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INRETS

SOLVING AUTOMOBILE DRIVING PROBLEMS IN SITUATIONS OF UNCERTAINTY (Theoretical Considerations)

Statement of the problem

Generally and cybernetically speaking, conduct and other adaptive behaviors are the result of transformation of information subjected to a process. Information thereby becomes one of the basic elements in all possible changes in the course of events.

Appropriate adjustment of conduct in a given context depends on the clarity, precision and certainty of this information. This involves complex intellectual processes, including perception of information, reactivation of knowledge, system state representations, through to the making of decisions.

As far as driving is concerned then, and in automobile driving in particular, information becomes primordial, especially since it is not only presented from the outside and received by the driver, but is also generated at the same time, as the driver processes various information elements".

Schemes and patterns, cognitive processes, anticipations and algorithms all come into play in processing information; in conflictual, problematic, or pre-accident situations, however, evaluation and evolution of situations depend much more on the specific nature of the information and especially on the state of informational certainty.

If the level of informational certainty is not sufficient, the decisions and actions taken may be seriously affected. This is why it can be of help to know something about failure mechanisms in information processing, if we want to find out where the reasoning process breaks down, and go on to prevent driving mistakes.

Generally speaking, a situation of uncertainty is understood to mean road "circumstances" that cannot be strictly ascertained in a given way, and the course of which cannot be accurately predicted. Predictability and unpredictability then become essential for perception, evaluation and risk taking (objective or subjective) in a given situation. It can be expressed in terms of probability.

Uncertainty also expresses quantity, ambiguity and the equivocality of information, doubt and lack of confidence of the subject concerning the content of the messages received. All information characterized in this way is in fact considered to be insufficient (subjectively, if not objectively) to construct a representation of a state or

to solve a situation.

The quality and specific character of the information presented, sought or memorized in terms of knowledge, are thus more or less associated with the state of uncertainty.

As soon as the state of uncertainty (informational or attitudinal) is triggered, the individual is forced to make several predecisions and adopt an ill-defined, teetering strategy of action, to make touch-and-go adjustments, and does so within a very short time interval (during which he does not have time to analyze or think). Major emotional implications and different personal dexterities quite often come into play in this case.

In this context, the concepts of uncertainty, decision, risk and safety behavior become very closely linked within the psychological concept of "problem solving" in the broad sense of the term, which in the case of automobile driving can be expressed in "situation constitution and resolution".

Cognitive mechanisms: from perception to action

To better understand the tasks involved when driving an automobile, a clear conceptual distinction should be made between tasks, the sequence in which they naturally occur and how they are cognitively taken into account.

Information

Several meanings can be given to this concept, depending on the reference frame chosen. Generally speaking, information is any manifestation or element liable to be coded, retained or communicated, that specifies the characteristics of a system or that might bring changes in other systems.

Mathematical theories define information only in quantitative terms - the quantity of information being the measure of uncertainty of a message as a function of the degree of probability of each signal making up the message.

Shannon, in his work on information theory in the fifties, proposed a formula for measuring the quantity of information of a system with respect to the probability of appearance of an event (signal) in a unit of time, in which entropy is considered to be the only unit of the global quantity of information that characterizes a system ($H = - \sum p_i \log p_i$).

Since the characteristics of the receiver and the significance of the messages are not taken into account, this type of approach is insufficient in the case of human reasoning, where the qualitative aspect of data is much more important.

In this context, we may consider that the information usable by the human operator can in fact be characterized by several attributes: quantity of information in the message, clarity, precision, reliability, timeliness, significance, usefulness, certainty, etc., which

can be used in a cognitive approach to give shape to mental images of situations and events, and to plan actions.

In the road world, "information" or "data" is taken to mean any static or dynamic manifestation of the surrounding configuration that the driver has to take into account to accomplish his task. This information may be either standardized and structured (more or less strictly) by the infrastructure designers, or the driver may have to pick them out on his own (perceptives or heuristics).

As far as standardization and structuring of information (mainly in the form of signs and signals) is concerned, the concept of "readability" so widely used today may be considered inadequate to improve the security and fluidity of the traffic. Comprehensibility or "intelligibility" would, on the other hand, cover a broader spectrum of additional variables linked to the structure of the space, its operation, and to the way the subject relates to and integrates with that space. These concepts can help trigger safety reactions so that there is a better adaptation to certain circumstances, and situations can be solved faster (orientation in space, navigation, self-guidance, conflict).

