From representation of operational knowledge to practical decision making in operations.

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Abstract

In various industrial fields, the operators use pre-designed procedures either to solve problems or for troubleshooting. In the Parisian subway, such procedures exist since 1900. However, these procedures are not always exactly suited to the case at hand, and the operators generally prefer to customize a solution than to rely on fixed procedures. A new generation of decision support systems, so-called "intelligent" assistant systems, offers more flexible possibilities of cooperation between the users and the system. SART is such a system, for its design, we have modeled operators' activity to model the cooperation between the operators and the system. As a result, we introduce the contextual graph paradigm, which appears as a possible computer representation of schemes that are used in psychology to describe human activities.

Key words: *Decision Support System, Knowledge Representation, Context, Contextual Graphs, Schemes of Action.*

1 Introduction

In high technical and heavily dynamical process regulation domains, operators who are responsible for the process control have to rapidly react. If an incident occurs, they have only few minutes to forge a representation of the issue, gather information on the situation, analyze the incident and undertake the correcting actions. To ease their job, many companies have established fixed procedures. Initially, general procedures have been designed to provide operators with a secure reference for incident solving. However, these general procedures forget the contextual dimension of the case at hand. Nowadays, companies are diversifying these procedures by introducing increasingly contextual considerations. This operation multiplies and specializes the available procedures for each type of incident type.

In parallel, operators prefer to replan their action in real time rather than to rely on these procedures based on company's experience, this is due to two main reasons. Firstly, the selected procedure is not always perfectly adapted to the situation at hand and can lead to improper actions or sub-optimal incident resolution strategies. Secondly, if the operator relies on a procedure, he can miss some important facts and notice them too late to adequately solve the incident. Operators prefer generally to replan their action continuously according to the situation. Procedures are then used as frames to construct a genuine strategy tailored to the specificities of a given situation. Such practices are based on operational knowledge and are shared by operators. This well-known phenomenon was studied by Leplat (1985) that distinguished between the prescribed and the effective tasks. The former is the task conceived by the "method office" of the company, and the latter is the effective task that is executed by the employee. The effective task corresponds to the goals and conditions effectively taken into account during the activity.

For the design of precise procedures, it seems important to gather operators' practices and to analyze their operational knowledge. Using computers, we can manage large databases and data structures, and thus design decision support systems based on real practices. The SART project (Brézillon *et al.*, 1997; Pasquier, 2000; http://www.lip6.fr/SART) aims at the design and development of such a decision support system for the operators in charge of the control of a subway line. This project is based on the interaction between the operator and the system and will ease their mutual comprehension. For this purpose, we base the system reasoning on the operator's one. Thus, we needed to analyze the operational knowledge used by operators and to store it in an adapted structure, which will be easily understood by operators and efficiently used by the computer.

This paper presents the results obtained after Bled'98 (Brézillon and Pomerol, 1998). We present, in Section 2, general information about the application field (the Parisian subway and its control) and our results about activity analysis. Section 3 presents several available representations of the operational knowledge identified in the operators' community. We present our model for knowledge representation in Section 4: This representation is based on decision trees and we explain the structural modification we introduced to adapt these decision trees to our particular domain. In the same section, we discuss the parallel between our representation and action-directing mental structures (schemes) identified by cognitive ergonomic studies.

2 Operational knowledge

2.1Parisian subway descriptions

The Parisian subway is a dense underground railway network and a high technical transportation system. A line can be represented according to several points of view:

1. One can see it as a succession of **stations** and **interstations** (interstations are the rail track portions between two successive stations). This is mainly the travelers' view of the line.
2. A second viewpoint is based on electrical supplies. The power needed for all the trains on the line is too high to be supplied by a unique **rectifier sub-station**. Thus, several rectifier sub-stations power the line. This permits to divide the track into several **sections**, each of them being powered by at least one sub-station, so that each section is independent from the others from an electrical point of view. For practical reasons, each section is also made of **sub-sections** to reduce the impact of an incident on the traffic.
3. There is a third view of the line according to the organization of the regulation (Laville and Zanarelli, 2000). Two main classes of operators regulate a line: first, the **local control point** agents who manage the trains and their departure time, second, the **centered control room** (PCC in French) agents, which we call here operators, who are responsible of the traffic supervision and incident solving. The two classes of agents are working at different places and communicate by telephones. Operators at PCC can also communicate with train drivers, station managers and exploitation supervisor (himself connected to emergency services).

