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# Without a common mental model a DSS makes no sense (a new approach to frame analysis using mental models)

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## **Abstract:**

In order to understand why the use of model software and its results in decision making is surrounded with a diversity of problems, this paper presents a new theoretical framework. The framework is based on the notions of frame and mental model that are commonly used in social sciences and psychology. Mental models are found to guide the activities of knowledge producing scientists, DSS builders, decision makers and stakeholders. These activities are described in a modelling cycle and a decision making cycle. The model – both software *and* mental – functions as an intermediate for knowledge transfer. The theoretical framework, together with a new approach to frame analysis, has been tested in a case study. The case concerns the decision making process related to the environmental impact assessment procedure of a storm surge barrier in the Netherlands. The case was analysed with regard to the emerging controversies between stakeholders, on an individual level. Different representations of reality, meanings, and points of views are revealed using a mental model mapping technique. The approach, in this case, revealed knowledge barriers between stakeholders, which could not be overcome by intensive communication and participation. Technical factors were discussed extensively, but had limited effect on the final decision. Interaction within and between the institutional, legal and physical systems produced a decision outcome, which was in conflict with available physical system knowledge. The approach offers a better understanding of how data, information and knowledge are acquired and manipulated during processes of decision-making. The approach has the potential to support interactions between stakeholders, to improve communication and learning between individuals and their organisations involved in a case study.

**Keywords:** Integrated Water Management; Knowledge Communication; Decision Making; Modelling

## **1. INTRODUCTION**

Model results are not always welcomed with open arms, and models are not instantly accepted, as readers of scientific papers might be led to believe. Rogers & Fiering [1986] have identified 2582 papers published since 1965 in three journals in which authors present system analysis tools for water-resource planning and management. They argue that model builders often show a lack of concern with user involvement. The problem seems to be not in developing the model system, but in getting someone to use it. Woolsey et al. Swanson [1975] already wrote: 90% of the problem faced by the practitioner is *not* technical. In many examples the right method yielding the

optimum solution was not used because the analyst was unable to sell it. According to Ford [1991] this situation has little improved since. Ford concludes this to have become commonplace in the development of computer-aided support systems for water resources research and management. Listening to users appears not to be a strong point of many model developers. Brunner [1996], in a discussion on global climate change, concluded that a predictive model is neither sufficient nor necessary for improvements in the rationality of policy decisions and that *the contribution of science should be to provide insights not predictions.*

In those cases where decision makers do actually accept computerised models as representation of scientific knowledge, and believe that they can utilize the information contained in the model output correctly, there can be another type of problem. Schneider [1997] mentions that not all potential users of integrated assessment models will be aware of hidden values or assumptions that are inherent in all such tools. He suggested that for both the explanatory and policy purposes of such models, it is necessary to test the credibility of their structural assumptions, input data, parameter values, outputs and predictability limits. Jäger [1998] mentions the broader problem that the values, choices, assumptions, limitations and difficulties within a scientific model builder paradigm are seldom openly communicated.

The above examples from literature indicate a problem with user involvement in the model development and use. At the same time there seem to be problems with the involvement of model developers in the decision-making process. The result is a sub-optimal decision from the technical or scientific point of view.

We will illustrate these problems with a recent example: the decision to construct a storm surge barrier downstream the city of Zwolle in the Netherlands. Closing the barrier will block the discharge. Because storm conditions have been observed always to coincide with considerable discharge, blocking it will cause the water level in the city to rise quickly. Additional measures to retain discharge upstream have just started (in a 40 year planning). Furthermore these plans are considered by engineers to insufficiently reduce discharge for high precipitation events, which makes additional detention in low areas just upstream of the city a necessary collateral measure. These detention areas could have been used to reduce storm surge flood height without a barrier. The Zwolle example illustrates how information about the physical system and the forecasted effects of the barrier appear to be disregarded by decision-makers. The question rises how data, information and knowledge are acquired and manipulated during processes of decision-making, and what is the role of effect forecasting models in this process.

