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COMMUNICATION AND COOPERATION ANALYSIS IN AIR TRAFFIC CONTROL

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INTRODUCTION

As pointed out by the literature, the recent growing interest in cooperative work studies is motivated by technological and organizational changes and by the design of computer systems for cooperative activity which requires models of human-human cooperation. The analysis of communications between group members is one of the powerful tools to identify and describe the functioning of cooperative activities (Falzon, 1991; van Deale & al., 1991; Reinartz & al., 1989). Cooperative activity (Leplat, 1994), as the activity of a group of people interacting to accomplish a task, requires (1) coordination of individual activities, (2) common representation of the field in which the activity takes place, and (3) communication between group members to exchange information and to define a common representation and language. Cooperative work is characterized by a number of basic issues: the information and the means used to communicate can be ambiguous; the understanding of the intentions of the operators can be altered; and conflicts can generate problems in the task distribution and synchronization. Nevertheless cooperative work and the flexibility of the means used to interact permits the avoidance of conflicts and errors. The analysis of the richness and flexibility of the communication in the working group contributes to the understanding of cooperative activities and the identification of their weaknesses.

This paper presents the methodology used to develop a COmmunication MODel in cOoperative work (COMODO) and its features. COMODO is a descriptive model showing the mechanisms supporting the transfer of information in a cooperative working environment. This objective is achieved through a study of the communication process, more precisely of the flow of information amongst operators. COMODO has led to the description and modeling of how, in complex tasks, operators: (a) manage individual and cooperative tasks (b) share several tasks in order to realize one or many joint objectives (c) communicate and exchange the necessary information to carry out these tasks. Air Traffic Control offers an experimental environment for the development of COMODO.

The first part of this paper presents a global human-machine communication model which explains data flow in an organization based on working position. This model is illustrated by the Air Traffic Control domain. A methodological approach is then proposed for studying the communications between Approach Control working positions, with regard to cooperative work. The second part of this paper presents the basic features of COMODO as a result of the human communication analysis. Here, two types of cooperation related to the physical separation between working positions, i.e. face-to-face and distance cooperation, are detailed. Two case studies illustrate face-to-face cooperation using the communication flow representation.

HUMAN-MACHINE COMMUNICATION MODELING

Working position as communication network

Related to human-machine representation, both human operators and technical supports interact to perform individual and cooperative activities. Those interactions are usually made through the interfaces of working position. In basic working position architecture, human-machine interactions occur through two main control systems (Vanderhaegen, 1995), figure 1.

The human control system is constituted by one or more human operators. The technical control system is constituted by a local supervision system, one or more assistance tools, working tools and exchange protocol tools. The supervision system manages the input and output data from the controlled process. On the other hand, the assistance tools provide the human control system with a help to action and/or decision. The human operators are integrated into the main control and the supervisory loop of the process. Using different working tools that provide them all the information they need, they manage the local control goals and the process abnormalities that the automated system (i.e. both the assistance tools and the supervision system) cannot solve. They also take into account the collective work goals. In such a way, they manage the data they have to send to and/or to receive from other working positions.

The representation of the human-machine system in figure 1 includes these external and internal data flows. Internal communications correspond to the internal data flow between the components of a working position. External communications are the result of procedures that exchange data between different working positions using (1) human communication protocol media (e.g. verbal or non verbal communication, manual transfer), (2) specific working tools (e.g. telephone, radio, screen, printer, pen, paper, office supplies) and/or (3) exchange protocol tools (network, telephones lines, radio waves, radar).

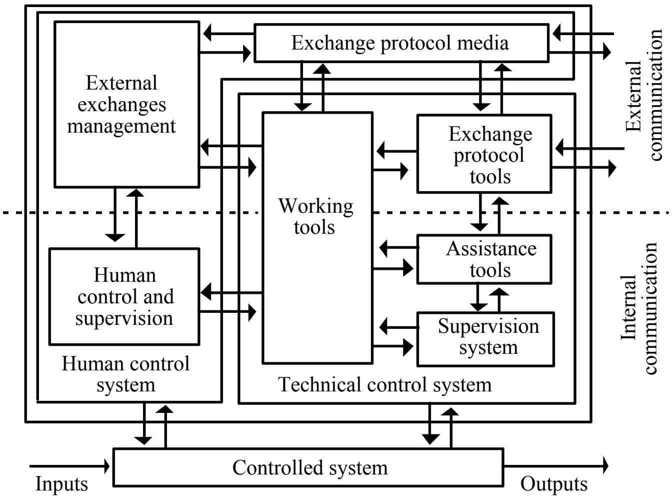

Figure 1. Working position modeling.

