision support effects on decision performance: the first relationship represents "conformity" between networked decision support system and tasks' characteristics since the second stands for "complementarities" between internal representations of the problem domain and the systems ability to provide the decision maker with an accurate representation of that problem.
Conformity is commonly reckoned as a relevant criterion for studying decision support systems. Literature introduces conformity, whether to understand how people conform to decision proposed by the system [12], or to observe conformity between the system and the decision maker's expectations. This paper draws on the latter perspective, considering that the decision maker can be in conformity in totally agreeing with the picture delivered

by the system on the one hand, or in being forced to agree on the other hand. In making users comply with a set of contextual requirements and comparable forms, conformity refines understanding of how data picturing and quality support decision making. In that way, conformity criterion allows responding questions such as: does information displayed on the screen match with the decision makers expectations? According to Rowe [12], researches on conformity are mostly based on experimental studies and need to confront real situations to acquire robustness, in particular through qualitative studies. For instance, our case study findings do not reveal big issues concerning conformity and the system used by pilots and navigators. One explanation could be that the system studied is networked centric and allows all users to acquire the same picture at the same moment. Since pilots are trained together all year long, they share a mutual experience and a collective knowledge that help them to generate coordinated expectations and behaviours.

Regarding the complementarities criterion, issues concern the way additional information is able to refine user's representation of the problem domain. Such a criterion allows answering questions such as: does individual representation of what the task must be and what is achieved comply with the picture displayed by the system? Case study findings suggest that the pressure generated by the environment fundamentally impacts the complementarities criterion. Especially, in extreme environments where decision makers cannot allocate time to double process information and the ability of the system to provide an appropriate picture of the situation becomes critical.

We suggest a model when studying fit relationships between networked decision support system and individual decision performance. We call our model "decisional fit model" (Figure 1). It can be considered as a specific derivative of the extended cognitive fit model since:

- External representation of the problem exclusively comes from information system or, more specifically, networked decision support system.
- Three fit relationships are studied: fit 1 analyzes the interplay between task and networked decision support system, fit 2 focuses on the relationships between the decision maker and a networked decision support system and fit 3 concerns the link between the decision maker and the task's characteristics. In exploring these three relationships, we seek to complete a micro-level analysis of fit.
- Unlike extended cognitive fit model, we linked the decisional task with two other components: first, the networked decision support system designed to manage the task and second, the impact of an extreme environment on decision making. In effect, under extreme circumstance, decisions must often be made quickly. As a result, the mental representation of the problem can simply represent the decision an individual will finally make. This decision is significantly influenced by the level of fitness.

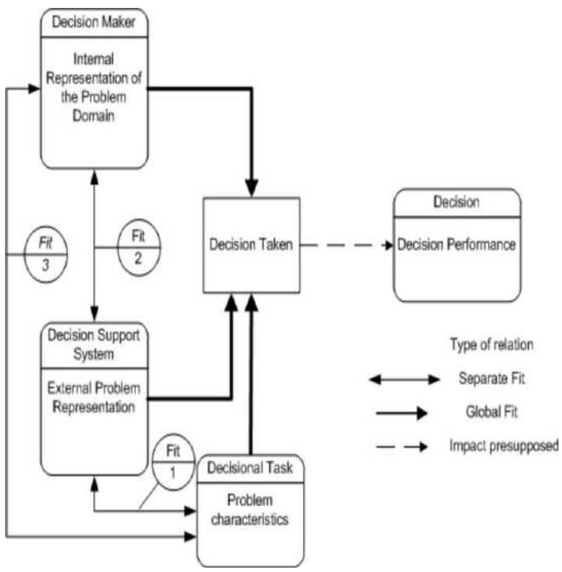

Figure 1. The decisional fit model

6. Conclusion

In this paper, we investigated the way a networked decision support system affects decision making performance under extreme situations. To address this research question, we developed an extreme case study analyzing pilots and navigators' perceived values of a new system called Link 16 on air missions, in comparison with the previous information and communication devices. The case study pointed out two important results: the first one concerns conformity enhancement between the characteristics of tasks and information representation conveyed by the system. The second result concerns the high level of complementarities between the internal representation of the domain problem developed by users and the system. Broadly, our analysis tends to confirm the assumption that Link 16 adds value to decision making by improving performance. From these results, we developed a theoretical framework named decisional fit model, which considers the degree of fitness between decision maker, networked decision support system and decisional tasks. We investigated the role played by conformity and complementarities in examining the level of fitness.

Our results have implications for both research and practice. On the one hand, they provide new perspectives to refine fit approaches, in providing a specific model of the effects of networked technologies on decision making performance. On the other hand, these results offer a better understanding of how and why decision making improvements arise, giving some valuable insights to assess the benefits of a networked decision support system for decision makers. More specifically, the individual ability to process and exploit data provided by the system into practical knowledge appears critical to perform networked decision support system usages. Decision making performance relies on the users' capacity to interpret information and turn it into new game plans and tactics.

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