Conduct behaviour

Considering that "conduct", from a psychological standpoint, means organization and self-adjustment of internal-subjective activities with external-motor actions, it is found in the accomplishment of nearly all human tasks. Therefore conduct is what links the mind to behavioral facts. If "behavior" is taken to be an objective and observable reaction, then "conduct" includes all psychological, sensorial, intellectual and emotional processes. Conduct is the way the psychic processes and functions are directed, the way one acts and behaves. According to P. Janet, intelligence is nothing other than an internal, instrumentally mediated conduct (by way of signs and symbols), through which the subject maintains adaptive relations with the world and the environment.

Before it is materialized in the form of behavior, conduct implies classifications and hierarchical rankings, deliberations, and relational types of adjustments that transform themselves into new pre-decisional, pre-action conduct processes, and do so in relation to the information and to the intra and inter-individual processing capacity. They are therefore mainly acts that are internal to the subject, are more or less elementary but complete in themselves, and have their own purposes and means. Anticipations, for example, are part of finalized internal conduct (according to H. Pierron) subsequent to the construction and structuring of external system state representations.

Behavior, on the other hand, is the entire adaptive reaction, which can be objectivized by an observable fact and which is supposed to accomplish either an immediate reflex-type adaptation, or to enrich the internal conduct.

The behaviorist movement at the beginning of the century (the works of J.B. Watson) wanted to promote psychology to the rank of the objective sciences, and claimed to

predict behavior deterministically by reducing it to stimulus - response variables. Later, the works of E. Tolman and C. Hull carried this theory further, though more variables were used (purpose, intention, impulse, etc.) to interpret behavioral patterns. In fact, behavior patterns as such have no meaning as long as they are thought of as being instinctive reactions pre-embedded in an $S \rightarrow R$ structure. It forces us to do without the "black box" with all of its perceptive, intellectual and emotional conducts which seems to us to be totally inadequate to understand certain human actions.

However, a certain amount of confusion as to the level of analysis is simply due to the fact that in everyday language, the two concepts of "conduct" and "behavior" are often used interchangeably.

Problem

The concept of problem has in fact several meanings, but in general its definition is: a question or set of questions that must be answered through rational, logical or intuitive methods found in different fields of human activity. These questions may be either explicitly stated from the outside, imposed by reality itself, or devised by the subject himself.

Etimologically, "problem" comes from "pro + ballein", or something that is thrown before us like an obstacle. A problem is therefore also a cognitive difficulty, that is a demand for which the responses available at a given moment are insufficient or inadequate.

The degree of complexity of the problem varies widely, and depends on a great many factors: to name just a few, the type of the questions and the domain, the clarity, precision and exhaustivity of the given data, the time available to find the answer, the processing capacities, the inter- and intra-individual characteristics, etc.

In this framework, the concept of problem situation is the set of situations, defined in time and space and in relation to the subject, which is characterized by the mismatch existing between means and purposes or between possibilities and demands.

Moreover, conflict - and especially internal conflict - is closely related to problem in the sense that a debate of greater or lesser length occurs whenever decisions have to be made, and actions taken.

Internal conflict is the struggle between motives, tendencies, interests, uses, and generally all attitudes that are difficult to reconcile.

If the conflict persists in time, it will cause, as far as the individual is concerned, emotional tensions that will evolve into stress and ultimately into panic, if circumstances suggest a certain danger for the subject.

- Claparede showed that conflict is an interdependency between the intellectual (means) and the optional (purposes) character.

- Asher distinguished between cognitive, motivational and emotional conflicts, which are almost always accompanied by emotional tensions.
- K. Lewin has focused on attraction-repulsion tensions, and psychoanalysis on the cravings for satisfaction and security.

Intellectual conduct

Belonging to the sphere of conducts in general, intellectual conducts are the hard core of the cognitive approach to human behavioral patterns. They are related to the operational side of thought, includes a set of mental acts characterized by structuring, organization and purpose, and occurs either consciously or unconsciously.

The complexity and priority of intellectual conducts are capital in solving situations and conflicts. Therefore, these conducts can be grouped together, according to the purpose of the moment and the functions to be fulfilled.

