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Taxonomy based models for reasoning:
making inferences from electronic road sign information

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Abstract

Taxonomy Based modeling was applied to describe drivers' mental models of variable message signs (VMS's) displayed on expressways. Progress in road telematics has made it possible to introduce variable message signs (VMS's). Sensors embedded in the carriageway every 500m record certain variables (speed, flow rate, etc.) that are transformed in real time into "driving times" to a given destination if road conditions do not change.

VMS systems are auto-regulative Man-Machine (AMMI) systems which incorporate a model of the user: if the traffic flow is too high, then drivers should choose alternative routes. In so doing, the traffic flow should decrease. The model of the user is based on suppositions such as: people do not like to waste time, they fully understand the displayed messages, they trust the displayed values, they know of alternative routes. However, people also have a model of the way the system functions. And if they do not believe the contents of the message, they will not act as expected.

We collected data through interviews with drivers using the critical incidents technique (Flanagan, 1985). Results show that the mental models that drivers have of the way the VMS system works are various but not numerous and that most of them differ from the "ideal expert" mental model. It is clear that users don't have an adequate model of how the VMS system works and that VMS planners have a model of user behaviour that does not correspond to the behaviour of the drivers we interviewed. Finally, Taxonomy Based Modeling is discussed as a tool for mental model remediation.

Auto-regulative Man-Machine Interaction (AMMI) Systems

Auto-regulative Man-Machine Interaction Systems are systems that adapt to the user and take the user's behaviour into account. The user's behavior is also adaptive, he or she reacts to the changes in the system, so that the system has to adapt to the user's changes in behavior in turn. An example of interactive systems is the spelling corrector built into word processing applications. When the user, U, corrects x set of characters by replacing them with y set of characters, the system, S, asks him if he authorises it to automatically replace all future occurrences of x by y. If U authorises S to do so, then whenever U types x instead of y, U will not bother correcting x because he knows that S will do it for him. Furthermore, when in the future S processes x by replacing it with y, S will not inform U of this fact because S "knows that U knows" that it is going to do so.

In this example S has a representation of U which we will designate "[U]s": the user is always the same person, he remembers, is consistent, etc.

It is also clear that U has a representation of S that we will designate "[S]u": S makes all authorised corrections and only the ones that are authorised, in S's memory is a list of authorised replacements….

In order for the self-regulating interaction to work well, [U]s should fit U and [S]u should fit S, otherwise the self-regulation will dysfunction. Suppose a second user, U', a child for instance, uses S and makes spelling corrections U would never have made. U' also authorises automatic replacements that U would never have approved. The situation will quickly deteriorate if U and S know nothing of U''s intrusion: U will no longer understand what S is doing and S won't "understand" U's inconsistency either.

< INCLUDE FIGURE 1 >

Variable message sign (VMS) systems belong to the category of Auto-regulative Man-Machine Interaction (AMMI) systems (see figure 1) that we have studied in the context of Mental models as applied to Human-Computer studies (Ackermann & Tauber, 1990). Progress in road telematics has made it possible to introduce VMS's. These are devices designed to improve the flow of traffic according to a self-regulating process: the driving time between two points is displayed in real time, drivers can evaluate the state of traffic and may choose another less encumbered route if need be (Danech-Pajouh & Bercu, 1998). To make this possible, the information VMS's display on alphanumerical signposts is very concise: the name of a place, followed by a "driving time," the time it takes to drive to the place. For example, on the expressway that circles Paris, a ring road 37 km. long, called the "Boulevard Peripherique", that connects the 38 "Gates" into the city, the VMS's indicate two destinations (which are "gateways" into the city), followed by the driving time it will take to get there (see figure 1).

The VMS system was designed to resolve problems of traffic saturation in urban areas. Though urban expressways were originally conceived for easing transit, little by little they have also become the scenes of frequent traffic jams. This state of things is not without consequence for the quality of life in the cities, on account of the loss of time involved or even the irritation expressway users may feel when they are trapped in traffic jams. The whole system works as follows: when the traffic becomes less dense, driving times decrease, and this leads drivers to get on to the expressway or stay there. As a result, traffic increases, driving times increase, and this leads drivers to abandon the expressway. Then the traffic becomes less dense. By processing the number of vehicles and their speed, the System (S) estimates what the user (U), who is considered as one of many agents in the traffic, is experiencing, and communicates this to him by means of a Message (M). The user (U) in turn takes the state of the System (S) into account when he decides to enter or leave the traffic. The system will then re-act to the new situation that the behaviour of each user has created. Successful regulation nevertheless presupposes that the System and the User have adequate representations of each other. Progress in technology is making such self-regulating systems more and more numerous.

This system should constitute a precious aid to the authorities in regulating traffic as well as to drivers who wish to avoid heavy traffic. However, the semantics of VMS messages are clearly different from traditional signposts which do not provide for announcing transitory events in real time. How do drivers interpret these messages, what decisions do they lead drivers to take?

According to opinion polls commissioned by the transportation authorities, drivers are overwhelmingly (98%) happy with this new service. Nonetheless, since it was installed, traffic counters seem to indicate that it has not significantly changed driver behaviour, drivers are no more likely to change their itinerary when the expressway is crowded (Cohen & Hadj-Salem, 1996; Jardin & Laterrasse, 1998). In other words, VMS's must serve some purpose because otherwise drivers would not be happy with them, but whatever this purpose is, it is not the one for which the system was intended.

Our aim was to attempt to understand the interpretations that drivers may have of the messages delivered by the VMS's by using Taxonomy Based Modeling (Poitrenaud, 1995; Tijus, Poitrenaud & Richard, 1996; Tijus, Poitrenaud & Barcenilla, 1997). Taxonomy Based Modeling is used to analyse the mental model, (S)u, that drivers have of how the system functions and to study the effect the model has on their decision making. We also attempted to determine whether drivers' intentions corresponded to the user model, (U)s, implicit in the VMS system (wanting to minimise time spent in transportation, to avoid traffic jams, etc.). As such, we studied the correspondence between (S)u and S on the one hand, and between [U]s and U on the other.