Operators alternatively use these three descriptions. When the issue principally concerns traveler transportation, the first description is preponderant. When a technical problem or a located long-lasting incident occurs, operators choose sectioning and sub-sectioning to limit the impact of the issue on the residual traffic. If trains on the line are delayed by the incident, operators communicate the information to the end station (third aspect). Most incidents need a combination of the three representations to be solved: the operators keep in mind that (1) travelers' security is an important contextual factor that constrains incident solving, (2) the consequences of an incident must perturb as less as possible the traffic, and (3) appropriate actions (*e.g.* train redirection) is intended to maintain as far as possible the regularity of the transport, but interfere with the end station agents' work.

2.2Parisian subway control organization

For each line, there is a principal terminus and one or more secondary terminuses, each of them having a local control point controlling the departure of the trains, whose the PML agents have also to manage the traffic in the terminus area, to choose which train will start, to order the departure according to the theoretical timetable and to adapt it to the actual conditions.

A particularity of the Parisian subway is that the PCCs of all the lines (except the new line called METEOR which is entirely automatic) are in the same room, so that the operators of several lines can solve together an incident. Moreover, operators are organized in several teams and two turnovers are defined, one based on 7 days, the other on 10 days. Thus, all operators rapidly share each new experience. Hereafter, we consider the problems from the viewpoint of operators. The PCC is distant of the line and the only information available to operators is indirectly available by telephones and a synoptic panel of the line. Operators have to mentally construct a model of the local situation to make their decision in the spirit of what Clancey (1992) proposed for diagnosis seen as the building of a situation-specific model.

The operator of each subway line is assigned for one part of the day to the corresponding **control console** that allows to cut the power in any section, to stop trains at each station, to communicate with train drivers with high frequency telephones, terminus agents, station agents, local operators or exploitation supervisor with automatic telephones. The operator faces a large **synoptic panel** (called **TCO** at the RATP) representing the line, the sectioning and sub-sectioning, the stations and the train position. On the TCO are some commands such as energy commands and switching commands.

Thus, the actions available to operators concern mainly train regulation (delaying), train redirection, section and sub-section power cutting and supply, or waiting for information, event or action from local or external agents. Operators play an important role of two-way communication dispatching center from local agents (drivers, station agents, end station agents or local-situated executives) to exploitation and line executives. Any information is relayed by the operators. As a consequence, operators are the coordinators of all the people solving the incident and the managers of the needed means.

When an incident occurs, the operator responsible of the concerned line becomes the "incident manager" and the eventual operators, which may possibly help him, are the assessors. The incident manager stays at the control console, responding to phones, controlling the trains and making decision. Assessors help him on several points: for all incidents needing line power control, an assessor stays at the TCO to cut or reestablish the power on sections or sub-sections and for eventual train redirections; for more important incidents, a second assessor observes the activity, advises the incident manager and take notes on the resolution (the time of the actions and events, the train number and location of train redirections…). When the incident is solved, the incident manager writes a report containing incident description and the actions undertaken to solve it.

2.3Company's operational knowledge enhancement

Since 1900, the company faces incidents and its agents solve them. These practices reflect the construction of operational knowledge, step by step, by the operators. Security sake and the willing of incident solving uniformization pushed the head of the company to compare the practices and to establish secure procedures for each encountered incident. In this sense, procedures are collections of safety action sequences permitting to solve a given incident in any case. These procedures are based on practices, but eliminate most of contextual information and particularities of each incident. Trying to promote sufficiently general procedures results often in sub-optimal solutions for incident solving. In this acception, procedures are useful guidelines for operators, but they have to be adapted for each new incident situation.

Nowadays, we observe the multiplication and the specialization of procedures in a number of domains. This is a general trend overtaking the railway control process, which is also observed in aeronautics. In this later field, operators always adapt the actual procedures to the current situation. De Brito and Boy (1999) explain that the aircraft operators prefer to replan their actions instead of following non-adapted procedures, even if the new plan is inspired of these procedures. Britanik and Marefat (1999) also propose a plan merging methodology that merges partial-order plans based on the notion of plan fragments. Their notion of plan fragments encapsulates actions with their context. Hayes-Roth & Hayes-Roth (1979) proposed a so-called opportunistic approach to planning. This non-hierarchical planning assumes that a plan is executed with the help of some kind of mental blackboard where pieces of information, relevant cues and possible sub-goals are stored. They claimed and showed that planning happens asynchronously and is determined by the momentary aspects of the problem. No fixed order of operations exists; the plan execution and the steps to be taken, grow out of the problem stage at hand.

In such a context, operators face more and more procedures and need adapted tools for constructing their solution from procedures and practices. The SART system (French acronym for Traffic Regulation Support System) will help the operators in several tasks, namely configuring the system, simulating the traffic and managing the incidents. This last part of the SART system will propose solutions to a current incident or information on past events. To ease the mutual comprehension between the system and the operator, we based the artificial reasoning on the operators' one. For the design of this part we have modeled operators' activity.

