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Paper for the Workshop
"Work activity analysis in the perspective of organization and design"
Paris, October 15-16, 1992

TRAFFIC CONTROL ACTIVITIES AND DESIGN: CASE STUDIES

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Support or prosthesis?

The investigations which we will be discussing here form part of a programme whose objective is the design of computer systems in terms of **support systems for users.** This programme was initiated by an investigation aimed at designing a system for a data collection and coding station (Pinsky 1979). Since then, it has been applied to various work situations, in offices, services, the management of sequential and continuous processes, air and urban traffic control, and agriculture.

Such a design in terms of support systems for the users involves:

- helping the user to understand the situation and take action himself, including the search for information;

- relieving the user as much as possible (within technical and economic limitations) of the details of data supply and the fulfilment of action, in so far as these are unnecessary for an understanding of the situation.

The computer system is, in that case, a tool among others, one element in a **support system** which, apart from itself, is composed of **documentation**, **training, organization, and other sources of information** on the situation here and now.

This design in terms of support is an alternative to the design in terms of cognitive prosthesis which emerged at the beginning of computerization and is still dominant. A computer system designed as a **cognitive prosthesis** is supposed to concentrate the intelligence of experts (hence the commercial name "expert systems" for the most sophisticated of these systems). Ideally, the role of the user is that of a cognitive invalid:

1) to provide data for the system in so far as the latter is unable to acquire them in other ways (within technical and economic limitations);

2) to understand the instructions of the system and to act accordingly, in so far as the latter cannot act alone (within technical and economic limitations).

Such systems generally reveal they have not attained the desired ideal by also allocating another role to the user :

3) to manage on his own when the system fails.

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Hence a contradiction which can entail a heavy price to pay: on the one hand, if the user thus accepts to lose, under ordinary circumstances, his decision-making powers and the means to implement them, he becomes a cognitive invalid; on the other hand, he is called upon to play the role of a super-expert in certain isolated circumstances.

Human Factors or Human Actors?

What knowledge is required to design computer systems in terms of support in given situations?

The classic knowledge of "human factors" is useful but insufficient. It consists of generalities on Man divided into segments: cognition (itself divided into planning and problem-solving, in turn sub-divided into diagnosis and solution, etc.), action, perception (itself divided into hearing, sight, etc.), reactions to separate elements of the environment (lighting, ventilation, etc.). In this way, the whole Man disappears, and also the individual Man (specific characteristics of the users and their culture) and the Man in his specific situation (characteristics of the overall situation).

Three categories of additional knowlege are necessary:

1) on the global activity of specific users, having a specific culture, in situations that are studied, non-computerized or comprising an unsatisfactory computer assistance (for the definition of what must be assisted by computer);

2) on the global activity of assistance supplied to the user by other more competent users in these situations (for the inspiration provided for the design of computer support through the knowledge of human aid);

3) on the global activity of users in other situations with a more satisfactory computer support.

These various global activities may be approached, within the present limitations of the means for data collection in a natural work situation, by studying the **course of action**:

The activity of one (or several) specific actor(s), engaged in a specific situation, belonging to a specific culture, which is significant for the latter, in other words, that can be related or commented by him (or them) at any moment.

The aim of this study on the course of action is to understand its **intrinsic organization and its extrinsic constraints and effects in the state of the actors, their situation and culture.**

This significant activity for the actors, constituted by the course of action, includes action and communication, but also other elements: interpretations, feelings, perceptive, proprioceptive and mnemonic judgements, their commitment to the situation and their use of past experience in the present course of action.

The data necessary to study the course of action must therefore include **continuous observations** of the behaviour of action and communication in a work situation as well as different kinds of **instigated verbalizations** from the actors which would provide access to other elements.

The analysis of this data is carried out according to the principle of the **primacy of the intrinsic description of the course of action over the extrinsic description of the state of the actor, the situation and the culture**. As in fact demonstrated by various ergonomic studies (Montmollin 1972), the definition of the "aptitudes" of the actors outside their work activity is limited, and leads to scientific errors with disastrous practical consequences. Likewise, to reduce the work activity to a component of the situation, the "task", even if it is only to demonstrate the divergences from it, is of limited explanatory interest. For example, it makes it possible to distinguish the errors but says little on their origin. Finally, the pertinent characteristics of culture are difficult to define outside the work

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activity. The actors put into practice all or part of their acquired experience in other practical activities.