## 2. METHOD

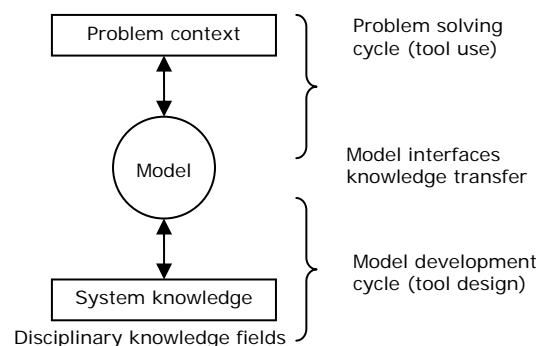
### 2.1 The model interfaces knowledge transfer

Before we can design tools to support the bridging of gaps between scientific knowledge and its use in decision making, we first need to diagnose the

causes of the non-optimal communication, which in turn needs a description of the system to be diagnosed. The description starts from a theoretical framework for integrated problem solving seen from the perspective of *knowledge production and use*.

Funtowicz et al. [1994] detail the policy legitimisation process by describing how decision makers delegate choice responsibilities to scientific information. Models facilitate the delegation of responsibilities from decision makers to experts by offering methods, predictions, explorations, etc. Models do not solve the decision problem. Models, however, do make the problem manageable, by reflecting the way reality is reduced to simple abstractions, and by offering a way to demonstrate effects of possible choices. The model is the connection between the scientists that want to solve the technical problem and the social context in which it is often not completely clear what the problem is. This situation is schematically depicted in figure 1.

This situation may create an area of tension. The essence of this tension lies, according to Birrer [1996] in the imparity of knowledge between the experts and non-experts. Experts are often indispensable for the determination of the best possible options and thereby the non-expert becomes dependent on the expert. The model user, in his intermediate position, has to weigh the interests of the problem owner and the scientific model-developer, and will experience pressure from either side. Hence the use of models in the decision making process requires an experienced model user who will function as an intermediate between abstract scientific knowledge and the specific decision situation. This experienced model user will give meaning to the model results.

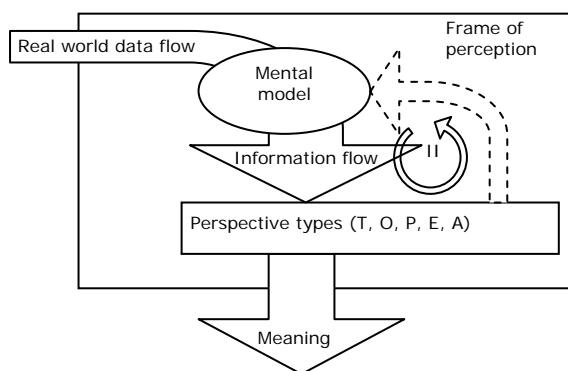


**Figure 1.** A simple sketch of the intermediate function of models in the transfer of disciplinary knowledge. The notion of model is not limited to

computerised models, but can refer to any type of model.

## 2.2 Frames and mental models

The transformation of data into meaning is guided by “mental models” and “perspective types”, see e.g. Churchman [1971], Grant et al. [1977], Mitroff et al. [1993] and Doyle et al. [2001]. Other authors, e.g. Schön et al. [1994] use the notion of “frame” or “frame of perception”, to explain the construction of meaning. Kolkman [2005a] combines these notions from social sciences and psychology into a new definition of the concept of frame, which we briefly summarise below.



**Figure 2.** Transformation processes from data into information and subsequently into knowledge.

The mental model acts as a ‘filter’ that selects information from the ‘real world’. This information is used as input to a meaning-producing process that is driven by perspective types. Perspective types contain all kinds of assumptions, interests, values and beliefs that shape our perspective. The perspective types and mental models mutually influence each other in a second order (II) learning process. Perspective types are heavily determined by the professional (micro), organisational (meso) and political (macro) environment of an individual (decision maker, scientist, or stakeholder). These transformations are operating for all parties involved in a problem situation: decision makers, scientists and stakeholders. Scientists use these processes to produce models and software, decision makers to argue their decision, stakeholders to support or oppose proposed decisions.

A mental model resides in the mind of an individual person, and contains the elements and relations a stakeholder considers relevant for his position in the decision making process. A mental

model restricts information flows to only those aspects that affect the person, more specific, to those aspects that can be accommodated in the mental model present in the person’s mind. Restrictions may be on the scale (geographical boundaries, time horizon, and level of detail) and on the processes and relations considered relevant (including physical, biological, legal, financial, social).