An organization based on several working position aims also at regulating human activity. Indeed, the human and technical tools enable regulation both by retroaction and anticipation or by defining different filtering levels between working positions. In such a way, an organization can be structured to manage data sharing and to make possible negotiations in case of lack of information or knowledge (Vanderhaegen, 1995). Depending on the connections between working positions, different kinds of human-machine organizations can be represented. For instance, centralized organization is characterized by a single working position that takes into account the whole command process. In other types of organizations in which the global process is divided into different semi-independent sub-processes, the decentralization enables the distribution of tasks over working positions. The control system components have to cooperate so as to synchronize, exchange data, or access a common resource. Nevertheless, in the case of a more complex process, it seems necessary to coordinate each individual component so as to optimize the overall process. This function can be performed by other upper command levels in a hierarchical organization.

In this representation of organizations, such as an air traffic control system, nuclear power plant control system or manufacturing production system, the COMODO deals with explaining the data flow management between working positions to perform the cooperative activities, and with understanding the cooperative external communications.

Air traffic control organization

As practical example, the Air Traffic Control is a kind of multilevel system which allows a control data filtering from different control levels, figure 2.

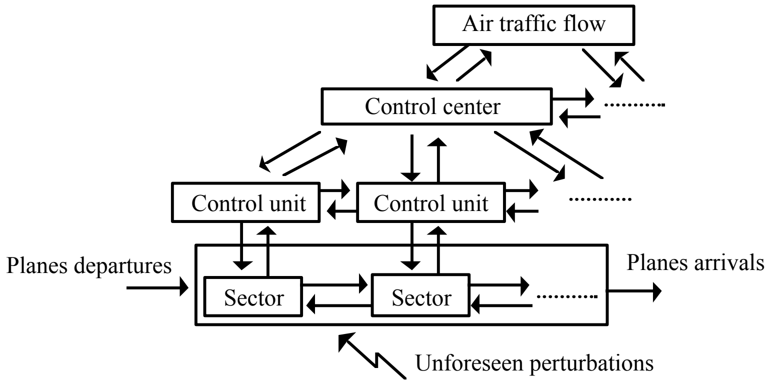

Figure 2. Air traffic control organization.

In particular, the present control unit organization will change according to the variable abilities of human and technical control systems of the corresponding working positions. Indeed, (1) the present increase in air traffic, (2) the increase in controllers' workload and (3) the saturation of probable means of control entail the possible reorganization of the human operators' role in the control and supervisory loop of each air traffic control working position.

In any case, the global organization of Air Traffic Control can be represented as a generic hierarchical one. The upper air traffic flow management is rather a long-term planning and regulation of the traffic flow, whereas the control center level concerns a medium-term management of the control units. Both levels organize the traffic (1) quantitatively because they act on the number of aircraft taken in charge by the lower control units level, and (2) strategically because they do not command the controlled process directly. The lower decisional level is decentralized in order to distribute control tasks between different units.

A control unit supervises a given geographical sector and is decomposed into different working positions managed by human controllers. At this lower control unit level, controllers evaluate qualitatively the situation because they optimize the control quality in terms of (a) safety constraints to avoid possible conflicts, (b) an economic criterion to minimize the aircraft fuel consumption and (c), a regularity criterion to allow take off and landing at the expected times. The corresponding activity to assume this control quality is characterized by (a) cooperative work between operators and (b) a high number of communications between them. Therefore, ATC offers an experimental environment for the development of COMODO studying the external communication between working positions of an Approach Control unit.

Methodological approach for COMODO

A field study has been conducted at Milan airport, where activities of twelve air traffic controllers were examined during the phase of Approach Control (Bellorini & al., 1994). The Approach Control unit is divided in three working positions managed by the North radar controller, the South radar controller and the departure planner.

The field study, based on an ethnomethodological approach, consists of a data collection, a data transcription, and a data analysis. Ethnomethodology (Garfinkel, 1967) is introduced to identify the environmental characteristics, the organization of cooperative work and communications, and the cognition involved in the task.

The data collection consists of the following elements:

(a) *observations*, during video-recording, of the situation controlled by the South radar controllers;

(b) *video-recording* the South radar controllers during the execution of their tasks in order to record face-to-face communications between North and South radar controllers, radar interaction, strip manipulations;

(c) *audio-recording* the distance communications between South radar controllers and Pilots and between South radar controllers, Adjacent Sectors and Tower controllers;

(d) *self-confrontation* against video-recording including the verbalizations of the South radar controllers and the explanations of their cognitive activities and strategies;

(e) *subjective rating scale of stress* during the self-confrontation at appropriate temporal intervals concerning the South radar controllers' subjective measure of stress according to their experience and stress tolerance.