We hypothesised that [U]s, the system's implicit model of the user, should be reconsidered. We also felt it was imperative to attempt to understand the impact that VMS messages have on the reasoning which goes into deciding on an itinerary, considering the user's model of the way the system functions [S]u.

The VMS system as an AMMI system

On the expressway that circles Paris, the VMS system provides drivers with messages. Sensors embedded in the carriageway calculate several variables in real time: traffic flow, speed and a representation of traffic density (called "rate of occupancy"). The sensors are spaced approximately 500 metres apart, as are the VMS signposts; and measurements are taken every minute. Driving time is calculated from each separate signpost to the next 2 major expressway intersections along the expressway that circles Paris. There are 7 of these major expressway intersections, each of which corresponds to an exit toward one of the expressways leading away from Paris, and 66 signposts. The information displayed on the signposts is refreshed every minute, in real time, and indicates driving times which are ultimately theoretical, hypothetical, but which represent what the actual driving time will be if nothing changes the current conditions along the road between the signpost and the poles situated further on. Its value is thus indicative.

Taxonomy Based Modeling allows us to describe the functioning of the system as a network of categories associated by "IS-A-KIND-OF" inclusion links. We call this description the "ideal expert model", which means the knowledge an expert might have of the functioning of the system, or, in other words, the objective description of the functioning. Figure 2 shows the ideal expert model of [S] : the VMS system is composed of CARS (that move on the road), SENSORS (that collect data from [cars (moving on the road)]), COMPUTERS (that compute data from [SENSORS (that collect data from [cars (moving on the road)])]), and ELECTRONIC SIGNS (that display results from [COMPUTERS (that compute data from [SENSORS (that collect data from [cars (moving on the road)])])]). The SENSORS, COMPUTERS and ELECTRONIC SIGNS are a kind of electronic DEVICE that, along with CARS, are kinds of ENTITIES.

Taxonomy Based Modeling shows the semantic structure of the categories of the parts of the system as well as the causal links between categories of parts through attributes of categories.

< INCLUDE FIGURE 2 >

The model of the user, [U]s, implicit in the VMS system

The VMS system works by collecting data from the sensors, computing these data and then displaying the results in the form of "driving times" on the VMS's, in such a way that drivers can see the results and change their behaviour (change their itinerary, slow down, etc.). When driver behaviour changes, this produces new data that will be collected from the sensors. Our first observation was that the self-regulating system includes, as an integral part, driver behaviour, and that this behaviour is predicted on the basis of a certain model of the driver.

What is the user model and is it adequate? An analysis of the self-regulating function of the VMS system allows revealing the assumptions about the user it is based on. To draw up the list of these assumptions, we noted the intentions attributed to the driver, the model of the system he is assumed to posses, his supposed knowledge, the mental operations he is assumed to engage in and the memory required for these tasks (Figure 3).

We thus noted that the time it will take to travel a distance is assumed to be useful information because it is supposed that what interests the driver is to travel that distance as quickly as possible. The speed at which he can reach his destination is considered to be his principal criterion in choosing a route. Secondly, the driver should believe that the information delivered is dependable and in order to do so, that it is objective. This requires the driver having a model of the system (whatever the model) that assures him that the information is objective. Thirdly, the contents of the messages delivered by the VMS's should be meaningful and usable for the driver. But this information can not be useful to the driver unless he knows where the places designated by the VMS's are (for example, Porte d'Auteuil), where exactly he is (he may, for example, be at Porte de la Chapelle), and also, what the approximate distance is between the two places. The information will be useful if it allows him to reason about his own route by making basic mental calculations ("If I'm going only half the distance to the Porte d'Auteuil, then it should take me half the driving time indicated").

Table 1. Description of the implicit user's model of the system, [U]s, which is the set of properties the driver is supposed to have in order for the Variable message signs (VMS) system to work as an Auto-regulative Man-Machine Interaction (AMMI) systems

[U]s : how the user should operate	
intention	the fastest route
model [how VMS works]	know how VMS work
belief about VMS information	VMS information is objective
knowledge about place and delay	knowledge of pole position around Paris
	knowledge of distance between poles
	knowledge of the ration distance/time
calculation and memory	Know how to estimate the time it will take
	(all other things being equal)
decision process	knowledge of other routes (how to go there)

Even this however is not enough. Though the information may be useful and significant, the driver must be in a position to evaluate it. The indicated driving time is relative to another driving time which either has to be calculated (given the distance, the usual driving time should be about...) or known (it usually takes me x time to get from here to there...).

Does [U]s correspond to users [U]?
Does [S]u correspond to [S]?

Does the model of the user the system has, [U]s, correspond to users [U]? Does the mental model of the system the user has, [S]u, correspond to the functioning of the system [S]?

Our hypothesis is here that drivers, U, do not behave accordingly to [U]s. In addition, we advocate that the representation users have of the VMS system, in other words the mental model they have of how to use VMS's and the way VMS's function, determines their decision to take action or not (to change itineraries or not) considering the nature of the task at hand (among other things, time constraints) and knowledge (knowing alternative itineraries, how much time each takes, etc.).

The method consists of drawing up the list of all the mental models of the VMS system and studying their effect, depending upon other knowledge factors, on decision making in the course of executing a certain number of tasks. In this way, the interpretation of a VMS message can be modelled for each of the different mental models and finally, the decisions drivers will make can also be modelled. Indeed, we believe that the decision a driver makes after reading a VMS message depends on the interpretation of the message and that this interpretation is a mental construct which depends on the current task, the context (which is to say, the present situation), and the driver's mental model of how the VMS system functions.