We shall illustrate the study of the course of action of users and its contributions to the design of support systems based on two current investigations on the control of air and metropolitan traffic. These two investigations are complementary in that the former emphasizes the relationship between the air controller and the computer interfaces, while the latter stresses the relationship between the controller and other actors (signal assistants, information assistants, drivers, station masters, etc).

Data on the activity of air traffic control

The purpose of this study, which should help modernize the system of air traffic control, is to identify the support that would be needed by the controllers, experts in their present position, when faced by a transformation of their position.

The study sets out to analyze the activity of the controllers in the present system, then to analyze their activity using a mock-up of the future position (simulation of the traffic in real time, simulation of the comunication at the position, interactions with the system to handle the traffic).

To be able to analyze the activity of the controller at the present position, *it is necessary to collect data which take into account the numerous aspects of the activity of the controller*, who permanently watches the traffic being controlled on the radar screen, receives, takes into account, annotates, classifies the the strips (a kind of identity card for each plane), communicates with his colleague at the position, or other positions, contacts the pilots by radio, the controllers of other sectors, even other control centres, by telephone. These behavioural manifestations of the activity must be complemented by additonal data in order to understand the activity.

Let us for example take a section of a video film on the activity of the controller at the present position of control:

> The controller says (on the radio frequency he uses to communicate with the pilots of the planes under his responsibility in the space covered by his sector): "Swissair 831 start descent fly level 220 and maximum indicated speed". He notes the authorized level on the plane strip while the pilot replies: "Roger, we're level 370 for 220, and maximum indicated speed will be .81". The controller answers: "It's OK, thank you"

The video film shows an action of the controller who is giving a landing instruction to pilot S831, and who asks him to take maximum speed, as well as the value of this speed. It also shows the replies of the pilot to the controller following his action. This information needs to be completed by other data in order to explain the content of the video film. In fact, the film alone does not make it possible to know why the pilot is descending or why the controller asks for the maximum speed that the plane can fly.

To obtain these additional data, the controller is confronted by the film of his own activity, and he comments on this activity and the events under consideration. It is what we call *self-confrontation.*

> Confronted by the section of the film presented above, the controller comments: "I oblige the first Swissair to descend so that it frees the levels to speed up the process a little, so that my conflict does not drag on for very long. That is to say that afterwards I will leave my space, this will loose time, at the coordination level, and the work will be a little heavier. There, it is only with the radar that I will make my choice. They are 10 nautical miles away from each other, I have prepared my thing and I will stick to it. So I will try to solve the problem before the planes leave my sector."

This self-confrontation makes it easier to understand what this plane implies to the controller. The plane is linked by the controller to other planes by a risk of conflict: previously, the controller had already identified and chosen the solution he would put into effect; at present, he sees on the scope

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of the radar that the planes are separated by 10 nautical miles, and this permits him to implement the solution he had selected, particularly as he wants to solve the problem within his own sector.

It was possible to complete the data of observation and self-confrontation by using the fact that there are "replica" positions in the control room which reproduce in real time a control sector from any position. This "replica" position has a radar image and receives strips and frequencies, but it does not give telephone messages, it does not reproduce the interactions between the controllers of different positions, and no action concerning the traffic can be taken since broadcasting over the frequency is impossible. We used this position as a medium for verbalization by asking an experienced controller to make comments, during the analyzed activity, on the traffic under control and the activity of the controller placed in a real position. In this way, the following commentaries were obtained on the example described:

"There, he is in the process of asking for the descent speeds of the aircraft in order to know what decision to take."