A mental model contains the elements and relations a stakeholder considers relevant for his position in the decision making process. The mental model represents a causal chain of argumentation that starts from the original problem and contains selected data and interpretation thereof, to present convincing evidence for a favoured solution. The mental model can be “run” to simulate the effects of intended actions, and in this way determines what knowledge a stakeholder derives from the real world data flow. According to Doyle et al. [2001] “running” the model is equivalent to following a chain of argumentation. Different stakeholders may use the same starting point and the same data, but with different interpretations, to arrive at different effects. These effects are subsequently evaluated in the frame against the perspectives. But the perspectives are not independent of the mental model. The mental model determines what interests are perceived to be at stake. And the insights gained within the perspectives can update the mental model by adding elements and relations.

## 2.3 Mapping mental models

Mental models can be made visible with mapping techniques. Different kinds of mapping techniques exist in different disciplines, e.g. Eden [1994] in business organisation design, Novak et al. [1984] in knowledge structuring and learning analysis. Different content and structure are contained in concept maps depending on the contexts for which they are generated.

The strength of mental model maps lies in their ability to express a particular person’s knowledge about a given topic in a specific context. Mental model mapping provides a framework for making internal knowledge (of stakeholders involved) explicit in a visual form that can easily be examined and shared. All methods and types of mental model mapping are considered (by their disciplines) to reveal individual and group differences in experiences, perceptions, assumptions, knowledge and subjective beliefs related to the problem, assess tacit knowledge, broaden the narrow understanding of a problem by

confronting one stakeholder's mental model with the mental models of others, make aware of alternative perspectives on the problem, encourage negotiation and help to reduce destructive conflict. Mapping techniques can be suitable for changing the focus of decision makers from the actual decision-making to more early phases in the problem solution process. Mapping may also assist those committed to a certain alternative to climb out the "certainty trough", by making visible new questions about the problem.

## 2.4 Frame reflection

By separating mental models from the frame of perception we can start our analysis of a problem situation by eliciting and analysing the mental models of stakeholders involved in a decision making process without explicitly making reference to the more sensitive frame aspects of responsibilities and interests. These aspects are dealt with in a subsequent phase of our frame analysis method, where five frame perspective types are used to characterize the position of the stakeholder on mutually contested elements of their mental models. The approach brings to light and separates the "facts" and the "opinions", which subsequently could be discussed in an attempt to construct a common mental model and to, possibly, overcome (some of the) frame differences present.

Within a frame, perspectives determine what stakeholders see as their interests. Perspectives differ between stakeholders, influence every step of the decision making cycle, and will result in the creation or support of different alternative solutions. It is the perspectives from which alternative problem solutions are deliberated and decided upon. Five major perspective types are identified in literature, e.g. Courtney [2001], see table 1.

**Table 1.** Perspective types are indicated with the letters T, O, P, E, A, respectively.

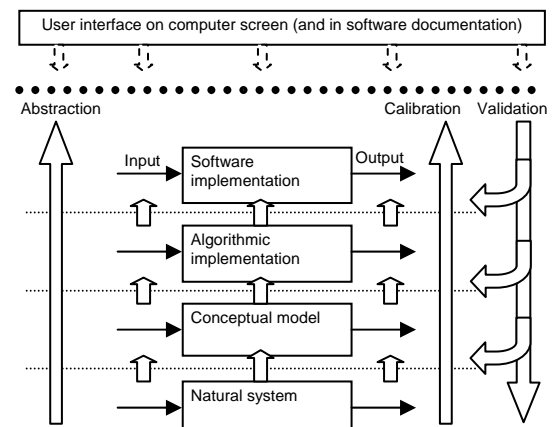
T	Technical	A functional and rational orientation with regard to system behaviour
O	Organizational	A manager's interpretive orientation with regard to institutional and legal
P	Personal	A political and individual orientation with regard to position and power.
E	Ethical	A moral orientation with regard to codes of conduct and values (e.g. environment).
A	Aesthetic	An orientation on the beauty and harmony of a design.

In order to better understand how data, information and knowledge are acquired and manipulated during processes of decision-making, we will describe the use of frames in both the process of knowledge production (modeling) and the process of knowledge use (decision making).