Experiment

Starting from the perspective that representation users have of the VMS system determines their decision to take action or not, to change itineraries or not, the aim of the attempt was (1) to consider the nature of the task at hand (among other things, time constraints), (2) the knowledges (knowing alternative itineraries, how much time each takes…), the representation users have of the VMS system, and (3), the context, which is to say, the present situation.

We tested the hypothesis that :

U ≠ [U] s
[S]u ≠ S

The method consists to determine whether drivers' intentions, U, correspond to the user model implicit in the VMS system, [U]s. For example, wanting to minimise time spent in transportation, to avoid traffic jams, etc. and in making a diagnosis of the mental model, [S]u, that drivers have of how the system functions, S, and to study the effect types of [S]u has on drivers decision making.

Method

We used the critical incident technique (Flanagan, 1954) which consists of collecting memories of events as they took place from participants in semi-directive interviews.

Participants

The participants in the interviews were 30 drivers who drive to work several times a week, who take the boulevard peripherique (BP) in Paris and are familiar with the toponymy, average driving times and other features of the route. Because they are habitual users of the BP, they are capable of correctly interpreting the meanings of the messages in terms of traffic density and flow, something which is probably not the case for all drivers. Finally, the network of roads around the BP is sufficiently rich for drivers to be able to change their itinerary at any moment without extending driving time (something which is not the case for most expressways).

Material

The interviews were recorded and retranscribed in their entirety. Each interview lasted approximately 45 minutes.

Procedure

The participants were told that they were being interviewed in order to obtain a description of the route they take to get to work. The interviews with the driver-participants were conducted in such a way as to gather information on the following themes.

1. The choice of the automobile over other means of transportation, the importance of "time pressure" in this choice and the reasons for using the boulevard peripherique (BP).

2. An account of the most recent actual itinerary taken, the objective of which was to gather the route the driver actually takes and the actual decisions he makes.

3. Evocation of the different routes taken, in order to get the participant to spontaneously reveal the importance of VMS messages on driving time in choice of an itinerary.

4. A description of the way the VMS system works.

Results

Do drivers correspond to the VMS system's implicit user model (U vs. [U]s)

The VMS system contains an implicit model or representation of the user, [U]s. According to [U]s, if the driving time displayed on a signpost seems to indicate the presence of a traffic jam, it is supposed that the driver will abandon his original route for a faster one. This presupposes that the driver has knowledge of other routes and that he wants to reach his destination as quickly as possible. According to this representation, the user needs to know how much time the route he has selected will take (as that is the information the system furnishes), and if the driving time is longer usual, he will look for another itinerary, and this will have the effect of improving traffic flow.

In order to determine whether actual users correspond to this implicit model, we analysed their decisions, justifications, goals and knowledge. The data was processed using STONE software (Semantic Tree Based Object Navigator and Editor), Poitrenaud, 1995) which, through a hierarchical analysis of properties, reconstructs the semantic links between the successive states entailed in an action.

Figure 3 presents Stone's formalization of the links between the successive states entailed in the decision to stay on a route or to abandon it when the VMS system announces a seemingly excessive driving time. The arborescent structure represents the alternative motives which compose the plan of action: the intention inferred from the reasons for choosing to go by automobile, to take the BP; knowledge about the configuration of the system, the grounds on which drivers make their decision; the inferences they draw from the messages displayed on the VMS before getting on to the BP (action 1), then when they are already on the BP and a traffic jam suddenly forms (action 2). In both cases, the decision is either to change itineraries so as to avoid the jam, or to rest in traffic and think of something to do while waiting.

< INCLUDE FIGURE 3 >

The data corresponding to a participant form a sub-tree of the general tree presented in figure 3 and constitute a user profile. Data analysis revealed that there are several profiles or user categories which are a function of the mode of action they adopt in reaction to reading a message about driving times. The property which allows grouping all of the participants into one of two groups concerns motorists' basic intention, either to "reach my destination as quickly as possible" or, on the contrary, "to feel comfortable in traffic". The drivers' intentions were inferred from the justifications and reasons they gave for their choices to take the Boulevard Peripherique instead of other roads and for taking their car instead of public transportation.

When there are traffic jams, what do drivers decide to do? We ascertained that there are three different types of behavior regarding this decision : some (group 1, 7 participants, 23 %) change itineraries whenever traffic is slow, others (group 2, 18 participants, 60 %) stay in traffic no matter what (even in the worst traffic jams), and still others (group 3, 5 participants, 16 %) will enter or stay in slower traffic providing that the driving times displayed by the VMS's are not excessive.

The first group (23 %) is composed of the drivers whose primary goal is to reach their destination as quickly as possible. These participants seem to be familiar with alternative routes: 4 use secondary routes inside Paris (city streets). Because they know alternative routes, they can quit the BP when traffic is slow. All of them use various sources of traffic information in addition to the VMS system before deciding on the route to take. All except one change itineraries if when they arrive at the BP, the VMS's indicate a traffic jam. If a traffic jam forms while they are already on the BP, they get off. If the driving time the VMS displays when they arrive at the BP seems excessive to them, they decide on an alternative route and do not enter traffic on the BP. Their decision to desist is facilitated by the fact that in general they have a working knowledge of alternative routes, "emergency" routes to which they turn in case of traffic jams. Thus, driving time information helps them avoid crowded routes. These drivers correspond to (U)s.

In contrast to the first group are the group of participants (60 %) on whom the system seems to have no effect: they do not change itineraries when the driving time displayed suggests there are traffic jams. They seem to accept traffic jams very patiently and are the most numerous among our participants. They never change their itinerary regardless of what is announced on the VMS at the entry to the BP or while they are on it, preferring to make themselves as comfortable as possible and wait out the time. Most of them know of few alternative routes and do not try to find out what these may be. Users in this category show little readiness for finding alternatives to the BP, their knowledge of the network of roads outside of the BP is limited, and this limits their ability to choose an alternative route. However, even after years of driving, they do not seem to want to venture off their familiar itinerary, which they seem attached to. Nonetheless, they also try to save time; some of them even leave earlier to avoid traffic jams. The information on driving times reinforces their conviction that *"in any case, it's the same on all the roads…"*, and that there is little use in attempting to change routes.