The commentary at the "replica" position requires that the controller, whose activity is being studied, gives it a status in relation to his own activity. In the selected example, when the controller is confronted with the commentary of his colleague, he explains the way he acted:

> "First, on the strips, all the planes were either at 210, or descending towards 210. Therefore, there was a potential conflict between the FGFGB, the S 723, and the S831. So I had already first detected a conflict from the strips, and it was afterwards that I consulted the radar to decide what I would do next. I ask the speed of the first in order to impose speeds on the others, so that they do not catch up with the first one. I have therefore fixed my order and everything, but on the other hand, I ask the speed of the first so that I can impose speeds on the others."

This additional commentary reveals that although the solution had been anticipated, it was only partially, and that the effective solution is determined by the speed requested.

When the interpretations of two controllers are different, as is the case here, the confrontation leads the controller to explain his own choices compared to the arguments put forward by his colleague at the "replica" position; and in the opposite case, the commentaries at the "replica" position" confirm and complement the interpretation of the controller who had in reality controlled the traffic.

Data on the activity of RER traffic control *

This investigation is part of a wider research which links public information to the analysis of the work of traffic regulation in order to study the complete chain of traffic control, starting from the control room and ending up with the user.

To achieve this, the information collected must permit a thorough analysis of the cooperation between the staff in the control room. But in order to understand the group as a whole, we believe that one must first focus on individuals in the situation. This analysis brings out the extent of cooperation in terms of the *individual social course of action:* the action of each person depends on the action of the others, it is linked to and can have a bearing upon that of the others.

Thus, as a first stage, we carried out a detailed analysis of the individual courses of action of the various staff members in the control room : controllers, signal assistants, information assistants. The purpose was to clearly show the reasoning of each person concerning the activity of traffic control on their line, while seeking to understand what the action of the other means to a given operator.

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* Réseau Express Regional (high speed suburban branch of the Paris metro)

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One can then consider collective action as such, as several individual courses of action which take place synchronically, so as to see how they are linked to each other to constitute a coordinated collective activity whose characteristics would then have to be defined.

Furthermore, by drawing from studies in cognitive anthropology, for example those by Hutchins (1988) in which he puts forward the notion of "distributed social cognition", a complementary approach consists in using the group as a unit of analysis, that is to say, a functional cultural unit, rather than individuals. This theoretical approach makes it possible to describe cognitive processes by tracing the movement of information through the "joint cognitive system" (Woods and Roth, 1988) composed of men and technical artefacts.

In the case of RER traffic control, the work in the central control room is a complex collective activity which involves about a dozen operators at a time (a team of three controllers each having two signal assistants under them, an information assistant and, in the event of incidents, the managerial staff of the line). The controllers are responsible for ensuring the smooth running of the trains in case of disruptions (which is the normal situation during peak hours), implementing actions to control the traffic by taking into account the supervision of drivers, following the rolling stock and handling their entry into the depots (maintenance and repair). The signal assistants check the times the trains that pass through their sectors and inform the traffic controllers of any delays, they establish the itineraries, control the movement of the rolling stock by carrying out the instructions for the trains to be shunted in or out of the sheds and by keeping an accurate account of the shunting positions. They also check the time-tables posted in the stations and make amendments when necessary.

The technologies available in the control room have been added in accordance with traffic developments and were not designed as a coherent apparatus. This includes means of communication (telephone and radio), a fix-line diagram representing the line and trains running on it, computer terminals showing the same thing but in greater detail, and working documents. Some of these documents are only for consultation (the GDM, a theoretical graph of trains and drivers movements, the duty roster for drivers, the logbook for breakdowns) while others, consisting of a blank section to be filled in, are at the same time consulted and modified as the needs arise (the sheets for trains entering or leaving the sheds, the cards for the use of equipment, the state of the sidings in the stations, etc).

We therefore have a situation of work whose collective character is fundamental, and which is immediately reflected by the importance, on the one hand, of the verbal communication between the various control room officials, and on the other, of the radio and telephone links with persons external to the control room, particularly those belonging to the line, such as the drivers, station masters, depot managers, and other operators.

The choice of data to be collected is induced, on the one hand, by what one is seeking to know, in this case, the cooperation between officials in the course of their traffic control activity, and on the other hand, by what it is possible to know, that is to say, the possibilities offered by the work situation.