Twelve hours of communications are being transcribed in MacSHAPA (Sanderson, 1995). All contextual observations of each recorded situation are being transcribed within MacSHAPA according to their temporal sequence. This includes the face-to-face and distance communication, the Controllers' explanations and comments about their strategies, the rating scale of stress of the Controllers.

An Exploratory Sequential Data Analysis ESDA (Sanderson & al., 1992) is being applied. ESDA offers a set of data analysis activities in the human sciences which deal with recorded data in which temporal information has been preserved. ESDA consists of: (a) a task analysis, obtained through interviews and observations; (b) a video analysis consisting of the extrapolation of cooperative situations between air traffic controllers and of the abstraction of generic cooperation mechanisms; (c) a self-confrontation analysis; (d) a communication flow analysis.

COMODO is based on the result of a field study in Approach Control. The communication flow analysis of collected and transcribed data determine the basic features of COMODO. COMODO takes into account the communication for two types of cooperation, face-to-face and distance cooperation, between different working positions.

HUMAN-HUMAN COMMUNICATION ANALYSIS

Face to face and distance cooperation

Two different types of activity are performed during the Approach phase by the various controllers: individual activities and cooperative activities (Bellorini & al., 1995). Individual activities, i.e. activities performed by a single human operator, include: management of separation rules, of approach procedure, and control of the arrival and departure. Cooperative activities include sequence/order of landing and anticipated transfer of aircraft. Successful achievement of these activities requires a correct management of the adequate sequence of operations and actions distributed over human operators. On the basis of a geographical working area criterion (Schmidt 1991), two basic types of cooperation have been defined: (a) a type based on face-to-face communication and (b) a type based on distance communication. Figure 3 describes the elements involved in these two types.

TYPE	FACE-TO-FACE COOPERATION	DISTANCE COOPERATION
AGENTS	south radar controller - north rc south rc - departure planner	north/south rc - pilot north/south rc - adjacent sector north/south rc - tower cont.
TASK SUPPORT	direct	mediated: radio frequency, phone
TASK ASPECTS	anticipated transfer of aircraft distributed decision making of landing order of aircraft synchronisation mutual knowledge of workload	anticipated transfer of aircraft information transfer of aircraft
MODES	explicit, implicit	explicit
COMMUN. STYLE	mutual and tacit knowledge free flowing	operative language rules temporal constraint
COMMUN. CONTENT	request/confirm anticipation of future state sequence of future actions	instruction/clearence information request/confirm sequence of future actions anticipation of future states

Figure 3. Face-to-face and distance cooperation in ATC.

Face-to-face cooperation is realized by two modes: an explicit mode through verbal communications and an implicit mode through non-verbal communications supported by the common representation of the task. The controllers reach common decisions through distributed decision-making processes about the landing order of aircraft. These decisions are the result of negotiations between controllers on the actions to be performed, the tasks synchronization and the management of each controller's tasks. An important aspect of this type of cooperation is the use of mutual implicit knowledge and of non-verbal behavior. These elements play an important role in the process of collective regulation .

Distance cooperation takes place mainly between pilots and radar controllers through radio. Telephone allows distance communications between Approach, Tower and En-route controllers. The task consists of the anticipated transfer of aircraft and related information.

Communication Flow Analysis

An important aspect of Air Traffic Control is the management of the sequence of landing of the aircraft. The determination of the sequence is the result of a distributed decision-making process between air traffic controllers. In this activity two relevant aspects of cooperative work are: (1) the anticipated transfer of an aircraft from a sector to another sector; (2) the synchronization of the tasks of the various operators involved in the decision-making process.

The communication flow analysis studies the cooperative management of information to identify the basic actions and mechanisms, including breakdowns in the communication process. The analysis consists of (a) the identification of the agents involved in the communication; (b) the analysis of the information content and (c) the identification and analysis of the sequence of "units of communication". The results of this analysis will be used as starting point of COMODO. COMODO is presented hereafter through two examples of communication flow analysis (figure 4 and 5). These examples refer to two specific situations of face-to-face cooperation between Approach radar controllers. Although the two situations were different in nature (e.g. number of communications and of agents), the communication flow analysis has identified a common communication mechanism that support cooperation.

The first case consists of a communication flow between North Radar Controller (NRC), South Radar Controller (SRC) and two aircraft A1 and A2. Figure 4 illustrates the corresponding flow of communication. The plain arrows indicate the requests being performed. The dashed arrows indicate the responses that were not given. The temporal order is indicated by the number on the arrows.