## 3. A DESCRIPTION OF THE SYSTEM OF KNOWLEDGE PRODUCTION AND USE

### 3.1 The knowledge production or modeling cycle

The process of model development can be seen as a series of transformation steps (see figure 3), in which at each step a more abstract and simplified projection of reality is constructed, which corresponds less with the original reality with every step that is taken. See e.g. Jørgensen et al. [2001], Beck [1998], Molen [1999], Goldsborough et al. [1999].



**Figure 3.** Steps of abstraction in the modeling cycle.

Models constitute specific representations of the real world. The information collected within models is authored by model developers, and inevitably contains distortions. Depending on the purpose, a model builder (ideally) selects, from available information, the aggregation level and the amount of detail required and constructs a more or less user-friendly computer system. After each transformation-step the correspondence with reality will be less. Not only the model itself, but also input and output data from the real system must be translated in the same process, in order to perform a calibration of the resulting model

software. The end result is a narrow view on reality, from a specific scientific viewpoint.

Different scientific disciplines will produce different types of models for the same problem in the same natural system. When applying the model the user has to be aware that the conclusions based on the model results are primarily valid only within the imaginary model world of the specific discipline. The interpretation of the results in the real world context involves an inverse transformation. In both the modelling and the interpretation of results the model validity is an important issue (see e.g. Oreskes et al. [1994], Dee [1995]). When integrating information from different scientific disciplines in the solution of complex problems, validation has to deal with the different methods of inquiry of the disciplines. Each discipline has its own rules for gathering relevant evidence and uses various types of evidence.

A model user's understanding of the abstraction process will depend on the script that is implemented in the software user interface. The question rises whether the user interface does adequately inform the software user to reconstruct the conceptual model(s) embedded within, including any assumptions and limitations introduced in modeling steps. For large software systems (DSSs) we can extend this question to the designer's understanding of the scientist's conceptual model.

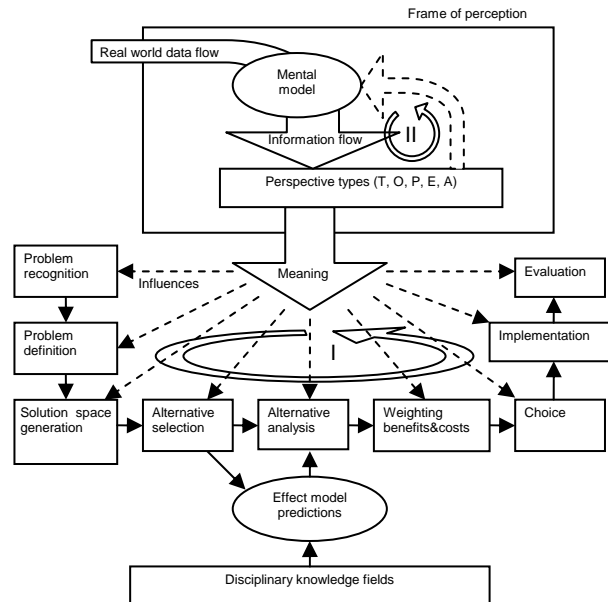
### 3.2 The use of knowledge in the decision making cycle

Decision making involves the problem of choice between alternatives (doing nothing also being an alternative). Choices are made in all steps of the cycle, and are driven by the frames of stakeholders. But behind the frames are mental models that determine what data the stakeholder perceives in the real world, and what knowledge they derive from it.

In all the different methods for problem solving found in literature, a common distinction can be made between, on the one hand, problem analysis and, on the other, problem solving. The latter is equivalent to decision-making concerning possible alternative solutions (e.g. using effect forecasting and decision methods). Figure 4 presents the steps that are generally taken, in one way or another, within the problem-solving methods of diverse disciplines. The steps partly overlap and interact with each other. The process of problem solution is an iterative one, where the iterations continue until the project demands and conditions are met,

or the project resources depleted. The middle part of figure 4 represents the "simple" decision making cycle, which contains first order learning only.

The choice for the most favourable alternative solution appears to be made toward the end of the problem solving cycle. In reality, however, choices are made at all steps of the cycle.



**Figure 4.** Understanding the decision making cycle. The dotted lines represent the influences cycle. The process is cyclical in that new alternatives may be sought within a given problem definition and solution space.