The collection of data relates to the work activity in a natural situation. We decided to observe *moderately disrupted situations*, that is to say, all the usual incidents that occur nearly every day at peak hours (emergency breaks, late trains, etc.), rather than to focus on major incidents which, on the one hand, are too complex to understand in detail and, on the other, imply very heavy individual reponsibilities which the persons involved must account for to their superiors. This choice therefore depends just as much on methodological criteria as on criteria linked to the social organization of work.

During the first stage, with a view to analyzing the individual social courses of action, we made several observations, each time centred on a traffic controller belonging to one of the two teams with which we regularly worked during the investigation.

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Likewise, in order to perceive the synchronic linkage between individual activities, we collected systematic data on the "subsets of cooperation":

- a traffic controller and the signal assistants of his sector,
- a team of three traffic controllers.

The duration of the observations was about three or four hours, corresponding to the peak hours and their preparation, that is to say, roughly from 6h30 to 10h00 in the morning and 15h30 to 19h00 in the evening. The choice of these observation periods corresponds to the times during which the common incidents which we wished to study were likely to occur.

The data collected comprised:

- recordings (by tape recorder or video camera, depending on the cirucmstances), with a wealth of communications completed by notes on the events taken into account by the operator and the actions of the others when related to his course of action;

- self-confrontation interviews.

Because of our desire to understand the collective nature of the work, and the complexity of the situation, we had to face specific methodological problems:

- to study the interactions between the traffic controller and his colleagues, we used a microphone placed in a relatively central position so that we could record the communications of many persons, if not of all at fairly quiet times.

- with respect to the use of the video, the time/space and organizational constraints of the work situation prevented the installation of several cameras which would have produced different kinds of images, such as images focused on the behaviour of the operator, precise images of the contents of the screens and the fix-line diagram, images of the other operators. We therefore chose to install a camera in a fixed position, placed in such a way that its field of vision was a little wider than the post of the official under observation, in order to have data on the interactions with his immediate neighbours while retaining a fairly clear picture of the official himself, as well as an idea of the technical apparatus at his disposal without having the exact content. The data collected with the camera were always completed by the audio recordings described above.

- when data were collected only with the tape recorder and a pencil and paper, the self-confrontation was carried out with a written transcription, a few days after the observation session, for a tape-recording can't be used as a basis for a self-confrontation interview. It should be noted that if in one respect the fundamentally collective nature of work renders the gathering of data more difficult, it is also endowed with a methodological interest for the researcher: in fact, many actions and telephone communications are spontaneously related and justified by the operators for the others who need these for their own courses of action. We found evidence of this in the recordings of the communications.

- in the case of the process of complex work, the self-confrontations based on transcriptions, either of an audio tape or a video film, were of definite relevance: the researcher, having himself assimilated the incident during the transcription, had time to spot the critical moments that merited closer questioning. Thus, self-confrontation does not serve principally to create an understanding of the work process for the researcher who is unfamiliar with the situation. This would be lengthy and could tire the operator. In addition, the written transcription gives temporal reference points to the operator during the self-confrontation sessions whereas watching the video tape does not always enable an accurate chronological reconstruction of the actions and events.

Semiological Heuristics

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Now that we have data on the courses of action of air traffic control and RER traffic control, it is a question of analyzing them. The theoretical framework, which we have described as **semiological**, makes it possible to explain the **global dynamics - or composition** - of the courses of action, their **local dynamics - or generation** - and the linkage between these two dynamics.

The three central hypotheses of the semiological theoretical framework are:

1) **global dynamics - or composition**: the units of courses of action are **significant units** for the actor (or actors) which are classifed by **significant structures** of different **ranks**;

2) **local dynamics - or generation**: **the basic unit** - in other words, the lowest rank - of the course of action has the **triadic sign** as its underlying structure;

3) **linkage between global and local dynamics - composition and generation**: the transition from one unit of the course of action to another corresponds essentially to a modification in one of the three components of the triadic sign: **the object**. This modification is more or less great depending on the gap between the respective ranks of the significant structures classifying these units.