In driving an automobile for example, the main functions the driver executes, more or less in succession, are (a) information reception, (b) storage, (c) processing, (d) decision, and (e) action, or response to environmental situations.

Within the framework of the subject's mental functioning, a few additional important concepts should be underscored, though it is somewhat artificial to single them out: they may help express certain mechanisms and mental activities involved in resolving uncertainty.

Information Processing

"Processing information" means transforming it and giving it a sense or meaning. Consciously or not, this is done at all levels of intellectual processes, from perception all the way up to decision and action. It is difficult, though, to distinguish between reception and processing of information, because of the many interdependencies among the processes involved.

Generally processing means reasoning. But the routing of sensorial messages from the peripheral organ to the brain also includes a certain processing that will finally help in integrating certain "informational structures" on which a more elaborate processing is to be made.

In fact these processing elements, or transformations, all work toward an eventual synthesis at a higher level. They are especially tied to the reception and acquisition of information needed in downstream processing, and make the primary data more intelligible and usable.

Schematically, several phases can be seen in this mental-perceptive type of activity which in fact represent the basic functions man executes in his cognitive approach:

- detection of the signals, involving individual perceptive factors and physical characteristics of the signal, is the subject's "discovery" of a signal out of a background of noise which tend to mask it (J.C. Sperandio, 1988);
- discrimination of signals entailing relative (comparison of two or more signals) and absolute reasoning factors and based on a mental standard (J. Mc Cormick, 1970),
- identification of signals, which means recognizing one of several signals and relating it to a class;
- interpretation of signals, whereby they are coded and even recoded and a meaning is given to them for diagnostic or action purposes. This is done either at the elementary information reception level or at the higher level where more complex inferences are made. It assumes associations, comparisons, classifications, generalizations, pre-decisions and representations. The context, the conscious organization of perception, previous experience and the capacity to anticipate are factors that facilitate this phase.

The complexity of the steps followed in acquiring information suggests that the data fits into a kind of "informational structure" and is not simply presented or received passively.

Considering the speed at which visual images occur in a highway environment, and the way the analyzers are "occupied", improving the presentation of standardized information is essential in order to make message reception easier.

Solving Problems and Situations

"Problem solving" is the mental process used to get past a cognitive obstacle through appropriate means, in the sense of transformation from the unknown to the known. It includes all thought mechanisms, and its effectiveness in fact characterizes the quality and quantity of intelligence. If there is a solution, a problem necessarily exists, which comes either from the outside or is made up by the operator himself. So we state that there is problem solving if the "weight" of obstacles to the cognitive process is large and if the processing applied to the incoming data or stored knowledge calls for greater psychic energy than under normal conditions. A problem can be posed and solved at the same time, and the type of mental organization used in defining, observing and analyzing the problem, the accumulation of data and the construction of hypotheses, all support the validity of the saying, "stating a problem correctly goes half the way to solving it". Einstein fully endorsed this saying, and in the seventies A. Crosby took it up in his analyses to better understand the cognitive mechanisms of process and resolution.

As we have already stated, the problem situation in automobile driving includes similar mechanisms. In routine and "normal" situations, the structuring of a complex action involving an anticipative-orientative basis is done with a set of execution modes that must be elaborated, perfected, reorganized and implemented. The most appropriate

procedures are brought into action and automated, and situations are more or less slotted into categories. According to W. Reitman (1966), and Newell and Simon (1972), a situation becomes a problem when the usual procedures are no longer up to solving it.

A great many research workers have investigated problem solving over the past forty years, and various types of approaches have contributed to understanding human reasoning processes. For the reference framework of interest to us, let us consider a few variables and factors that might explain certain conducts and intellectual mechanisms in situations of uncertainty.

* Artificial intelligence and cognitive psychology, the practical goal of which is the automation of cognitive processes, make the following distinctions and offer the following concepts:

- Declarative knowledge (DK) is the body of knowledge linked to the properties of objects, acquired by learning and stored in memory, which is actualized and expressed in natural or symbolic language (this is the theoretical static facet of knowledge or "learning").

- Procedural knowledge (PK) is the body of knowledge that manages implementation of the processes applied to the DK by rules, procedures, algorithms and heuristics, for the purposes of actions (this is the practical, dynamic facet of knowledge, or "know-how").