As a limit of this top-down approach, there are two points to note for complex incident solving. Firstly, it is not possible to establish a global procedure, but only a set of sub-procedures for solving parts of the complex incidents. Secondly, procedures cannot catch the high interaction between the solving of the incident itself and the number of related tasks that are generated by the complex incident.

2.4Operators' activity and operational knowledge recovery

We studied the activity of the operators while they are solving an incident by observing and interviewing them. We constructed step by step a model of the applied strategies and of the procedures used. We then tried to recognize some activity invariants. By comparison with the results of Zanarelli (1998) and a cooperative work with her (Zanarelli *et al.*, 1999), we identified a two-phases activity. First, when operators have no information about the causes of the incident, they apply general procedures for traffic regulation and incident diagnosis. Once they know the causes of the incident, they follow more precise procedures to eliminate the causes. It happens that some incidents are solved before the operators discover the causes. In such a case, operators stay in the first phase up to the end of the incident.

A second important fact is the importance of context on the decisions made to solve an incident *e.g.*: an incident happening at peak-time will not be solved as the same incident occurring at off-hour. These pieces of context are numerous and of various types. Moreover, some are always relevant (time period, incidental event…) but others are not used in all cases (train number, position on the line…) and the list of these pieces of context is *a priori* not exhaustive. The operators deal with a set of heteroclite and non-complete information on the line state to make their decisions. This explains the variety of strategies observed for incident solving, from an operator to another one, but also for the same operator at different times. The importance of context and the lack of precise procedures oblige operators to adapt the procedures to the reality.

Procedures are generalizations of practices. They simplify the context of the incidents and are officially more guidelines than directives. Operators use them as examples and replan more or less the strategy for each incidental situation. In such conditions, operators often apply actions that were not expected by the procedures. This is an important point to take into account for the enhancement of the procedures and for the design of our representation based on practices.

3 Available models for operational knowledge representation

Practices are difficult to model: first they are numerous, second they are strongly linked one each other and third the main distinction among them is the context in which these practices are applied. To gather and study operational practices, we record the incidents as a set of characteristics, including context description and the action sequences applied to solve them. With this feedstock, we can construct an adapted representation to collect and organize this type of knowledge for reuse purpose. In this section, we present the models underlying our representation.

3.1Importance of the contextual dimension and the dynamics of context

The set of contextual elements is too big to be considered as a whole. Pomerol and Brézillon (1999) distinguish the **contextual knowledge** as a subset of the context, useful for an operator to understand, explain and solve an incident situation. The complement of this subset is called **external knowledge**. The subset of contextual knowledge is known *a posteriori*, since some elements appear important to understand, explain or solve the incident during the incident solving, not beforehand. For one given contextualized incident, the frontier between the subset of contextual knowledge and the subset of external knowledge is fixed, we just don't know, before the incident, if an element is part of contextual or external knowledge.

Moreover, all contextual knowledge is not used at each step of the decision-making. We defined the **proceduralized context** as the subset of the contextual knowledge that is used explicitly at a given step of the decision-making (Pasquier *et al.*, 1999). Figure 1 presents the set of the whole context and the defined subsets.

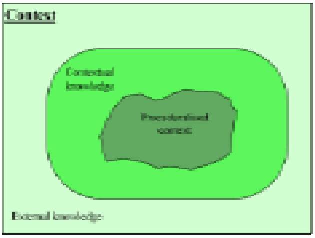

Figure 1: Context set and its sub-sets

This distinction holds during the whole problem solving. However, the proceduralized context must take into account the dynamism of the focalization of the operators on particular contextual pieces of knowledge at each step of the incident solving. Indeed, at each step of the decision-making, some contextual pieces of knowledge enter the operator's focus. These elements are thus proceduralized. Conversely, some proceduralized pieces of knowledge leave the operator's focus (the operator is no longer influenced in his choice by these elements). Then, these elements are deproceduralized. The time period during which a piece of contextual knowledge is proceduralized must be represented explicitly to avoid a combinatorial explosion. This proceduralized state of contextual knowledge and its dynamical change from step to step are important in incident solving and have been integrated in our representation.

3.2Computer science approaches

Artificial intelligence develops, for several years, formalisms for operational knowledge representation. Here we present some approaches linked to our representation (presented in Section 4). In an expert system-like representation, knowledge is gathered as production rules. These rules are pieces of knowledge of the form “if *conditions* then *conclusions*.” They are recorded in large rule bases difficult to update. The rules are structured pieces of knowledge, which are easily understood (by the domain experts). However, the lack of structure of the rule-base impedes the comprehension (even for the experts of the domain) and the maintenance of the knowledge.