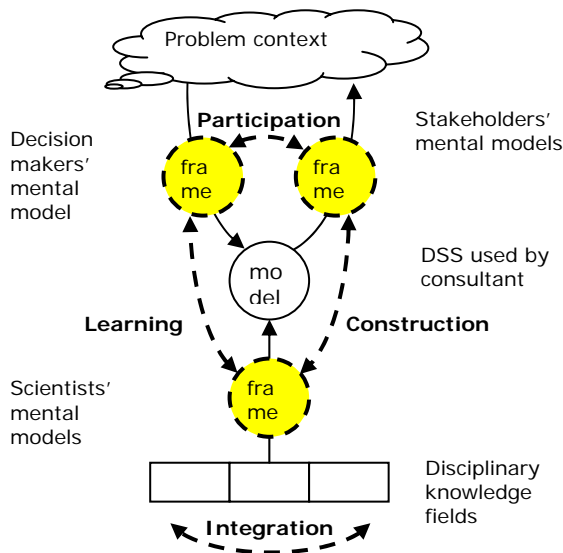
The problem can be defined in many ways, or awareness can be deliberately stimulated (e.g. by publications in social networks, discussion groups, newspapers and journals). Putting the problem issue on the agenda of responsible or affected stakeholders can be stimulated or resisted. The amount of data gathered on the problematic behaviour of the system can differ from nothing to full scale monitoring. The formulation of the problem definition demarcates the solution space, which can be broad, or narrow and focus on a stakeholders' favourite issue. Within the solution space some alternatives will be chosen for further analysis, depending on prevailing preferences. The choice of effect prediction models will depend on the client's preferences, stakes, budget, time, and legal obligations, and will influence the outcome of the predictions. Selection of decision criteria and weighing factors depend on the client and the participation of some or all of the stakeholders involved. The choice of the decision method may

influence the ranking of alternatives, see e.g. Kolkman et al. [2000]. Thus, before a decision method is applied, many choices in fact have already been made. A good quality problem solving process should, therefore, make all the choices and the underlying assumptions, values and preferences visible for the stakeholders involved, thus promoting an open discussion about the most favourable alternative.

## 4. RESULTS

### 4.1 The theoretical framework

Our final theoretical framework (figure 5) shows the positions of the various stakeholder frames. In the problem solving cycle the decision-maker's frame is positioned in the problem analysis phase, and the frames of various stakeholders in the problem-solving phase. In the modelling cycle the frames of various disciplinary experts are positioned. Mismatch between these frames can explain various decision-making difficulties experienced in practice. The mismatch is commonly denoted as "the gap" between science and policy. The dotted arrows represent the communication processes L (learning), C (social construction of meaning), P (public participation) and I (integration between scientific disciplines). Frame differences may present barriers for the adequate use of knowledge in decision making.



**Figure 5.** Visualisation of the "bridging-the-gap" problem. Above: the d-m cycle. Below: the modeling cycle. Middle: the intermediate position of the model in transferring knowledge. Additional "bridging" processes are needed: integration, learning, participation, and construction.

### 4.2 Case study results

The theoretical framework has been applied to the Zwolle storm surge barrier case. Data for constructing mental model maps was collected by document analyses (e.g. the EIA-report [2001]) and interviews in depth. Mental model elements and perspective types were elicited from 14 stakeholders. Interviews were processed into an overview table, which contains the map elements disputed between stakeholders. A total of 67 disputed elements were identified. The elements were processed into a causal decision explanation model. The reader is referred to Kolkman [2005a] for further details. In this section we will present some results of this case study with regard to the use of information and communication.

#### 4.1 The use of information

The Zwolle surge barrier case exhibits the characteristics of a complex, unstructured problem situation in a multifunctional system, where knowledge is uncertain and values are disagreed upon.

Debated values in the case are, for example:

- The interpretation of the Flood Defences Act;
- The restrictions placed on the discussion of the dike ring approach;
- The distribution of responsibilities and tasks;
- The disregard of technical-scientific objections against the chosen barrier alternative, in favour of administrative and legal arguments;

Uncertain knowledge (as experienced by one or more stakeholders – this does not correspond to a scientifically underpinned uncertainty) in this case are, for example:

- Extreme precipitation frequency distributions;
- The frequency of the worst case high water scenario (ranging from 1/1 and 1/10 to 1/1250 and 1/10000);
- The calculated design high water levels;
- The possibility of backflow of discharge water into the upstream areas;
- The effect of closure of the Zwolle barrier on the upstream water levels;
- Worst case water depths and potential damage in potential inundation areas.

