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A MODEL OF DECISION-MAKING IN CONCEPTUAL DESIGN

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ABSTRACT

Systematic models for concept evaluation and selection have been proposed for decades to support decision making at the strategic level of design. However, in conceptual design, engineers do not approach decision-making in a systematic manner as these models propose. The area of decision-making in conceptual design still has few fundamental works, which can serve as a theory base, especially in terms of understanding the role of knowledge in decision-making. The objective of this paper is to propose a coding system that can be used to explore the role of knowledge in decision-making and to propose a model of decision-making derived from the analysis of a design experiment using the system proposed. The model shows that engineering designers make tentative decisions based on tentative knowledge. Knowledge plays a fundamental role, since decisions become validated as the knowledge does, and hidden assumptions are not proved wrong. The results have important implications on decision-making traceability and decisions storage.

Keywords: decision-making, conceptual design, design experiments, protocol analysis, knowledge

1 INTRODUCTION

Hatamura [1] points out that the reason why it is necessary to describe the decision process of inventing a technology when the technology already exists is that just looking at an established technology does not allow people to reach a real understanding of it, to use it and to develop it further; but that, in fact, to enable such further steps, it is necessary to see the process of giving birth to the technology, especially the process of making decisions. This means that the inventor needs to record the mind process in a form that can be communicated to other people. In industry, decision-making traceability is increasingly becoming more important, e.g. [2].

Another reason why it is important to describe the decision process is that it is necessary for researchers if they want to produce useful tools or guidelines to support designers.

To improve decision-making traceability and decision-making tools, we need to understand decision making, and in order to understand it, we must be able to analyse and describe it. There is much interest among researchers in providing support related to product knowledge to aid designers in making better decisions, but the role of knowledge in decision-making remains quite unexplored.

Systematic models for concept evaluation and selection have been proposed for decades to support decision making at the strategic level of design, e.g. [3]. However, in conceptual design, engineers do not always approach decision-making in a systematic manner as these models propose. The area of decision-making in conceptual design still has few fundamental works, which can serve as a theory base [4], especially in terms of understanding the role of knowledge in decision-making.

2 OBJECTIVE

The objective of this paper is to propose a coding system of decision-making in conceptual design that can be used to explore the role of knowledge in decision-making. The coding system is based on a literature study and the analysis of a video-taped team-design experiment. The experiment is analysed and a model of decision making is proposed.

3 RESEARCH METHODOLOGY

The methodology has three steps:

- Definition of a coding system to analyse the relationship between knowledge and decision-making. It has been made by means of a literature study on decision-making in design and observation of a recorded design session to decide a way to code a team taking design decisions. Then, the coding system has been applied to this design session.
- Study of the reliability of the coding system. It has been applied by a third person for validation of its reliability. The coding system is reliable if the same results are obtained to a reasonable extent. The percentage of agreement is studied.
- Analysis of the protocol. Finally, the coded experiment has been studied. This analysis has resulted in the proposal of a model for decision-making. The disagreements between coders have been studied to decide whether the model applies in spite of the disagreements.

4 DEFINITION OF THE CODING SYSTEM

4.1 State of the art of evaluation in conceptual design

In the literature, it is stated that when evaluating between alternatives, all of them should be developed to the same level and represented in an external form [5]. However, Ahmed and Hansen [6] have observed designers evaluating designs that had yet to be externalised. The designers did not externalise their design alternatives unless their evaluation had been successful; if not, they would generate another design alternative. Hence, evaluation is done between alternatives in a "synthesise and evaluate activity".

In the same line of thought, Dwarakanath and Wallace [7] had observed, in an empirical study of design work within an experimental setting, that individual designers tend to apply a single-string solution-oriented approach, where alternatives are not considered unless the pursued direction in the solution space is recognised to be infeasible.

This is what Stacey et al. [8] call premature focus. They discuss that design is also characterised by modification of similar products, following habitual paths, and the description of new designs with reference to previous similar designs.

In this respect, Derelöv [9] contends that depending on the status of the design process, the alternative solutions are defined at different levels of detail. In the early phases when solutions are characterised by non-quantifiable, unclear and incomplete information, they are often addressed as concepts. Later in the process when solutions are more quantifiable, detailed and concrete, they are denoted as products. The difference in characteristics reflects the possibilities of conducting a proper evaluation on each level respectively. Ullman [10] had already distinguished between concept and product evaluation. For the concept evaluation, the goal is to use the least number of resources on deciding which concepts have the highest potential for becoming a quality product. The difficulty is to choose on which concept to spend time developing when the information that the selection is based on is strongly limited. Product evaluation, however, is more about determining, with certain validity, the performance of the product, and comparing it with the specification, the performance being interpreted here as the measure of function.