Let us clarify these various hypotheses and notions. The notion of triadic sign comes from C.S. Pierce (1839-1914), but was made operational thanks to several innovations.

A triadic sign is the relationship of a **representamen** (R) to an **object** (O) through the mediation of an **interpretant** (I).

The **object** characterizes the active engagement of the actor in the situation. It is a range of possibles, organized in a sychronic and diachronic hierarchy, delimited but indeterminate. It is essentially unconscious, but its delimitation may be conscious, and the elements of the latter can be related and commented a posteriori by the actor.

This notion reflects the hypothesis of the situated character of cognition, its dependence relative to specific circumstances which constitute a whole. The object is not "the real", the "reference", it is actively constructed by the actor. It is to be distinguished from the **situation (partial or global)** - such as an observer of the actor could describe - of which it is the extrinsic counterpart.

The **representamen** reflects the hypothesis that at each moment cognition focalizes on partial elements, on perceptive, proprioceptive and mnemonic judgements (**original representamen**), as well as on the specific interpretations (we then talk of **interpretative representamen**) which are imposed upon the actor actively engaged in the situation, having at his disposal a range of possibles. The actor is not solipsistic; he is constantly sollicited by the world.

An original representamen possesses an **anchorage** in the **situation**. An original perceptive representamen may also be **symbolic** (including linguistic) as well as **indexical** (perception of a difference against a background) or **iconic** (perception of the background).

The **interpretant**, the actual follow up of a rule, is essentially unconscious, but a linguistic expression may be conscious and generally relatable and commentable a posteriori by the actor.

It reflects the intervention in the cognition of elements of generalities resulting from the past cognition of the actor. The latter are not limited, theoretically, to one or several of their linguistic expressions. They obviously have a content, and are not formal. They enact **types** or **typical relations between types**.

In its mediation between the representamen and the object, one can distinguish on the one hand, the **schematization** of the representamen and, on the other, the **delimitation** or the **determination** of the object.

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These three components of the sign are dynamic. They are relative to the actor in a "here and now" situation. They cannot be separated when implemented. In particular, both the appearance of an interpretant as well as that of a representamen partly depend on the object.

The effect of a sign is on the one hand, its **interpretative representamen**, which can be an action, communication, feeling or interpretation and on the other hand, the **modification introduced by the sign in its object:** delimitation of a new object, or new determination of an object in hand.

Notice that by the terms "conscious" and "uncouscious", we do not refer to any theory of conscience, but only to the existence or not of a private discourse more or less developed (which we call "interpretations") during the course of action.

According to this theory, what is essential in the course of action are the sudden or gradual changes of the object, of the active engagement of the actor in the situation. Thus, we move away from cognitivism in which the mental processes consist of formal operations on symbolic representations of predefined elements of the environment, in "data processing". On the contrary, it is closer to a trend in research described as "enaction" (Varela, 1989), whereby information is considered not as predefined but as "enacted", that is to say constructed in context.

The two hypotheses of global dynamics and of the linkage between global and local dynamics are then easy to understand. They state that the course of action is composed of a stratified set of significant units and that this gives depth to the range of possibles for the actor at any moment, and finally, that the different significant units are classifed by more abstract structures.

There are two aspects in the studies of the course of action. The first is the validation of these three hypotheses and other secondary hypotheses. The second is the use of the different notions which participate in their formulation as so many tools of concrete knowledge of the courses of action and the design of support systems. We shall now concentrate on illustrating this second aspect, the heuristic one, through studies on traffic control.

The analysis of the activity of the air traffic controller and the definition of support.

The close analysis has been made of data for a period of three hours of activity of a team of controllers in the control room and threeperiods of one hour of control activity with three different teams of controllers in a simulated situation with a mock-up of the future interface.

The activity is modelled from data in the form of a chain of signs determining the activity. For example, it is established that the controller uses an event he has previously identified, (the S831, S723 and FGFGB are staggered), together with a calculation of the time left before the planes leave the sector, from commentaries "I oblige the first Swissair to descend so that it frees the levels, to speed up the process a little"; "so that my conflict does not drag on for very long, for afterwards I will leave my space, this will make the work a little heavier at the coordination level."