Some works have been done on rule-bases structuring, namely on the splitting of the rule bases into several rule packets, each containing a subset of rules applied to solve a specific sub-problem (Brézillon, 1990). Clancey (1983, 1993) proposed to add screening clauses to the condition part of the rules so that they are activated only in some kind of context, this amount to add in the preconditions of the rule some clauses constraining the triggering to a certain context. This is burdensome because the designers must anticipate all the possible contexts to define the preconditions of the rules.

The decision tree approach (Raïffa, 1968) tries to represent the decision step by step. This is obtained by the presence of two types of nodes: the event nodes and the decision nodes. At an event node, paths are separated according to an event on which the decision maker has no influence. On a decision node, the person makes a choice. This approach might be a way to structure rule bases. For each new element analyzed in the conditions, a new event node is created. For each new value of an existing contextual element, a new branch is created, and so on. Rule after rule, a tree is constructed. The leaves give the rule conclusions. The main problem with this structure is the combinatorial explosion. The number of leaves is an exponential of the deep of the tree. The addition of a contextual element may easily double the size of the tree.

Bayesian networks are composed of nodes, representing random variables, and links representing the causal relations between the different random variables (Jensen, 1996; Pearl, 1988). Each node is associated to a table giving the distribution of probabilities of the corresponding random variable according to the values of the random variables of which it depends on. The influence diagrams introduce decision nodes into Bayesian networks (Oliver & Smith, 1990; Neapolitan, 1989). These networks are possible solutions to limit the combinatorial and information explosions in decision trees with probabilities. Moreover, both approaches, Bayesian networks and influence diagrams, necessitate, to be handled, some information about the probabilistic dependence between the different random variables and are anyway limited to a reasonable number of variables.

Another network representation relies on simple Petri-net or colored Petri-net (CPN). CPN are very useful to represent the dynamics of a situation and simulate a process. Humphreys and Berkeley (1992) give such an example for simulating an organizational process.

Another interesting approach is the Case-Based Reasoning (CBR), which is a kind of analogy reasoning. To solve a current issue, one selects the most similar problem in a problem base and one adapts the solution to the problem at hand. Note that instead of adapting prior solutions, Leake (1996) proposes as an interesting alternative to store and reuse trace of how those solutions were derived. The main advantage of this reasoning is its great power of generalization and its maintenance. However, it fails to provide explanations on the obtained solution.

These computing approaches are six well-known paradigms to introduce human-like reasoning in automatic systems or support systems. Psychology and ergonomics are also interested in this activity representation.

3.3Cognitive ergonomics approach: the notion of scheme

The notion of scheme was proposed first by Kant around 1800, with an emphasis on its temporal dimension (Eco, 1997). Schemes are a kind of collection of tape-recorded thoughts and actions which human beings use (or replay) to interact with the world and to solve problems. Piaget (1936), working on learning during the childhood, defined the notion of scheme as organized patterns of actions or thoughts used to represent the world. The notion of scheme plays an important role also for structuring operators' activity: Béguin (1994) for drawers, Galinier (1996) for truck drivers and Duvenci-Langa (1997) for workers on tool machine, have all identify schemes of activity. A scheme is composed of a structure of actions, but also other things as the means used to accomplish the actions. Eventually, an action structure may be composed of several elementary schemes. Vergnaud (1985) describes a scheme as a dynamical organized totality containing four categories of elements:

4. operational invariants (objects, properties, relationships and processes),
5. acting rules for guiding and create the action,
6. inferences or calculi (kind of reasoning),
7. predictions, which are goals or intermediary steps.

Conversely to a schema, a frame or a script, a scheme possesses a dynamical dimension because it is triggered by a change in the current context when a new event occurs: A change of the context implies a change of the scheme, and the change of the scheme of a given task may concern the task itself or the tool that is used to solved the task. Schemes evolve respecting different rules:

8. A scheme may be **updated** as a set of procedures that are relevant according to the singularities of the given situation.
9. A scheme may be enriched by **addition of new strategies**. Following Piaget (1936), Rabardel (1995) underlines their capacities of assimilation and accommodation. Assimilation involves putting information into an existing scheme without changing the scheme. Assimilation is our mind's way of saying, "This new information is already familiar to me". Accommodation is the process of changing our existing schemes in order to create new ones suitable to the new information or situation.
10. Schemes may be build by **adapting** existing schemes to a new one. For example, you use to work with a tool (you have constructed a scheme for using this tool) and you discover a new tool based on the same idea. You try to use the new tool like the old one (this does not work exactly the same way) and this way you create a new scheme derived from the old one integrating the differences between both tools.

