The systemic dimension of operational decision in complex systems work

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This paper refers to some of my research findings on Decision Making processes in complex systems work. Starting as a complex cognitive process strongly contextualized in the operating environment, it ends up, in complex systems work, as an equally complex network of actors and systems (human and technological) that are confronted, in real time, with uncertainty , a large amount of information and feedback and with multiple standards and operating procedures...

"The Society of the Future will be a cognitive society"
European Commission White Paper on Education and Training, 1997.

Although one can identify small differences in work organization, according to the specificity of each operational context, complex systems work appear as open systems in continuous evolution of the interactions that are established, at all levels and dimensions, among their constituents and respective environments. Thus, Operational Decision shall not be considered as the linear processing of information available in a given operational context (in a direct recursion perspective) but, essentially, as the combination of that processing with its environmental constraints[1] and with the global systemic dynamics[2], which are controlled by rules and instructions (operational or of a strategic nature) that are responsible for maintaining system stability.

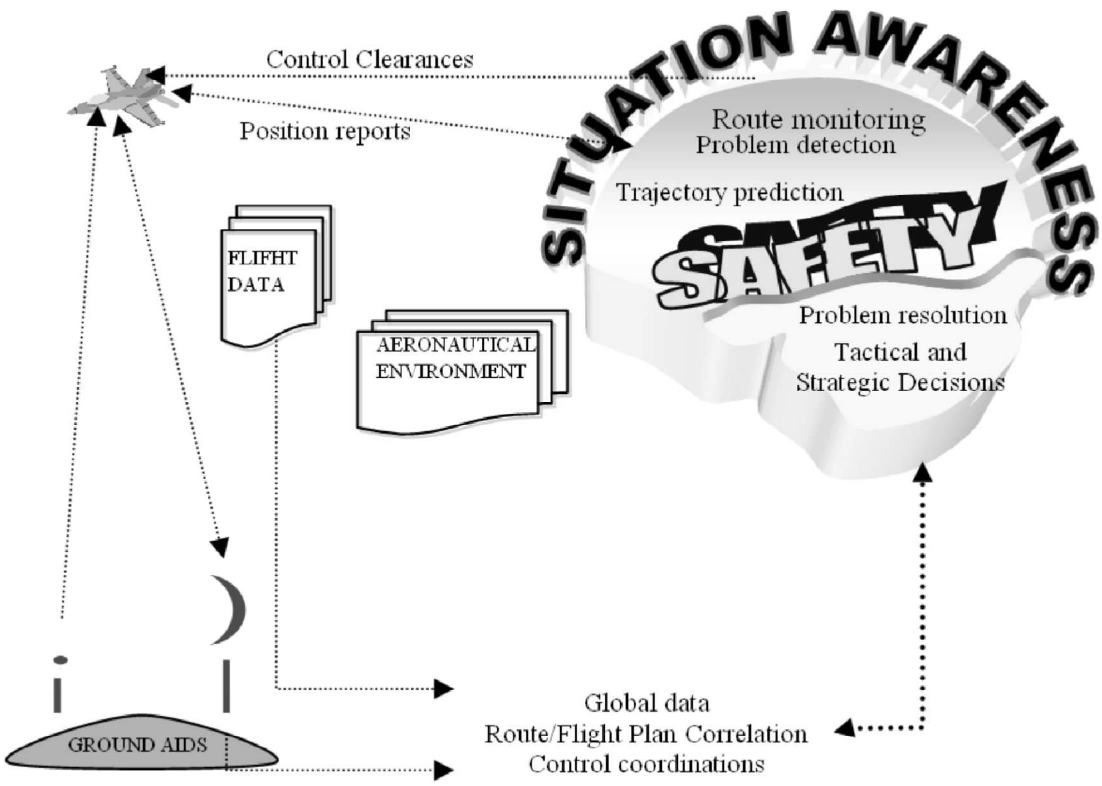
[1] Organization of airspace, operating characteristics of aircraft and systems navigation support, safety parameters, etc.
[2] Global situation in terms of traffic volume and complexity, infrastructure support, available capacity, business objectives, etc.

This reality requires a high capacity for managing the flow of information (direct or retrospective) with the aim of reducing the uncertainty underlying the inherent complexity of the system. But, the truth is that the ability to decide resides exclusively on the human element, which, in its multiple dimensions, characteristics and potential, is assumed to be the most complex component (sub-system) of the whole process – See Fig.1.