This event and temporal constraint, taken into account within the context of controlling the exit of the three planes in question, allow the controller to identify another event: the planes now have to start their descent. In terms of action to be taken, this means that he must authorize the first plane to descend and ask for the speed of descent in order to impose speeds on the aircraft behind so that they do not catch up with the first plane. This interpretation of the data is based on the following elements:

- the communication to the pilot, "831 start descend fly level 220 and maximum indicated speed";
- and the commentary "I ask the speed of the first (S831) so that I can impose speeds on the following (S723 and FGFGB), so that they do not catch up with the first one".

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What is the corresponding triadic sign? Its **object** is the dynamics here and now of a configuration of three planes (S 831, S 723 and FGFGB) potentially in conflict around Geneva (the end of the sector), which has been delimited and has received different determinations previously; the **representamen** is at the end of a chain whose original representamens are the indications on the strips and the distance of ten nautical miles perceived on the scope of the radar; the **interpretant** is a complex relation between types: a typical configuration of planes in potential conflict; a typical chain of events and actions concerning the planes.

This analysis in signs relates to the significant units of the course of action of the controller. In fact, to explain the activity corresponding to the example quoted, it is necessary to take into account the period of activity encompassing all the interpretations of the controller, starting from when he identified the intrusion of the three planes up to the end.

> In the example, the controller first considered that the three planes had the same destination and were catching up with each other. He chose to separate them according to an order he selected; to do this, he accelerated the fastest plane, set the other two planes on a parallel course, then shortened the route of one of them when the first one was sufficiently ahead.

An analysis in significant units shows that the controller at work divides his time between different stories which take place simultaneously, stemming from the continuous activity of supervision and general management of traffic. They require the controller to manage the passage from one activity to another. Above all, it appears that while the control of a configuration of planes in conflict is rare, it represents an important part of the activity compared to the other stories concerning a plane with no problem or having a special feature, or compared to a couple of planes. Thus, for one hour of sustained traffic control, the activity corresponding to a configuration of planes in conflict takes up nearly 50% of the total time of the activity.

The interest of this modelization of the activity lies in building up an aid for reflections on the transformation of the work situation.

The Objects and Representamens show the complexity of what the controller considers as relevant in his environment. The example shows:

- that the controller takes into account a group of three planes linked to each other and whose dynamics are constrained by the need to transfer the planes to the next sector; this leads to proposing **a new design of the mode of the presentation of planes on the scope of the radar** in which the groups of planes linked to each other would be distinct from the rest of the traffic by emphasizing their relationships (on the initiative of the system and/or on the initiative of the controller); it is therefore not a question of representing traffic as subdivided into pairs of planes but into groups of planes linked together in a system of relationships.

- that the proximity of the exit of the sector implies giving priority to a decision concerning the descent of the aircraft. One could envisage a tool to assist the management of priority actions to be taken which would pinpoint the conflictual planes leaving the sector with an indication of the time left to solve the problem. The controller would then have the choice between solving it in his own sector or else passing the elements of the conflict on to the next controller.

Thus, the analysis of Representamen can lead to reflections on the presentation of information which help implement knowledge making it possible to identify events which occur. Within the context of the design of a new position, these descriptions provide reference points:

- to discuss how the choices of design can favour or not the use of the current knowledge of the controllers;

- to explain the difficulties of experienced controllers who are placed in a simulation position with a mock-up of the future interface. This refers either to the design of a new interface, or to the design of support to controllers through training.

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The interpretant shows the links between typical events which permit the controller to construct representamens, and the typical events and typical actions which ensure the determination of the activity in terms of events and/or actions. They therefore reveal:

- the active role of the controller in the construction of his activity;
- the progressive understanding of the traffic.The controller handles the uncertainties and doubts which are gradually removed.

Thus, the analysis of Interpretant enables taking in account the competence of the controllers in the desing and implementation of the new computer interfaces.