Finally, we ascertained that there was a third group of participants (16 %) who show behaviour somewhere in between the two behaviours described above. This category is composed of participants with mixed goals: some prefer the comfort of the ride, others emphasise speed. Unlike the previous group, drivers in this group do not get on the BP when a traffic jam had been announced. However, if a jam forms when they are already on it, they do not get off. They rely on the driving times displayed to make their decisions. All of them have a working knowledge of alternative routes, and all of them also use the time spent in slower traffic to engage in other activities. It is very likely that the messages on driving time reduce the stress of drivers in this group. As one of them says, *If I see that the traffic jam is going to last for a while and that… oh well, too bad, I'm just going to have to wait it out*. Like the second group of drivers, reaching their destinations as quickly as possible is not always what most interests them, however, the reason they give for taking the BP is that it is faster, and in this they resemble the first group. They will not get onto the BP if traffic is backed up but nonetheless, like participants in the second group, they accept having to lose some time, though this acceptance is not unconditional and remains within limits that they can usually specify. They know the road network well and can change itineraries when need be. They use VMS's either to avoid getting onto a jammed BP (as indicated by a VMS or from what they can see) or, if a traffic jam forms when they are already on it, the information helps them to plan how to use the time spent waiting.

The assumption that drivers wish to reach their destinations as quickly as possible is not valid for all drivers: only 23 % of participants emphasised wanting to reach their destination as quickly as possible and 60 % emphasised the comfort of driving. The whole set of results show that the implicit model of the user ([U]s) which is a necessary component of the self-regulating system does not correspond to all users ([U]s ≠ U). On the contrary, there are users who settle down comfortably into traffic jams: they make telephone calls, listen to music, etc. As one of them states very clearly *:… I like the intimacy of my car… it's like a small living room in which I can listen to whatever music I feel like hearing. I don't have to stand contact with other people, I can read the paper, there are many things you can do in a car…* Being stuck in traffic is thus not necessarily something that all drivers seek to avoid. This "comfort" category of user does not correspond to the user model.

Do drivers have an adequate mental model of the VMS system ([S]u vs. S)?

The reliability accorded to the contents of the messages depends on the way the messages are produced. Thus, if the displayed driving time is believed to correspond to the real driving time, the driver may use it for decision making. This presupposes that the driver's model of the system leads jim to believe it can produce reliable information.

The particularity of the VMS system is that it indicates information in real time, this means that the driving time displayed is the time it will take if conditions do not change during the drive (number and speed of vehicles). However, it often happens that conditions do change. This means that the real driving time is often different from the driving time displayed. So, if meticulous users attempt to verify these times and do not know how the system functions, they might develop some doubts about the system's reliability.

Finally, it is assumed that drivers are willing and able to change their behaviour, this assumption entails drivers knowing alternative routes, but above all, knowing how long it will take to reach a destination along alternative routes. These assumptions are summarised in table 1 below.

The interviews were analysed in order to evaluate the representations of the system that users have and the reliability they attribute to the contents of the messages. 28 out of the 30 interviews were analysed to this end. We identified 6 different models of how the system works.

Eight drivers believe the VMS system works by collecting data from sensors embedded in the carriageway which transmit information to a processing centre. The model these drivers have is the ideal expert model.

Well, there must be some kind of sensors that are placed uhhh… in the way every however many metres. But, it's probably pretty precise, because it's pretty precise, I think they've probably placed the sensors every… I don't know… 500 metres or something like that. So, it's probably calculated at an average speed as a function of…. of automobiles running over the sensors. So, uhh… it, it gives you the average speed at several points along the Peripherique and then uhh with the right formulas and the know-how…, know-how I mean, with formulas for smoothing the thingamabob etc. uh and with a little processing behind it, you should be able to calculate, I'd say, uh as a function of the time it takes to drive between several gateways and then, I suppose there's some place, computers you know where it all arrives, then they send it back uh, send it back to all the signposts uh… thingamabob etc. So, in detail, then according to wherever you are you have to calculate, I mean, how do you say it, as a function of the speed uh expected you know etc., the distance to travel how much time until… In any case, I suppose it's something along those lines like that.

Four drivers had a model of the system which functions on the basis of cameras. This model differs from the expert model on the level of how the information is collected (cameras replace the sensors). For them, images from the camera are directly processed by the computer.

I think they've got uhh cameras every whatever, I know on the Peripherique… and things to dose out speed people I think and… there's information on rush hour and all that and it all goes into a computer so it's… it's and the camera that tells how heavy it is on the expressway… and the time slots and all that so that you can establish the data to figure out uh … from the time figure out that system in minutes you post. I think it might be that. I think it's from to the cameras and the time slots that you get your averages.

One participant had a representation of the system which included an agent posted along the road. For him, an agent posted along the expressway times the vehicles as they pass. This agent is always posted in the same place and transmits the information he gathers via radio to a manager.

Uhmm, somebody spots a vehicle in one place and uhm… it's been spotted… uh… at another and then you… calculate the time how much time went by between the two….

Four participants had a representation of the way the system functions that contained agents in cars, helicopters or on motorcycles. In these models the user is no longer isolated, he is linked to other objects which have the same property he does, that of "moving". All four of these participants believe an agent in a vehicle informs a control centre about the sate of traffic. Two participants spoke of motorcyclists and only one participant mentioned helicopters flying over the expressway.

I think it's uh… some head office somewhere that manages… Well it's… I see it as a kind of... helicopters circling above uhmmm…I mean, helicopters, some helicopters that circle over regions and sectors… that can indicate especially for the expressways, whether there's traffic or not; for each car. On motorcycles Well I think there's several uh…

Eleven participants have a representation of the system which includes several ways of collecting data:

- data collected simultaneously by agents and by cameras: 4 participants had this kind of model. All of them had in common a representation including both sensors and cameras. Both objects have the common property of transmitting information. For one participant the camera provides information on accidents and for two others it provides information on the speed of cars. One participant believed the camera allowed an agent to time the vehicles.