In fact, these two types of knowledge are more different modes of manifestation than they are separate entities, knowing that going from one to the other is always more complex and not always well defined.

What should be pointed out, though, is that the state of the DK determines the manifestation mode of the PK; or, in other words, "what we know about things" determines "what we do with them", and if the former is uncertain or contradictory, the latter also becomes hesitant and inappropriate to the real situation (We accept the fact that the DK also includes information coming from the outside, or inferred).

* Representation. This is the centermost idea of cognitive psychology, even if it is not completely clear and differs from one author to another. In general terms, representations are circumstantial mental constructions put together to a specific end, with in particular contexts and situations and to face up to the requirement of a certain task. They are transitory and precarious by nature; and as long as they are not modified, whether voluntarily or by changes in reality or at the level of the structure of the subject, they persist in the same form.

Representation, in this context, means situating and structuring the information or knowledge within schemes of a spatial, temporal, relational or logical character. The role these schemes play in diagnostic, anticipation and decision is essential. Ehrlich uses the idea of "circumstantial structures" to designate representations, while Ochanine uses "operative image". Other concepts are also used - "internal model" (Bainbridge),

"operational memory" (Bisseret), etc. - but all go in the same direction and represent explicative elements in the problem and situation-solving mechanism.

* As far as the complexity of the problems or situations occurring when driving a vehicle is concerned, Michon discerns three levels:

- strategic level, when the driver plans his itinerary;
- tactical level, when the driver executes the appropriate maneuver in response to a given situation;
- operational level, when the driver controls the trajectory through cognitive skills.

These three levels are all characterized by the use of data found in the environment or searched for in the knowledge base which has been memorized and is more or less affected by uncertainty. In fact, these levels correspond approximately to the cognitive model and decisional process proposed by Rasmussen, who shows that the driver habitually dominates his tasks by way of a fairly universal mental mechanism characterized by three types of mental conducts, and implicitly by three types of behavior:

- skill-based behavior;
- rule-based behavior;
- knowledge-based behavior.

Generally speaking, the first two types apply more specially to familiar and repetitive situations, and the third to rare, unexpected situations.

* Depending on the author, the information processing, concerning in fact thought (and implicitly the resolution of situations) is taken to comprise either the intellectual operations alone or the entire process, which includes reception of data as well as memory and mental representation.

Some authors feel that man unconsciously transposes his model of operation on the products he generates, and which are much more "visible" than his own model, whence the possibility of understanding our operating mechanism by looking at our own products. Thus, drawing an analogy with the operation of a computer, Lindsay and Norman feel that some light can be shed on human thought mechanism by watching it attentively.

Taking into account basic computer science concepts like processor, memory, input/output, shared time, multiprocessors controlled by a supervisor, etc., they find three types of processing in the thought mechanism:

- Concept (idea)-oriented processing involves general event cognition and implies a certain expectation, predefined by a previous body of knowledge which orients the data analysis modes.
- Data-oriented processing is the opposite. It begins with an analysis of external

signals and ends with the interpretation of them. But certain hypotheses and concepts are needed in order to interpret these data, which means that this processing is transformed into concept-oriented processing.

- Program-oriented processing is a more or less automated procedural type of processing with algorithmic or heuristic type reasoning.

These types of processes are in fact interconnected, with one or another taking priority according to the situation.

* In our opinion, this is a continuous mental process involving perpetual confrontation between external data, previous experience, anticipations and planning. The solution to a problem presupposes that the problem truly exists, that it has been defined and that of necessary intellectual means are available.

In this sense, Newel and Simon considered that mental activity is a complex process that includes several variables, to which they assign the essential concepts of "task environment" (TE) and "problem space" (PS).

- TE includes the objective definition of the task in general and of its solution in particular, with its variables and its structure, as well as the perceived or predefined objectives of the problem or problem situation.

- PS is created by the subject. It is in his own representation of the TE, so that there may be several PS's for the same TE. The problem space includes:

- a) a set of elements concerning the task;
- b) operators producing new cognition states;
- c) the initial cognition state;
- d) the problem and set of desired final states;
- e) all available knowledge.

- PS constitution involves several sources of information: task directives, previous experience in analogous or global situations, programs stored in memory, programs combined with data accumulated during the processing phase.