The significant units of the activity show the relative weights of the different parts of the activity. For example, the importance of the stories linked to the handling of the configuration of planes in conflict in the activity of the controllers leads to a search for support specific to this part of the activity, and an attempt to relieve the controller of the rest of the activity when he has to control several planes in conflict.

The analysis of the activity of the RER traffic controller and the definition of aid for coordination

The analysis of data in significant units provides a particular description of the incidental situations observed. It is a matter of dividing the continuous development of the course of action into significant units by replying to the question: "What is this about, from the point of view of the controller?" By naming each of these units, an account is built up which gives meaning to the rough data. This analysis clarifies the temporal organization of the actions and events and provides a few elements on their sequence. Thus, the insertion of significant units reflects work carried out in divided time during which several preoccupations are handled simultaneously by the officials.

Let us, for example, take the following extract from the transcription of an incident:

S	ACTIONS AND STATEMENTS BY THE CONTROLLER	
2.1		Looks for ZHAN 07 on the train schedule graph.
	C1 -> Sig 2	"You have material, Max?"
	Sig. 2 -> C1	"No"
	C1 -> Sig 2	"Nothing at all?"
	Sig. 2 -> C1	"Nothing"
	C1 -> Sig 2	"Has OLAF been shunted out?"
	Sig. 2 -> C1	"Yes, but the time it will take to return..."
2.2	man -> C1	"Perhaps, you'd better cancel a XILO? Cancel XILO 09. When does RUDY 18 leave?"
	Sig. 2	"Immediately, it should be leaving at any moment now"
	C1 -> man	"It should have already left."
	man-> C1	"Well change with XILO 09, then replace the other leaving from Rueil."
	C1 -> man	Looking at the graph: "The only thing is... the following XILO, it will do NAGA ... no RUDY"
2.3	C1 -> Sig 2	"Do you still have an OLAF on the sidings, Max?"
	Sig 2	"There are still two on the sidings."
	C1 -> Sig 2	"And they are on their train?"
	Sig 2	"Yes, they still should be on their train, yes"

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This extract can be sub-divided into significant units belonging to three different ranks. They all concern the problem caused by the breakdown of ZHAN 07. This breakdown is relatively long and is tied to other problems that have to be solved. This is revealed in sequence 2, in which the chief controller is searching for available carriages to replace those of the train ZHAN 07 whose doors do not close. This sequence can itself be divided into sub-sequences all involved in the "search for replacement material".

THE BREAKDOWN OF ZHAN 07	2. Search for replacement material	2.1.Requests Sig 2 for available material 2.2. Discussion with Manager regarding possible exchanges with other trains 2.3. Asks Signal man about OLAF availibility

The analysis of this transcription is made in reference with what occurred before and after, and according to what the controller says about it in the course of the self-confrontation.

Through this example of a disrupted situation ("ZHAN 07" incident), we can characterize the individual social courses of action of the controllers.

> ZHAN 07, a train running in the direction of St Germain, calls about a breakdown (doors do not close and there is a continuous vibration) from Vésinet. A certain time elapses during which the driver of a train running in the opposite direction tries to help, before ZHAN 07 starts again. The controller decides to send ZHAN 07 without passengers up to St Germain, then have it make its return journey (NAGA 22) up to Rueil, where it will be replaced by elements from OLAF 18 which was supposed to leave a little later from Rueil. After searching unsuccessfully for replacement material for OLAF 18, he cancels this journey.

The handling of this incident in the collective context of the control room is accompanied by a situated planning (Suchman, 1987) that is relatively complex in that:

- the number of persons involved in the incident is high (drivers, station masters, signalman) and gives rise to uncertainty as to their reactions;

> For example, to replace the defective elements of ZHAN 07, the controller decides to change the journey of NAGA 22 (return journey of ZHAN 07) into OLAF 18 from Rueil.
> A warning has to be given to the station master and the drivers by telephone or radio-telephone:
> + the driver of OLAF so that he labels his train NAGA 22
> + the driver of ZHAN 07
> + the station master of Rueil so that he can make provisions for a standby driver to park the defective NAGA 22 and again for a request for confirmation
> + the standby driver to ensure that he is actually on his train and to indicate the siding where he must go.
> The controller informs the signal man at Rueil when the latter asks him what he should do. He makes sure that the information assistant and the other controllers have understood that a change has been introduced in the train schedule.