The notion of scheme is different from the notions of scenario or script proposed by Schank & Abelson (1977). For example, each event in a script follows each other in a fix manner. There is also a difference with the notion of schema or Memory Organization Packets, MOPs (Schank, 1982). Again, all the information on the way an entity (scenario, script, MOP) behaves is coded initially in the entity in a static way. Thus, these entities are invariant structures of activities and actions. They do not address the problem of the representation of an activity in context. Conversely, a scheme is not applied directly. Instead, a scheme must be instantiated depending on the specific context of the current situation.

4 Representation of operational knowledge in procedures and practices

4.1Particularities of Parisian subway control operational knowledge

During the modeling phase, we tried to understand the troubleshooting strategies applied in some incidents, such as lack of motor power on a train. Our first representation used rules. This representation was not well accepted by operators and was, as explained above, difficult to maintain. The main reason was that the level of description of the operational knowledge was too low (too many details) and no global strategy was perceptible.

Then we adopted a tree representation, made of two types of elements: the **actions**, which are directives to do an action, and the **contextual nodes**, which select a path depending on the value of a contextual piece of knowledge. Figure 2 shows the decision tree representation of the official procedure for “train lack of power” solving (the meaning of the boxes is not important here but can be found in Pasquier, 2000).

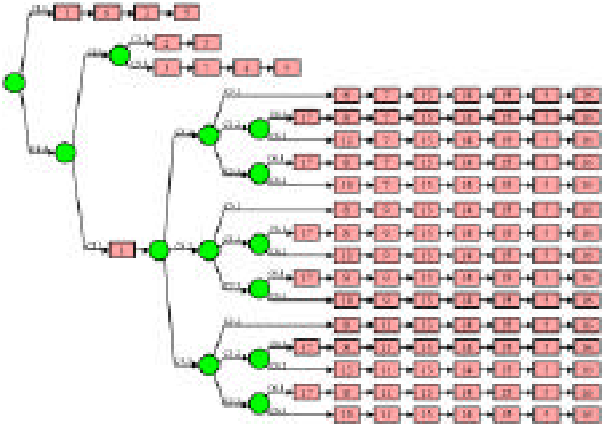

Figure 2: Decision tree representing the official procedure for “lack of train power” incident

Our tree representation is inspired by decision trees, but they differ namely on two points. First, our trees have no decision node, only “chance” nodes where a contextual element is analyzed to select the corresponding path. Second, There are no probabilities. This representation shows several important specificities that have consequences on the size and structure of our tree:

11. Operators have a single main goal: “to reestablish a normal traffic as fast as possible, respecting elementary security rules.” This point places emphasis on the fact that in the same situation, several strategies permit to solve the incident.
12. As said in section 2.2, operators use many contextual elements to perform their choice. This lead to a large number of practical strategies, even for the same incident. This point multiplies the number of branches and the tree grows rapidly.
13. The operators prefer to gather a maximum of information before making their decision. This attitude postpones most of the actions to the end of the branches of the tree. This observation is very close to the observation of Watson and Perrera (1998) that consider a hierarchical case representation that holds more general contextual features at its top and specific building elements at its leaves.
14. The operators choose actions that allow acceding to common intermediary situations. They can thus reuse common strategies to clear the incident. Graphically, the terminal action sequences are often repeated from one branch to another.

15. Several action sequences are done in the same order in different situations (paths).
16. Some actions could be done in different order, but must precede a given other. For example, before to link two trains, both have to be emptied, but the order in which they are emptied does not matter (partial order on the actions).

The tree structure is heavy and does not permit to represent highly-contextual decision-making in complex applications. In the next section, we explain the modification we have done, based on the specificities discussed above, to obtain a manageable structure for representing operational knowledge on incident solving on subway lines.

4.2 From decision trees to contextual graphs

First, we reduced the number of objects in the structure by replacing repeated sub-sequences of actions (specificity 5 above) by a single object called **macro-action**. The choice made for defining the different macro-actions is based on common sub-procedures known by the operators, such as “linking trains,” “return to end-station without travelers”… The principle of replacing is the following:

Figure 3: From a sequence of actions to a macro-action

This replacement simplifies the lecture of the tree, but do not reduce the structural issue of the tree. Secondly, relaying on previous specificities 1 and 4, we merge the branches of the tree as soon as the sequence leading to the end of the incident are similar, as shown in the figure 4.

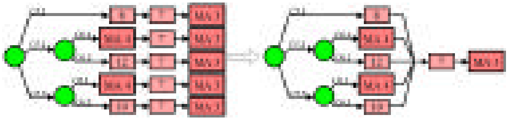

Figure 4: From tree to graph

Cognitively speaking, this amount to use a scarcity principle that leads the operators to try to reuse well-known procedures as soon as possible. This operation has several main consequences on the structure of the representation and on the meaning of the model.