Problems are solved mainly by algorithms and heuristics, put into play mainly for preparing decisions and planning actions.

* An algorithm(A) is a set of rules and operators defining a procedure for getting a determined result from certain information. More generally, it is a pre-structured, systematized procedure that gives the certainty that a solution for the type of problem for which the algorithm was designed can be attained. In mathematics, Markoff defined algorithm as a finite chain of elementary operations for processing data and solving problems of a certain type. A few examples of algorithms:

- functional A.: classification, transformation, exploration assembly algorithms;
- structural A: simple (sequences, loops), complex (logical conditions)

algorithms;

- identification, recognition, control, etc. algorithms.

* Since not all reasoning and problems are algorithmic, it is up to heuristics to solve most problem situations. Heuristics are open, active systems of operations in a continuous process of generation and modification. They are less precise and not so systematic procedures, sometimes faster, but cannot always be counted on to resolve a situation.

A few examples of heuristics:

- application of a mental model to a new situation;
- combination of two models or paradigms;
- restructuring and revision of hypotheses;
- intuitive modeling;
- reformulation of theories;
- initiation of experimental type disorder;
- modification, adjustment and transposition of knowledge, etc.

For J. Brumer, heuristics is the "discovery" type learning strategy, and for J. Guilford and R.B. Cattell it is based on "divergent thought" and "fluid intelligence". M. de Montmoullin sees a difference between "creative heuristics" and "incompetence-based heuristics", the former finding solutions to new problems and the latter modifying the instructions or rules to fit the situation (since in fact the problem has already been solved before).

Comments

- Of course, the mental mechanisms brought into play in particular situations are much more intricate, but all we wanted was to broadly show that the behaviorist approach is insufficient when we want to improve the operator's "black box" output (the behavior patterns). We must have some knowledge of the content of the black box, so we can structure and organize the input (the information) better.
- Regardless of the mode of reasoning or thought mechanisms that are brought into play, what is important in conflict and accident-generating situations is to know how the initial uncertainty about the information, presented from the outside or generated by the operator, is going to affect the decisions to be made.
- In classical reasoning, it is easy to tell if a set of premises is verified because the answer is of the yes/no type. But in the presence of uncertainty the answer is not as easy to give, which suggests a propagation of the uncertainty that becomes attitudinal and promotes risk-taking.
- In Bayesian-type inference, for example, the operator's mental approach consists in "updating" with new data, either sought or self-generated, the a priori probability of

an event. So each time an observation is made concerning the highway environment (vehicle position, signs, etc.), the initial behavior model is corrected by adding to the knowledge in the procedural memory (or to what is initially presented as basic data).

Bayes' old formula in fact models and standardizes human reasoning in a dynamic situation:

$$P(H_i/D_j) = \frac{P(H_i)P(D_j/H_i)}{\sum_{k=1}^n P(H_k)P(D_j/H_k)}$$

in which:

- $P(H_i/D_j)$ is the a posteriori probability of H_i once the data D_j has been obtained;
- $P(H_i)$ the a priori probability of the hypothesis H_i ,
- $P(D_j/H_i)$ the probability of a given data D_j occurring when hypothesis H_i is true.

Decisions in a dynamic situation therefore consist of a chain of more or less conscious decisions. After each processing action or decision sequence, the knowledge and data acquired are used as a basis for the following sequences.

As such, decisions are derived from subjective probabilities assigned to the hypotheses. These probabilities are based both on "preferences" and on "beliefs". Unfortunately, as Heath and Tversky show, the two concepts are the same in Bayesian theory, whereas a sharper distinction is needed if we want to better understand the role of "subjective priorities".

* However, in problem and conflict situations, decisions have to be made in a very short lapse of time; which means that the chaining analyzed above has to be as short as possible. In other words, the (memorized) knowledge base must be reliable and the data picked out of the environment must be precise, free from doubt, noncontradictory and just what is needed for a specific situation.

* Drawing an analogy with the control of complex industrial processes and with events that occur at the time of industrial disasters, we may say that, on the road, human behavior patterns and the sequence of micro-events follow along the same lines. Individual operational capacities can be influenced, decisions disturbed and behavior patterns affected, by the psychophysiological mechanisms of stress and its associated anxiety-generating elements, as well as by the speed at which the situations follow each other. The exponential event development typical of unusual situations may prompt "unavoidable violations" of the rules, and "aberrant attitudes" at the group level. The intensity of activity under these conditions exceeds the capacity of the operator's brain.