The high number of persons to be informed creates an additional difficulty for planning the actions of the controller, for he must ensure that everyone has completely understood what it is about and what has to be done. Thus, after having asked the station master for a standby driver to park the defective NAGA 22, he must first check with the station master, then with the standby driver himself, that he is ready to leave.

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- the implementation of a decision is gradual and shifted in time, that is to say that the handling of the incident is dependent upon the time needed to manoeuvre the trains as well as the possibility of communicating with the drivers;

> In the example of the breakdown of ZHAN 07, the controller eventually decides to replace the defective elements of NAGA 22 by those of OLAF 18 around sequence 10, when ZHAN O7 is still at Vésinet, and he must wait until sequence 45 for all the manoeuvres to be carried out, in other words, the time needed for the ZHAN 07 to go up to St Germain and return to Rueil as NAGA 22. In the meantime many other problems have cropped up and some have already been solved.
>
> The relatively long time it takes to sort out the breakdown - about twenty minutes - makes it impossible to turn back once a decision is taken, and it is therefore necessary for the consequences of this decision to be evaluated beforehand.
> Furthermore, this type of relatively long process time leads to work in divided time: other problems are tied with that of the ZHAN 07 breakdown and must be handled at the same time.

- each decision involves many repercussions (change in the duty roster of the drivers, management of rolling stock, etc) that the controller tries to minimize when he is deciding which solution to adopt to repair the incident.

> The decision taken to solve the ZHAN 07 breakdown had the following effects:
>
> - to look for replacement elements for OLAF 18 whose own elements had been used for NAGA 22;
> - to supervise three drivers: those of ZHAN 07/NAGA 22 and OLAF 18 whose journey was finally cancelled, and the standby driver to park the defective NAGA 22; in other words, to ensure that a driver whose journey has been changed is dispatched, within the necessary time limit, where he is needed so that he can continue his service normally, and to ensure that those who are at the end of their service do not work overtime and are transported to their duty station ;
> - to bring up-to-date the provisions for shunting and returning to depot;
> - a breakdown involving damage to a train has to be noted in the relevant register, with a description of the damage and the actions taken by the driver to remedy this.

The various forms of cooperation which emerge during incidental situations also reflect the importance of the group for the activity of the controller. For example, when the attention of the chief controller is focused on a specific problem, the intervention of the group makes it possible to "de-focus" on the general context when this is necessary. Or else, when a breakdown occurs at peak hours, the urgent nature of the situation immediately engenders an implicit sharing of the work: because of the geographic sector in which the train is in, the person concerned by the incident tries to solve it with the driver, while the two other controllers handle the upstream and downstream traffic.

In order to effectively help the activity of the control room staff, a modernization of the traffic control apparatus must take into account the supremacy of the collective nature of the work. It is with this in mind that we are seeking to contribute to the *improvement of the mechanisms for coordination support* of the present system. In reality, all the tools used by the staff (the fix-line diagram representing the trains, the paper documents and computer terminal) indirectly aid cooperation: each person regularly looks at the fix-line diagram, certain sheets of paper pass from one to person to another, etc. The results of the analysis of the work situation with the tools, such as they exist today, aim at orienting the *design of a support system for the coordination* of actions in future control rooms which can incorporate public information.

Future Research

We have only presented a few aspects of the investigations into the control of traffic and the programme of research to which they contribute. But in conclusion, we have said enough to point to

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two important but insufficiently resolved problems, both theoretical and methodological, which should be the object of future research.

First of all: how should the complex representamens be analyzed? This presents a particular problem in air traffic control. The improvement of recommendations on the design of interfaces will depend on a solution to this problem.

Next: how should the linkage between the individual courses of action of the various actors be analyzed? This presents a particular problem in metropolitan traffic control. The improvement of recommendations on the organization, training and specialization of the interfaces for each actor will depend on a solution to this problem. It is also a problem in air traffic control, with respect to two controllers who share the same control position.

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