17. We no longer face a tree but a graph. This graph is oriented without circuits, with exactly one root and one goal (because operators have only one goal and branches express only different strategies, depending on the context, to achieve this goal). The graph structure moreover allows extending of the representation.
18. The size of the structure is now under control and the consideration of a new contextual element will add some elements in the graph, but not increase drastically its size (specificity 2 above).
19. The change of the structure introduces a dynamics comparable to the dynamics of the change between proceduralized and contextual knowledge. Indeed, when two branches are merged, it means that the undertaken actions led to a common situation from different contexts. The contextual elements attached to the different branches are proceduralized at the diverging node. They stay in this state for the different action sequences, because they intervene in the branch decisions. Finally, they are deprocedurالized when the branches are merged. By this way we explicitly express the life duration of the contextual elements (Figure 5).

Figure 5: Proceduralization and de-proceduralization

Even in a part of a subgraph it may happens that the actions are only partially ordered (see the example above of two trains on the same line which have to be cleared of the travelers whatever the order of the operations). We need to represent this issue; this is why we introduced the **temporal branching** symbols to represent action sequences that can be done in different order (specificity 6). This symbol is made of two parts: a divergent branching and a convergent branching; the parallel branches wear the temporally independent decision blocs. Finally we obtain the following structure (Figure 6) that we call **contextual graph**.

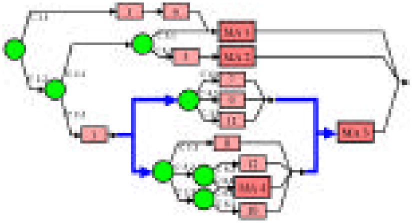

Figure 6: Contextual graph representing the official procedure for “lack of trains power” incident

This structure is called “contextual graph” to recall that it makes explicit the context and its dynamics for decision-making. This representation is more compact than trees and seems to be well accepted by the operators. As our initial trees were not decision trees, these directed acyclic graphs are not influence diagrams. They simply represent the succession of actions to do to solve an incident; the different possible paths express the possible strategies according to the situation. We must also mention that our representation is much simpler than colored Petri-net (Humphreys and Berkeley, 1992) but it has not the same expressiveness as regards the dynamics because the process of proceduralization de-proceduralization must “linearly” follow the left to right reading of the graph.

4.3Contextual graphs and schemes

In the contextual graphs that we have built for several incident types, we note that some parts of the different graphs are identical. Analyzing these sub-graphs we exhibit that they complete a common sub-goal (for example, when a train lacks of power and can not restart alone, or when a train has no more brake, both trains need to be helped by another train). Such a representation in contextual graphs/sub-graphs (Figure 7) is very similar to the generic tasks proposed by Chandrasekaran (Chandrasekaran *et al.*, 1992).

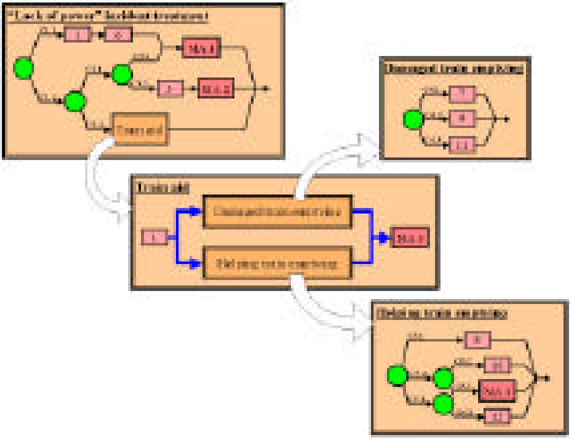

Figure 7: Set of contextual graphs used while "lack of train power" incident resolution

These sub-graphs, associated with a name (operators know the corresponding procedures and agree on a name) and a goal, are similar to schemes identified by the ergonomists and defined above. These structures may evolve according to two rules. First, one structure can be reused and adapted to another action. For example in Figure 7 the scheme “*Helping-train clearing*” is derived from the scheme “*Damaged-train clearing*” and adapted by the introduction of the fact that an available train may run to the next station, if this station is free, to evacuate its travelers in better conditions. The second possible evolution of the structures is the update of the acting rules by combination with a new action sequence achieving this goal. We worked on the possible algorithms for this combination (Niang, 1999). These algorithms will be tested as soon as the whole structure will be coded.

In this sense, we get a set of schemes, some for solving an incident situation, others for completing sub-goals. Each scheme has a name, a goal and a contextual graph representing the decision-making that allows achieving its goal depending on the context. Each scheme organizes the activity around an object and can call other schemes to complete specific sub-goals. Although different, contextual graphs present some similarities (in its static description) with the MOPs proposed by Schank (1982): A MOP is a set of elementary actions assembled in a causal way and a set of links toward other MOPs more specialized.