Also uncertainties are present in knowledge about the administrative system. These uncertainties depend on the interpretation of laws, guidelines and their explanations by the national authorities. Uncertainties regarding this type of knowledge become apparent through the objections brought

forward in the EIA procedure and the appeals to court.

#### 4.1 The communication process

In our case, we found a very open and deliberate communication in the first phase of the decision making process. Scientists addressed the complexity of the physical system and revealed the uncertainties in their predictions. Many stakeholders have been involved in a rather high (for this type of decision making) level of participation, and discussed the problem and its alternative solution in detail. They came up with and discussed many alternative solutions in addition to a full-scale dike improvement along the upstream waters and within the city of Zwolle. The involvement of all main stakeholders in the dialogue did, however, NOT succeed in building mutual understanding and a shared vision on problems, objectives and alternatives.

The persistence of the disputes in the later phases of the decision making process shows that open communication alone is not enough to prevent decision making barriers. Despite intensive communication between stakeholders in this case, their different frame perspectives maintained different mental models and therefore different preferred solutions. Apparently institutional and personal perspectives ultimately played a dominant role. These perspectives determined the way in which stakeholders dealt with details that were exposed in the previous more open communication. These details were, for example, declared irrelevant (like a new interpretation of the Flood defences Act, distribution of responsibilities, and need for further research), or were not explicitly answered (e.g. the necessity of detention, and the low frequency of occurrence of the worst case scenario).

Remarkably stakeholders with a Technical perspective not only presented their technical arguments against the effectiveness of barrier alternative, but also presented arguments to refute the arguments for its legal necessity presented by stakeholders with an Administrative perspective. It seems that, where possible, the conflicting elements with regard to legal matters have been interpreted by the Administrative stakeholders in such a way as to create as much a necessity for the barrier alternative as possible. The technical aspects appear to be countered with an appeal to uncertainty (“experts divided” and “complex situation cannot be modelled”).

Ultimately the problem became under high pressure of legal time constraints. The Water

Board, in their role as first authority responsible, decided to choose a solution which with certainty would conform to their legal obligations: a storm surge barrier downstream the Zwolle city centre.

#### 5. CONCLUSIONS

Our case (in integrated water management) presents an example of how the solution of complex, unstructured problems is faced with controversy and dispute, unused and misused knowledge, project delay and failure, and decline of public trust in governmental decisions. Although a decision was finally reached several years after the intended deadline, an integrated problem solution was not reached. The solution was limited to the well-structured part of the problem by deliberately separating in form it broader context. This limitation can, in our opinion, be contributed to the lack of possibilities to search for an integrated solution involving all levels of authority, and discussing the additional problems that were raised by the integrated approach in the initial phase of the EIA project. The persistence of the disputes in our case shows that open communication and intensive participation is not enough to bridge the gaps in decision-making processes. Apparently institutional and personal perspectives ultimately play a dominant role.

Frames and mental models play an important role in the building and use of model software. Decision makers, DSS operators and scientific experts are often unconscious of how their mental models determine the interpretation of a specific problem situation. The example of the Zwolle barrier shows how our mental model mapping method for frame reflection is capable of surfacing contradictions in the decision-making argumentation. The question remains in what way new approaches to DSS design will be able to bridge the gaps. We hope that our analysis and application of frame reflection can contribute to that goal.

Our approach offers a better understand of how data, information and knowledge are acquired and manipulated during processes of decision-making. The approach has the potential to support interactions between stakeholders, to improve communication and bring the individuals together. Discussion of the elicited mental model maps may promote communication and learning between individuals and their organisations involved in a case. Construction of a common mental model map of the problem situation would allow the structuring of conflicting elements of diverse argumentation chains without immediately



resolving the controversies, and may surface assumptions, interpretations and uncertainties involved. The nature of controversies and their rooting in institutional and personal contexts could be discussed. This would, however, require a willingness to break through institutional communication patterns and distributions of responsibilities, which presents new responsibilities for the stakeholders involved.

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