There are networks. They calculate the number of cars, the time, well… I think it's something like that. With cameras, I think. Sensors everywhere, the turtles I mean the spiders you see in the roadway there that can calculate the number of cars and then the speed at which they're going, depending on the time of day.

- by an agent in an office and by an agent in a vehicle or car. Only one participant had such a model. The agent in the car times his own driving times.

Well, there is one method there is that people have driven the distance a certain number of times and have correlated the time it took them and the measurements of density of, cars and traffic, density you should be able to measure on the expressway, I guess, or at least on expressways. You count the cars, you count the time and that gives you an idea of the flow. Well then to display it, it's a thing, an electric sign like those liquid crystal things, you light what you're supposed to light and the message that's supposed to appear appears.

< INCLUDE FIGURE 4 >

- Three drivers named the following objects: an agent in a vehicle (helicopter), a system of cameras (figure 4), an automobile indicator and sensors. These models showed the most diversity in kind of information-gathering object.

Uhm… cameras on the highway and then you can see if there's traffic jams where they start and that's it, see. It allows estimating how much time as a function of the speed of the cars, the time. I think anyway… In any case, I'm sure there are cameras, that's for sure because once I was at the CRS station just before the Peripherique and they've got cameras. They can see absolutely everything. Then, I don't know. But I don't think it's the main office in Rosny sous Bois that processes all the information..

- Finally, one participant said he believed the system worked using information provided by an agent stationed along the road and another in an automobile supervised by a camera. The agent posted along the road times the cars and transmits the information, the automobile agent gives information on the traffic and transmits it.

They do it by, there's cameras that're cameras all along the expressway; that gives you the traffic. Well there are policemen policemen in cars…they drive around in their car….there are men … all along the road, who time it; they announce there's a jam and uh; to the radios… if there are….there are managers uh, who put it all…: And then I think who put all the information together, and then they announce it on the radio announce how it looks and then the exits you can take uhh…

We ascertained that representations of the system are various and that some of them are quite complex, more complex than the real system, especially when they combine several different types of information transmitted through various channels. A partonomic analysis of combinations of components (figure 5) reveals the 6 types of mental models our participants exhibited.

< INCLUDE FIGURE 5 >

Are the systems the participants imagine capable of indicating the real time it takes to drive a distance and is this information reliable? Based on each of these modes, it is possible to infer displayed message contents which do not all correspond to the real contents of the messages.

Though one would expect the participants whose representation corresponded to the real system (those who have the same representation as the expert), to believe that the displayed times are reliable because they are based on actual traffic situations in real time, the participants in the other groups who believe the system relies on cameras should show less confidence. Cameras have a "point of view", they are not capable of recording all of the data on the traffic (all of the cars on the road). Additionally, the processes by which the camera images are decoded and analysed in terms of driving times were never specified by the participants (the camera as a sort of magic eye). From the point of view of reliability, the value displayed by this kind of system is contaminated by subjectivity: it is qualitative (the eye can "see" but no one knows how it can count) and is not based on the entire distance the driver has to drive (it isn't known whether or not the camera "sees" everything). The helicopter for example from which one can view the entire BP and thus the heavy and fluid traffic zones can not provide numerical data on driving times. According to this representation, the driving times displayed on the VMS's correspond to pre-established categories of traffic density, to values set in advance, but not to the current and actual situation of traffic.

Calculating the real values of driving times is even more difficult in the models of participants who believe it is done by an agent stationed at a fixed point along the BP, who then transmits this information to a manager: the value displayed is thus only valid for the place where the agent is and the rest of the 35 kilometres is left unverified.

In conclusion, it has been shown that the representations that users have of the way the system operates do not often correspond to the reality of the system and, that depending on the representation, the quality of the messages displayed on the VMS's is not entirely clear to them, because they have not grasped the fact that it is information given in real time and resulting from all current traffic on the BP. For this reason, the help provided by the system may be underestimated by drivers whose representations of the system are different from the actual system.

Conclusion

When a driver reads the driving time displayed on a variable message signpost (VMS) and the driving time indicates there are traffic jams ahead, two courses of action are open to him: he can either abandon the road for another he believes will be quicker or stick to his itinerary. Our approach was designed to reveal the modalities of this decision to stick to an itinerary or to change it, depending on the information delivered by the VMS's (for example, Porte d'Auteuil, 24 minutes), by studying interpretations of the contents of these messages in terms of how the system functions (where the data is thought to come from), and the contextual processing of the displayed data (the driver's task, how the traffic looks) and finally decision making processes, but also the implicit model of the user for whom the messages are conceived and displayed.

The set of problems we address has been enlarged to include the representation of action as a result of an individual's knowledge (representation of the system, topographical and toponymical knowledge used to mentally construct itineraries) but also knowledge as what is used to take action within the framework of the representation.

Prior to reading a message and making a decision, different kinds of knowledge contribute to the decision making process:

Prior knowledge of the route. The information displayed does not have any meaning in and of itself: "Porte d'Auteuil: 24 minutes" only makes sense if the reader knows where the Porte d'Auteuil is located, if he knows how long it usually takes to get there from wherever he is when he reads the message, and if he also knows where it lies along the route he has planned and in relation to his destination.

Familiarity with the network of roads adjacent to the route. In case of a traffic jam, modifying the route should be facilitated by knowledge of an alternative route. Without such knowledge, a driver may hesitate to take roads he doesn't know well and changing routes may not really represent a gain in time.

Confidence in the reliability of the information. The contents of a message announcing excessive driving times is not enough to produce changes in itinerary, drivers must also believe that the message is reliable, it should seem credible. Now, it is well known that road signs are not always considered credible by users who are apt to perceive them as an attempt on the part of the authorities to manipulate them (cf. for example, how drivers feel about the limitations on speed…).