NRC is in charge of A2; SRC is in charge of A1. NRC and SRC have to decide on the landing sequence of the two aircraft, i.e. A1 and A2. NRC and SRC communicate to each other by face-to-face communications. NRC calls SRC but does not receive an answer (figure 4-flow 1). One minute later it is SRC who calls NRC for the same problem and who does not receive an answer (figure 4-flow 2). Finally SRC takes an individual decision and informs his aircraft (figure 4-flow 3).

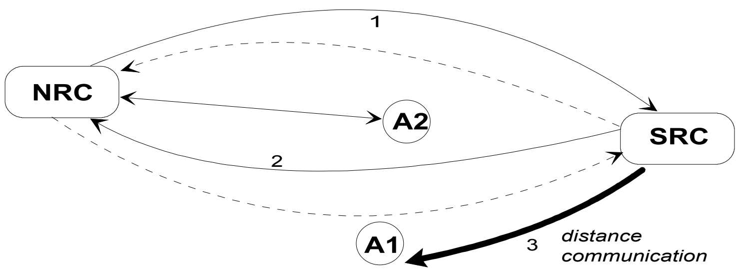

Figure 4. First case - communication flow representation.

In this example the two radar controllers have tried to open a new unit of communications (i.e. a pair "question - answer"), but have failed to establish a cooperative communication. No explicit verbal interaction for cooperation has been established. There is no cooperative work carried out. To solve this problem SRC, who has the lowest workload, acts individually. This pattern could be based of a decision mechanism that includes a distribution of workload. The controller with the lowest workload performs an individual action that solves the problem.

The second case consists of a communication flow between North Radar Controller (NRC), South Radar Controller (SRC), a Tower Controller (TC) and two aircraft A1 and A2. This case is an example of conflict resolution between A1 and A2, which are landing at and taking off from the same airport, respectively. Figure 5 illustrates the corresponding flow of communication

NRC is in charge of A1; SRC is in charge of A2. NRC and SRC communicate to each other by face-to-face communications. SRC tries to call NRC without success (figure 5-flow 1). NRC and then SRC call A1 both with success (figure 5-flows 2 and 3). A2 calls two times SRC (figure 5-flows 4 and 5) before receiving an answer (figure 5-flow 6).

NRC forgets to establish a distance communication with TC. Finally SRC takes an individual action and informs his aircraft. The cooperative communications between NRC and TC, and between SRC and NRC, do not take place. No explicit verbal interaction for cooperation has been established. The TC, through a cooperative call with NRC, could have acted in advance on the schedule of A1, for example, by not giving him the clearance for departure to A1.

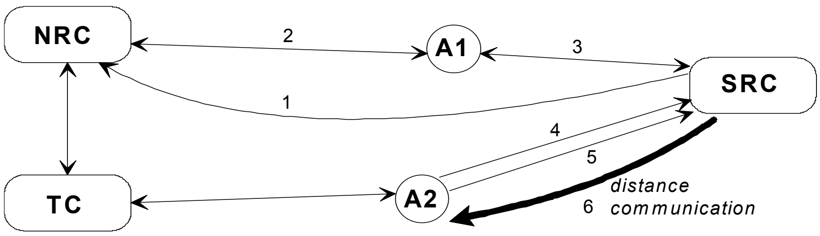

Figure 5. Second case - communication flow representation.

CONCLUSION

The paper proposes a way to represent systems where human operators and machines are integrated among working positions. A working position is presented as a communication network between human and technical control components. As an example, the global Air Traffic Control organization is proposed as a hierarchical organization in which data are filtering between different decisional levels. In the study of this kind of communication systems between working positions, the attention is focused on the development of communication models. A methodology for communication and cooperation study based on data collection, data transcription, and data analysis, is applied in order to obtain a descriptive human-human COmmunication MODel in cOoperative work (COMODO).

Conclusions from a field study in Approach control constitute the features of COMODO. Both face-to-face and distance cooperation characteristics have been described. Face-to-face cooperation is illustrated by two case studies. The common mechanism found through the communication analysis is related to a communication breakdown for cooperation and to an individual action performed by the controller without distributed decision-making. This mechanism depends on the distribution of workload.

This communication flow analysis of more case studies will be carried out in order to increase the knowledge of the cooperative human behavior. This study will contribute to determining the human limits and resources and to defining the interactions and information need to perform individual and cooperative activities. Therefore, it will be useful for human-machine dialogue specifications in the design of groupware, such as Computer-Supported Cooperative Work. Indeed, COMODO will give some indications to improve communication using adequate working position organization or to optimize task sharing between system components.

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