And considering that unusual situations are generally characterized at all levels (i.e. data acquisition, communication, processing, etc.) by imprecision, uncertainty, ambiguity, indecision and hazard which conspire to make situations difficult to control.

Even if they are not entirely independent, the ideas of imprecision and uncertainty must be differentiated in this context. For example, data of the type "tanker truck ahead of us" (therefore, slowing us down) picked out of the environment is imprecise as concerns its meaning for our task (we do not know how long the truck is, nor what it is hiding from our field of vision, nor the driver's intentions, etc.); but there is no uncertainty about it because it is not the truth of the data that is questioned but only its content.

On the other hand, this same data which automatically suggests another data of the "we can pass it" type (of course if the regulations permit it) becomes uncertain through the probability given to the hypotheses linked to the message content. We do not exactly know if the truck is hiding a bend in the road or an oncoming vehicle, we cannot evaluate exactly the power of its engine, nor the behavior of our own car, etc. If we do not take the time to process, adjust and complete the data, the uncertainty spreads and decisions become hesitant and the maneuvers random.

* In 1955, W. Edwards already proposed a formula for predicting decisional behavior patterns that takes into account the difference between the objective and subjective probability of events. In this formula, the expected subjective usefulness (ESU) depends on the numerical usefulness (NU) assigned to each consequence of an action (j) and the subjective probability (y):

$$ESU_j = Y_1 V_{1j} + y_2 V_{2j} + \dots + y_i V_{ij} = \sum_{i=1}^n y_i V_{ij}$$

But studies of real behavior have also revealed that subjective usefulness does not always go toward safety (at the level of the subconscious). At the same time it was observed that optimists attribute high probabilities to the desired events, even if the probabilities are independent of the usefulness. But this type of consideration makes things a bit more complicated for the present approach.

* Another situation of regulation-related uncertainty is the pedestrian crossing (with no traffic light). In certain countries, such a crossing gives absolute priority to the pedestrian (thereby regulating certainty); but it does not have the same meaning for users in other countries, where it has been observed that most pedestrians wait for the cars to pass by. This does not always correspond to the behavior of other users who follow the regulations more strictly. A conflict of criteria arises, as do random behavior patterns.

This means that corrective action is not sufficient to prevent accidents, and that this

must be done by anticipation, adjusted to real behavior patterns and their causes. This is the importance that ergonomics specialists attach to the difference between a "task" and an "activity", which can be described as the tendency people have to shorten the accomplishment of a certain task by avoiding external constraints as much as possible.

* As has already been suggested, solving problems means updating skills and knowledge, and gathering of external data. But in practice we rather often observed that, except in case of non-activation of the neuronal system responsible (fatigue, lack of attention) or lack of training, people persist in certain errors simply because external data does not always play the role of confirmation or precise adjustment, which are to fix and update the cognitive structures. They remain in a state of uncertainty and adapt to conditions in an approximate manner.

* Let us simply look at the execution of the navigation task in an unknown highway network. Taking information from road signs frequently becomes an excessively tiring task, insofar as information presented at a given point in time is not retained through the rest of the trip, so the driver no longer has the possibility of confirming his initial mental representation, which puts him in a situation of doubt or uncertainty.

Another quite common situation is the orientation of the directional panels at a large intersection. The rather approximate positioning often suggests two or even three possible directions to take. This causes tension and frantic scanning for other signals to eventually dispel doubt, and consequently reduced vigilance as to the movements of the other vehicles or safety signals.

The lack of consistency and uniformity in the way signals are placed in various localities and countries is one of the factors responsible for this.

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Of course, the number of factors that can upset the solution of problem situations is much larger, but objective or subjective uncertainty remains a decisive factor. It is determined mainly by the specific features of the roadway environment, and thus this uncertainty can be brought to light, modeled and even reduced. The effects will then be valid for a wide range of users. All we are lacking is the methodology.

This type of approach, even if not fully developed, suggests that for behavioral effectiveness in terms of safety, the priority is to define and pinpoint the situations of uncertainty found in or generated by the roadway environment and that an uncertainty management and solving methodology should be developed.

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