The particularity of VMS driving time messages is that they give information in real time, this means that the time displayed is the time it will take if conditions do not change before getting there. However, traffic conditions necessarily change, this means that the actual driving time will not be exactly what is displayed. Furthermore, the degree of reliability that drivers attribute to the messages will depend on their model of the way the VMS system functions.

Knowledge is certainly not enough to induce action. It seems to us that for a driver to use his knowledge, the desire to reach his destination as rapidly as possible must be accompanied by willingness and a capability to go by another route. The implicit model of the driver which is designed into the VMS system, ([U]s), is that driving is a kind of "wanting to save time", to go as quickly as possible, faster than one can go by public transportation for example. But the extent to which this assumption is valid is not known, despite the fact that it is a commonly held belief. It seems self-evident that the more a person wants to reach his destination as quickly as possible, the more he will avoid heavy traffic. There is a need to verify that the participants questioned on this point, aside from what they feel when they are actually in a traffic jam, really do have the intention of "saving time". It is then easy to see why it is important to verify this point with the participants chosen.

Our results show that only some of the users both fit the model of them which is built into the system and have a fitting representation of how the system works.

U[s]≠U

We attempted to determine whether the usual representation of users could be confirmed, in other words, that they prefer commuting quickly, so they attempt to reduce driving time, and consequently, they use the messages on driving time to avoid heavy traffic. The answer to this question has a real baring on the capability of the VMS system to serve the self-regulation function it was intended for.

Three different categories of participants were identified. The first of these corroborates the representation of users according to which their primary intention is to reduce driving time and they are prepared to do something about it, in particular, to abandon one route for another. Indeed, users in this category do change routes when the information displayed on a VMS suggests traffic jams. A second group, unlike the first, doesn't quit the BP when traffic backs up. Though we can not as yet claim that the messages actually inspire them to remain in traffic jams (more experimentation needs to be done), the messages do seem to make staying put tolerable. The observed behaviour of the second group is quite different from the representation of them that is inherent in the system. Finally, the last category is composed of users who also wish to reduce driving time, they avoid heavy traffic and do not take the BP when VMS's posted at on-ramps indicate jams. However, if traffic backs up while they are on the BP, they stay on it unless the driving time indicated is in excess of a specified time limit they feel is tolerable.

We were thus able to ascertain that reduced driving time is not necessarily the aspect that drivers desire the most. Only a third of our participants belong to this category, the others seem to be more preoccupied with driving comfort.

$$S[u] \neq S$$

Drivers often take a critical stance toward road signs, which they feel are often unjustified. Accordingly, they do not always follow guidelines. It is possible that they feel the same way about the driving time information they are given, it may seem capricious, or like an attempt to manipulate them… Inversely, for drivers to want to use the information, they must believe it is reliable, which is to say they must believe it corresponds to the actual state of the traffic.

We have supposed that this perceived reliability is a function of the representation individuals have of the system that furnishes the information displayed on the VMS's. This is why we attempted to probe the different representations.

We have been able to ascertain that only a part of the group of participants believes the system processes objective traffic data in real time and that it is thus a reliable system for anyone who wishes to be informed about the state of traffic farther up the road. For many participants the information displayed is the result of a qualitative evaluation, an estimate of driving time, probably delivered somewhat after the fact. Consequently, there is a gap here between the representation that users have of the system and the system itself.

One last question remains. Given that all users (98 %) admit they are satisfied with the system but that they do not use it as expected, what exactly are they satisfied with? Does it provide some other, unforeseen service? Should the representation of the user's role in the system be modified? If drivers prefer to stay in traffic jams, then loss of time is not considered a serious issue. But if it isn't, could this be because they are informed (reassured?) about the amount of time they stand to lose? Is it knowing that they are not in a dead-end situation as sometimes occurs in reality or in the cinema (L. Comenccini, "*L'ingogo, una storia impossiblile*") what they appreciate? Finally, the VMS system is perceived by some as a traffic regulating system and by others it is apparently viewed as a stress regulating system, which enables them to relax and drive in comfort.

These results nonetheless enable us to make a few recommendations. Concerning the information that is provided to drivers, it might be of help to improve driver knowledge about the system, however, it is unlikely that this would significantly modify response to the VMS messages on the part of drivers who are primarily concerned with making the drive more comfortable. What these observations on the practices of city drivers show is that the system is primarily used for regulating driver stress rather than for regulating the speed of traffic.

Finally, our conclusions can be summarized on two points. Firstly, concerning cognitive ergonomics, the conception of auto-regulative man-machine interaction (AMMI) systems have to pay attention to the user's behavior in order to have a compatible internal model. Since the system can be used for other purpose, as looking for comfort, as we saw, it could escape to its waited finality. AMMI systems managers should provide the user information about how the system works.

Secondly, concerning reasoning, we saw that very simple messages can have diverse interpretations depending on how the message is supposed to be produced. Displayed values are more confident when computed from sensors, than computed from posted agent, or from a car driving all day long on the Peripheric, or from cameras that follow a car from gate to gate in order to collect the delay to be displayed. Some participants think that when the traffic managers want them to take certain routes, they display the values that will influence their decision making. Participants inferences and decision making depend on knowledge, i.e., how long it usually takes from gate to gate, and on the participant mental model of the messages purveyor.

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Figure caption

Figure 1. Photo of a Variable Message Signs device

Figure 2. Description of the system, S, as the Taxonomy Based Model of the Ideal User's. Nodes represent categories and links represent the IS-A-KIND-OF relation of inclusion between categories. Causal relations, which is the way one category acts on another is provided through attributes since parts of the system are defined and differenciated by what acts on them.

Figure 3. The whole set of properties that can define drivers, U, as being a decomposition tree of actions, knowledge about routes, intention and motivs of choice for using automobile and for taking the the expressway that circles Paris (BP).