For this reason, the operational decision can hardly be circumscribed by rules and procedures resulting from a linear approach, and thus, ethologically reductive.

In a contingency perspective, the human element is assumed as an open individual subsystem, which interacts in a transactional way, at multiple levels and dimensions, with the surrounding environment.

Figure 1 – Air Traffic Control. The Human element as an open Sub-System



Source: Sampaio, José João (2009)

Therefore, Operational Decision is not a unique event, well established in space and time, but it represents the best answer (action scheme) to the mental stimulation provided by a specific operational situation. Operational Decision thus results in a cognitive process in constant evolution / adaptation, during which, through a set of interim evaluations, the operational reality is contrasted with the schemes of action in place. That is, the process of correlation between the perceived operational context and the more plausible assumptions (mental model) of what this perception may represent. So, there is some uncertainty, ambiguity and even (in)credibility, for the data which underpins the process of decision making, maintaining that feature throughout the whole process of knowledge / understanding of reality environment, ie building operational **situation awareness**[3].

The result is an adaptation /update of the operational **mental model**[4], through a set of actions appropriate to the perceived situation which are supported by schemes of action based on accumulated experience – See Figure 2.

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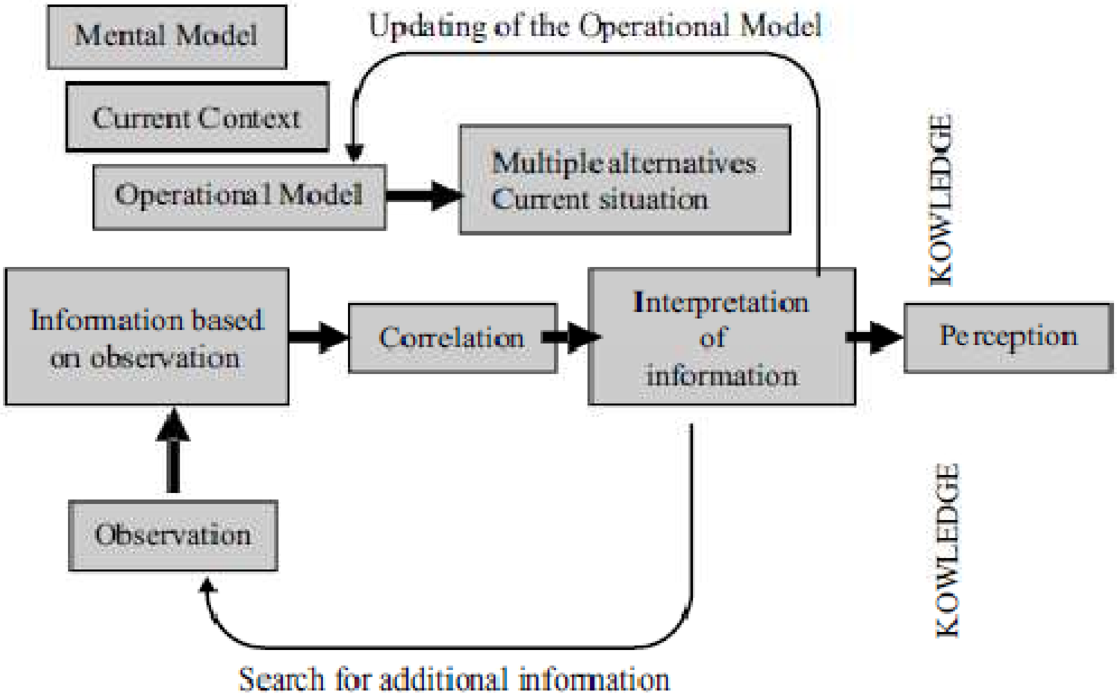
[3] SITUATION AWARENESS – Situation awareness is a relatively recent concept that emerged during the 1980s, although it is a concept that is not easy to explain and for which there is no universally accepted definition. In the Eurocontrol study, Situation Awareness, Synthesys of Literature Search, Dominguez (1994) established a table containing diverse definitions of situation awareness as suggested by diverse authors, coming to the conclusion that there were common aspects to be considered. Dominguez goes on to define Situation Awareness as "...the continuous extraction of environmental information and the integration of this information with previous knowledge to form a coherent mental picture, and the use of that picture in directing further perception and anticipating future events" (Eurocontrol, 2000, p.4). Again according to the Eurocontrol study, Endsley (1995) considers that Situation Awareness is not limited to the mere perception of the information on the operational environment presented. It includes the comprehension of what that information means, in an integrated form, comparing it with the operator's objectives and supplying indications on the future status of the environment, which are important for the decision making. The Eurocontrol Human Resources unit accordingly adopted a comprehensive and inclusive definition:

"Situation Awareness is the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future. This also means the continuous extraction of environmental information and the integration of this information with previous knowledge to form a coherent mental picture and the use of that picture in directing further perception and anticipating future events. Situation awareness is established by a continuous comparison between anticipation (predicted state of the system) and environmental input (actual state of the system)", (Eurocontrol, 2000, § 2.4).

[4] MENTAL MODEL - Canãs et al. m (1995) highlight a certain amount of ambiguity in defining the concept of the mental model, arguing that, for some researchers, the mental model is a representation existing in the short-term memory, whereas, for others, it constitutes knowledge of reality stored in the long-term memory. For this reason the authors propose a more dynamic definition consisting of the representation that is formed in the work memory in combining the information stored in the long-term memory and the operational reality information. According to these authors, therefore, the function of the mental model is to simulate reality in the work memory. The existence of a mental model explains why we arrive at certain conclusions, how we manage uncertainty and ambiguity and also why we are surprised every time an event turns out to be different than expected. Following this conceptualisation, I have given preference to the proposal of Rouse and Morris (1985), cited by Endsley (2000), in which they refer to the mental model as a set of mechanisms that enable the human agents to generate descriptions of the objectives and functionalities of a certain system, explanations of how it functions and of the states of operationality observed, as well as prediction of its future operational states. Also, Mogford (1997) defines the mental model as an organised set of knowledge consolidated and stabilised in time. According to Mogford, this is different from knowledge in general, as the term "model" suggests a conceptual training analogous to that of the outside world in order to understand and predict the behaviour of a certain system. Hence, an effective mental model will be one which, in addition to general knowledge of the operational environment, in a given context, also includes knowledge and comprehension of the electronic systems, including human/machine interfaces.

Figure 2 – Knowledge and Situation Awareness



Source : Adapted from Marsh, S. and al., 2001

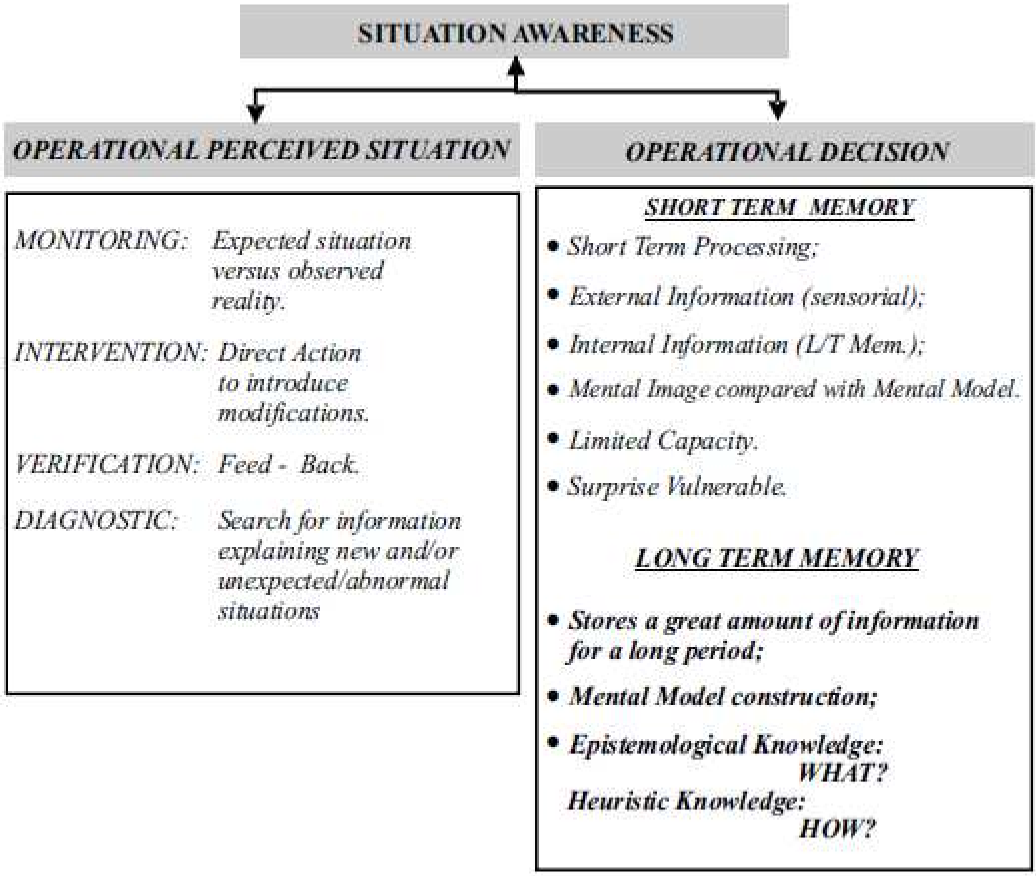
The aviation sector is a good example of a complex system work, where the entire process of operational decision-making evolves in real time and often at very short time intervals, leading operators to develop very specific cognitive abilities, in order to obtain the most possible efficacy of their operational performances.