Moreover, a contextual graph, as a scheme, permits:

20. to represent clearly operators’ activity and all its variant (procedures and practices),
21. to include automatic learning and adaptation in a system,
22. to make context explicit in the representation of operators’ reasoning,
23. to organize the operators’ activity.

4.4 From operational knowledge representation to practices

The SART decision support system uses our contextual-graph representation in association with case-based reasoning, respecting three main modes. The first mode updates the databases used by SART according to a new incident declaration and description. The two other modes are mainly databases interrogations, but differ in their principle. One of these two last modes helps the operator when a new incident occurs. In this case, the operator has no time to interact with the system. This one must gather a maximum of information automatically and propose well-adapted solutions. The third mode is a support system for experiencing and training. It allows to an operator, when he has time, to compare different situations and to analyze them for identifying the elements differentiating between two strategies and assessing the quality of the available strategies.

The two later modes are based on the following reasoning. Given a scheme base, an incident and its context description, the system proposes several possible solutions to this problem. First it selects the scheme corresponding to the resolution of this type of incident. Then, for each contextual element encountered in the associated contextual graph, it determines if this element is known or not for the current incident. If so, it selects only the corresponding branch. Otherwise several policies are acceptable: either it selects all the branches (this presents to the operator all possible strategies in this situation), or it selects the most often followed path, or it follows the path closer to the official procedure. It continues the path selection up to the end of the contextual graph and return the path(s) found. It presents the possible sequences of action, representing the integrated schemes as expandable actions. If the operator wants precisions on one of the integrated schemes, he asks the system to zoom on it. This mechanism looks like aggregation and expansion of Sowa's conceptual graph (1984, 1991).

5 Conclusion

Our interest for schemes in modeling of operators' reasoning comes from the need to make context explicit in reasoning representation. We show that the modeling of reasoning in a tree representation can be heavily simplified, thanks to three notions, namely macro-action, temporal branching and contextual graph. Going one step beyond the computer representation of reasoning on the basis of context and contextual graph, we have pointed out that some sub-graphs are shared by graphs representing reasoning held to solve different incidents of various natures. These sub-graphs, beyond the fact that they give a simple computer representation of reasoning, have a deep meaning for operators and can be explained, even once drawn out of the context of an incident. We thus are able to propose a set of interrelated contextual graphs that incorporate the notion of context in any problem solving (*e.g.* an incident solving) and represent the dynamics of the proceduralization de-proceduralization process.

We show that these sub-graphs behave as schemes of actions in Cognitive Ergonomics. Our approach for representing reasoning allows thus to model representations of human cognitive activities. It is interesting to note two points. First, our representation is not limited to operators' reasoning in subway control. Second, it is easily understood by the operators and computable.

Acknowledgments:

RATP and COFECUB in France and CAPES in Brazil provide grants. We also thank J.-M. Sieur at RATP, C. Zanarelli, and all the other members working on the SART project.

6 Bibliography

Béguin, P. (1994). Travailler avec la CAO en ingénierie industrielle : de l'individuel au collectif dans les activités avec instruments. *Thèse de doctorat en ergonomie*. Paris, CNAM.

Brézillon, P. and Pomerol, J.-C. (1998). Using contextual information in decision making. *Context Sensitive Decision Support Systems*, Berkeley, D. *et al.* (Eds.), Chapman et al., London., pp 158-173.

Brézillon, P., Gentile, C., Saker, I. and Secron., M. (1997) SART : A system for supporting operators with contextual knowledge. *First International and Interdisciplinary Conference On Modelling and Using Context (CONTEXT'97)*, pages 209-222, Federal University of Rio de Janiero, 1997 (also available at http://www-poleia.lip6.fr/~brezil/Pages2/CONTEXT-97/index.html).

Britanik J.M. & Marefat M.M. (1999) Hierarchically merging plans in decomposable domains. IEEE Trans. on Systems, Man, and Cybernetics, 29(1): 27-39.

Chandrasekaran, B., Johnson, T.R. and Smith, J.W. (1992). Task-structure analysis for knowledge modeling. *Communications of the ACM*, 35(9): 124-137.

Clancey (1979). Tutoring rules for guiding a case method dialogue. *International Journal of Man-Machine Studies* **11**(1), pp 25-49.

De Brito, G. & Boy, G. (1999). Situation awareness and procedure following. CSAPC'99, Villeneuve d'Ascq, Presses Universitaires de Valenciennes, pp 9-14.