Figure 4. Description of the model mental of one driver, U, using Taxonomy Based Modeling. Nodes represent categories and links represent the IS-A-KIND-OF relation of inclusion between categories. In this mental model description, cars are seen through cameras by an agent. There are car drivers (BPuser) that change lines while others stay on a singleline. The agent allways follows, from camera to camera, one car that stay on a single line (test-driver) and display on VMS the value of the delay that single line driver has taken to reach the next pole. The Taxonomy based model makes infer that this displayed value is not valid for changing line drivers. This value is valid for this participant because s/he is a single line driver. But the information is as old as the delay the test driver has taken to reach the pole.

Figure 5. Part-whole analysis of the different types of functionning of the VMS system our participants exhibit, [S]u. Nodes represent basic component (agent, captors, cameras, agent in car, agent in helicopter). Links represent "IS-COMPOSED-OF" relation. For instance Model-6 has a specic component which is a helicopter (Helicopt), its other parts are those of Model-3 which comprehends camera (as for MODEL-4 that has "computer" in addition) and an agent (as for MODEL-2 and as for MODEL-5 that has "car" in addition)

Figure 1

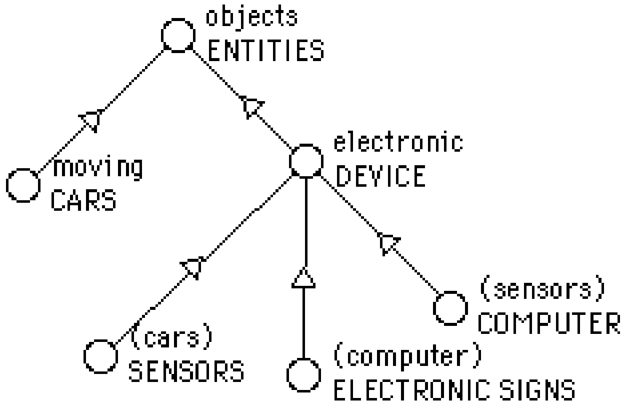
objects
ENTITIES
moving
CARS
electronic
DEVICE
(cars)
SENSORS
(computer)
ELECTRONIC SIGNS
(sensors)
COMPUTER

Figure 2

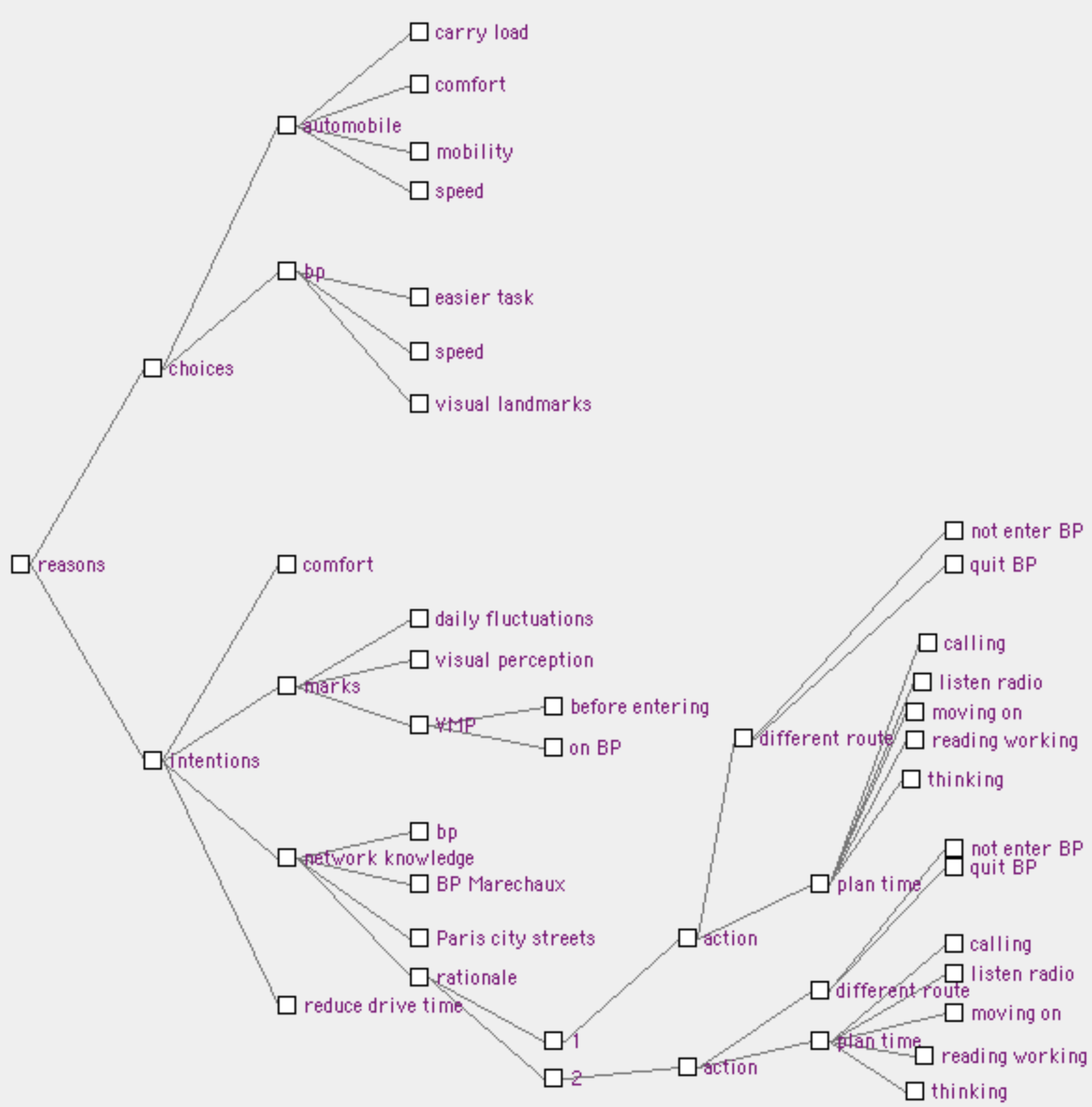
carry load
comfort
automobile
mobility
speed
bp
easier task
speed
choices
visual landmarks
not enter BP
reasons
comfort
quit BP
daily fluctuations
calling
visual perception
listen radio
marks
before entering
moving on
VMP
different route
reading working
on BP
intentions
thinking
bp
not enter BP
network knowledge
quit BP
BP Marechaux
plan time
Paris city streets
action
calling
rationale
listen radio
reduce drive time
different route
moving on
1
plan time
reading working
2
action
thinking