Research on air traffic controllers - ATCOs – decision making process, shows they maintain active different plans of action, at **working memory** level, using **long-term memory** whenever the monitoring of the carried out planning shows a failure to meet the foreseen objectives – See Fig.3.

Similarly, the ATCOs select only the most relevant information sources in a given operational context, allowing them to maintain a dynamic ability to memorize and forget, thus rapidly eliminating, from the cognitive process of operational decision making, all the information already treated or deemed irrelevant.

This dynamic is also an important catalyst element in the real time operational decision making process and is the reason why many ATCOs seek to work in a medium/high workload environment, as to achieve a level of cognitive activity that allows them to maintain a degree of surveillance according to the responsibility of their work.

Figure 3 – Situation Awareness and Operational Decision



Source: Sampaio, José João (2009)

Being a complex system work, the operating environment of commercial aviation, includes different human agents (aircraft operators, flight crews, service providers, air traffic controllers, etc...) and technology (terrestrial and airborne surveillance and safety systems, flight management systems, flight data processing, etc..) that act as actors of a distributed cognition, meaning that knowledge and cognition are not limited to the individual, but emerge as factors essential to understanding the relationship between humans, machines and the environment in which they interact. Our research applied to the air traffic control reality, (see Sampaio, José João, 2009) shows clearly this systemic dimension, when 75% of the ATCOs state they can perceive what other colleagues think, in general work situations, while 31% of them consider that there is a comprehensive cognitive dimension of the whole working team, which configures a scenario of enlarged operational situation awareness:

> *[...] Over time we learn to know how our colleagues work. But, this does not mean that we all function the same way. What happens is that we know each other and know each one operates [...] So, to know what is going on each other's head is a personalized knowledge, depending on who is watching who [...]*

On the other hand, developments in operational contexts, allow us to conclude for the existence of a trend towards gradual disappearance of some existing operational decisions, either by planned anticipation of the work processes, or by its breakdown into a set of automated tasks. The self concept of operational decision will then need to be reviewed, as it is now departing from its individual and individualistic nature, as a process primarily focused on the individual and on the working post, to assume a systemic cognitive perspective that integrates all the actors involved, independently of their human or technological nature.

Therefore, the greater the degree of technology/automation of the operating environments, the more evident is the need for operator's mental model to integrate the structural and functional characteristics of human and technological agents. The new paradigm requires thus the study of work organizing strategies, supported on the evolution from a structure founded on the one-dimensional relationship – Working post / Qualification / Systems Operator – to a systemic complexity - Individual / Competence / Systems Manager - where the human and the technological dimensions emerge concurrently through professional competencies, as determinant to the understanding and development of the work processes.

In fact, far goes the time where the work environment was confined to a one-dimensional, discrete and specialized working post. In complex systems work, each action is a cause and effect of other actions/processes either upstream or downstream in/of the production process in which they operate. Operational decision thus results of a new framework of human agents, as part of a functional network, where the search for operational balances requires a holistic approach to work processes as well as the development of new professional competencies enabling the interaction between all actors involved.

In this new systemic order, although each one is responsible for deciding at their own action level, the truth is that the final result depends on each one’s comprehension of the overall operational context and on the individual capability for integration that understanding.

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