Duvenci-Lenga, S. (1997). Evolution de l'activité et des compétences en situation d'automatisation : le cas des machines-outils. *Thèse de doctorat d'ergonomie*. Paris: CNAM.

Eco U. (1997) Kant et l'Ornithorynque. Paris: Grasset.

Galinier, V. (1996). Apports de l'ergonomie à la conception d'instruments : concevoir autour des schèmes d'utilisation. Un exemple dans le domaine du transport routier. Thèse de doctorat en ergonomie. Paris: CNAM.

Hayes-Roth B. & Hayes-Roth F. (1979). A cognitive model of planning, Cognitive Science, 3, 275-310.

Humphreys, P. & Berkeley, D. (1992). Support for the synthesis and analysis of organisational systems in deciding on change. *Decision Support Systems: Experiences and Expectations*, T.Jelassi, M.R. Klein & W.M. Mayon-White (Eds.). Elsevier Science publishers, Amsterdam, North-Holland, pp. 29-50.

Jensen, F. (1996). An introduction to Bayesian networks. UCL Press, London.

Laville, V., Zanarelli, C. (2000) La communication comme indicateur structurant de l'activité: illustration dans uns situation de régulation de métro. (submited)

Leake D.B. (1996) Case-based reasoning: Experiences, lessons, and future directions. Chapter I: CBR in context: The present and future. Menlo Park: AAAI Press/MIT Press.

Leplat J. (1985) Erreur humaine, fiabilité humaine dans le travail. In: A. Colin (Ed.), Collection Uiversitaire, pp. 100-120.

Neapolitan, R. (1990). Probabilistic reasoning in expert systems. John Wiley & Sons, New York.

Niang, D. (1999). Méthodes et techniques d'Intelligence Artificielle pour prévenir l'explosion combinatoire. Application au Gestionnaire d'Incidents de SART. *Rapport de DEA IRO*, LIP6, Paris.

Oliver, R. & Smith, J. (1990). Influence Diagrams, Belief Nets and Decision analysis. *Wiley Series in Probability and Mathematical Statistics*, John Wiley & Sons, New York.

Pasquier, L. (2000). Raisonnements basés sur le contexte: Contextes proc\u00e9duralisés, graphes contextuels et schèmes d'action. Research Report LIP6 N.2000-010.

Pasquier, L., Brézillon, P. & Pomerol, J.-Ch. (1999). Context and decision graphs in incident management on a subway line. Modeling and Using Context (CONTEXT-99). In: Lecture Notes in Artificial Intelligence, N° 1688, Springer Verlag, pp. 499-502.

Pearl, J. (1988). Probabilistic reasoning in intelligent systems. Morgan Kaufmann publishers, San Mateo, California.

Piaget, J. (1936). La naissance de l'intelligence chez l'enfant. Paris, Lausane.

Pomerol, J.-Ch. & Brézillon, P. (1999). Dynamics between contextual knowledge and proceduralized context. Modeling and Using Context (CONTEXT-99). In: Lecture Notes in Artificial Intelligence, N° 1688, Springer Verlag, pp. 284-295.

Rabardel, P. (1995) Les Hommes et les technologies. Approche cognitive des instruments contemporains. Paris: A. Colin.

Raïffa, (1968). Decision Analysis, Mac Graw Hill.

Schank, (1982). Dynamic memory, a theory of learning in computers and people. Cambridge University Press.

Schank, and Alberson, (1975). Scripts, Plans, Goals and Understanding: an Inquiry into Human Knowledge Structures, L. Erlbaum, Hillsdale, NJ.

Sowa, J.F. (1984). "Conceptual Structures: Information Processing in Mind and Machine", Addison Wesley Publishing Company.

Sowa, J.F. (1991). "Toward the expressive power of natural language", In: Principles of Semantic Networks - Exploration in the representation of Knowledge, Morgan Kaufmann, San Mateo, CA, pp. 157-189.

Vergnaud, G. (1985). Concepts et schèmes dans la théorie opératoire de la représentation, *Les Représentation, Psychologie Française* 30 (3 et 4), pp 245 - 252.

Watson I. & Perera S. (1998) A hierarchical case representation using context guided retrieval. Knowledge Based Systems Journal (forthcoming)

Zanarelli C. (1998) Identifier des classes de situations caractéristiques: quelques critères de différenciation des situations sont utilisés par les chefs de régulation et les chefs de départs? Document interne RATP

Zanarelli, C., Saker, I. and Pasquier, L. (1999) Un projet de coopération ergonomes / concepteurs autour de la conception d'un outil d'aide à la régulation du trafic du métro. *Actes de la Conférence Ingénierie des Connaissances*. Pages 171-180, Palaiseau.