Figure 3

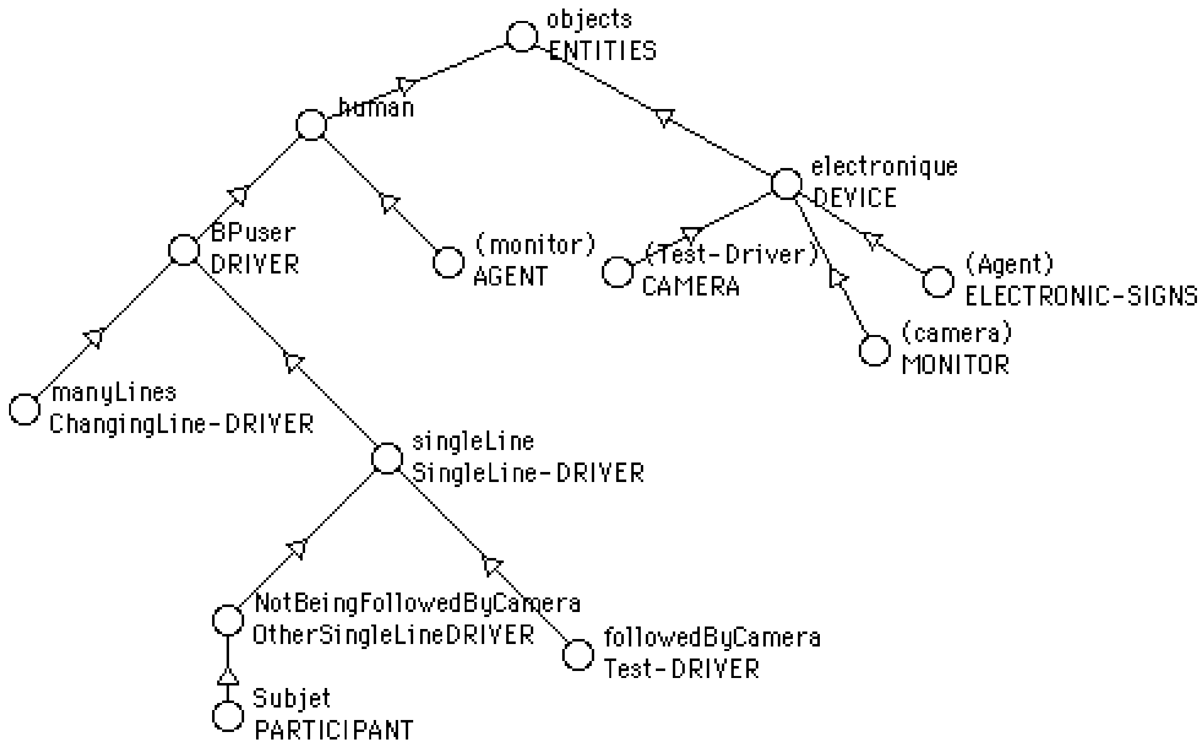
objects
ENTITIES
human
electronique
DEVICE
BPuser
DRIVER
(monitor)
AGENT
(Test-Driver)
CAMERA
(Agent)
ELECTRONIC-SIGNS
(camera)
MONITOR
manyLines
ChangingLine-DRIVER
singleLine
SingleLine-DRIVER
NotBeingFollowedByCamera
OtherSingleLineDRIVER
followedByCamera
Test-DRIVER
Subjet
PARTICIPANT

Figure 4

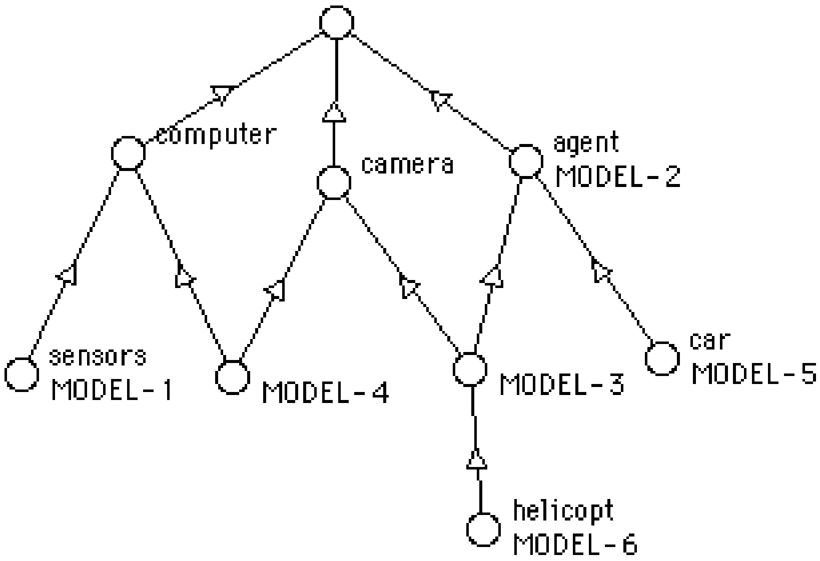
computer
camera
agent
MODEL-2
sensors
MODEL-1
MODEL-4
MODEL-3
car
MODEL-5
helicopt
MODEL-6

Figure 5