It can be concluded that there is agreement in the literature that sometimes in conceptual design, problems are not sufficiently defined as to apply a number of rules to evaluate a number of solutions and make a selection. This procedure would be excessively long and information is not always available. Instead, premature focus on concepts has been observed, meaning that designers will not go through a process of considering many solutions to select the best, but that they would consider one or few solutions (based on previous ones) that are perceived as potential carriers of the pursued objectives. This paper focuses on this type of decision-making.

4.2 What is *making decisions in conceptual design*?

4.2.1 To "decide" understood as a selection at a distinct moment

In the literature, two views of decision-making have been found. In the first view, to "decide" has been understood as to "select" at a distinct moment. In this line of thought, decisions have been grouped into three types [1]:

- Go or no go. There is only one choice to begin with and the decision is whether or not to do it.

- Single selection. One option is selected from multiple choices.
- Structured decisions. It is the state with multiple nodes, each with multiple choices, and selecting one option at each node leads to a structured route.

Derelöv [9] discusses two possible evaluation approaches, which can be applied to Hatamura's single selection and structured decisions:

- Selection of fittest solutions. A common interpretation of this approach is to compare the solutions with characteristic criteria, which have often been derived from the design specification.
- Exclusion of improper solutions. It focuses on the limitations of a solution, e.g. their shortages or disadvantages.

In the first case, solutions are evaluated on the same basis, with the same criteria. A comparison is, in other words, relatively easy to execute. However, as discussed in the previous section, this approach does not seem to be applicable in all cases of conceptual design, and it is not applicable to the case being studied in this paper. In the second case, a comparison is more complicated. The alternative solutions could be derived from different base-technologies, each with their own set of problems. This indicates that the basis for the evaluation might originate from the solution, rather than from the task [9]. This leads to the second view, which is presented below.

4.2.2 To "decide" understood as a process taking place over a period of time

In the second view, a number of authors consider decision-making as a process that takes place over a period of time that finishes when the decision has to be taken or when engineers feel there is sufficient certainty in the decision; but not at a distinct moment during that period. Hansen and Andreasen [4] contend that engineering designers make a tentative decision based on the available information. As new criteria and clarifications emerge, which to a satisfactory level support the tentative decision, it will be considered verified, and "the decision is made". According to them, during the decision process there are several decision-makers, and there are many stakeholders, which act as decision-makers influencing the design process and its outcome.

In accordance with this view of decision-making, Andreasen and Hansen point out that *to evaluate*, *to validate*, *to navigate*, and *to unify* are sub-activities, which result in a basis for making a decision. Hansen and Ahmed [6] have developed an encoding system of decision-making activity, which distinguishes the following sub-activities within the activity of decision-making:

- Specify: a statement concerning compilation of design criteria. This sub-activity sets the criteria for the decision. It is the engineering designer's task to compile stakeholders' goals and translate these goals into product design specifications.
- Evaluate: a statement concerning either the value of a design alternative, or the alternatives with respect to the current criteria.
- Validate: a statement whether a design proposal is "fit for purpose" with respect to identified product life concerns, e.g. manufacturing, distribution, or use.
- Navigate: a statement regarding the progression and feasibility of the design work, i.e. which activity to do next or in which direction to go next.
- Unify: a statement concerning the current design solution or design activity in relation to the totality of the product or process.
- Decide: a verbally expressed decision.
- Other: statements which do not belong to any of the first six categories.

Badke-Schaub and Gehrlicher [11] also assert that the decision making process includes a number of activities such as analysing, evaluating, and selecting, mainly in a group context.

The activities proposed by Andreasen and Hansen and by Badke-Schaub and Gehrlicher do not solve the objective pursued in this paper of doing analysis of protocols to study the role of knowledge in decision-making. This is why a new coding system is proposed next.

4.3 Initial observations of the design experiment

The design experiment consisted of a group of three engineers generating ideas for a tubular map case allowing for one-by-one removal and insertion of maps. The three participants were at that time Engineering Design PhD students with experience in mechanical engineering designing of more than 10 years.

When the design experiment is observed from the view point of analysing the decisions taken, the first thing that calls the attention is that most of the decisions are made without designers being conscious about it. The designer embarks upon the decision-making process by identifying solutions, specifying required functions, and changing direction intuitively. Decisions get manifested through the designer's actions and inactions. We could say that decision-making in the ideation process of design is mainly a knowing-in-action activity, in Schön's terms [12]. Knowing-in-action is often that tacit information that we know about doing something, which is often left unexplained or unmentioned when we describe what we do. It is revealed in skilful performance.

However, there are moments in which the designer appreciates a potential risk in an idea about which he/she does not have an immediate answer, and brings the decision-making activity to the conscious world. In team design, this becomes even more evident because designers may not agree on the directions to take, and consequently have to take decisions regarding ideas to reach consensus.

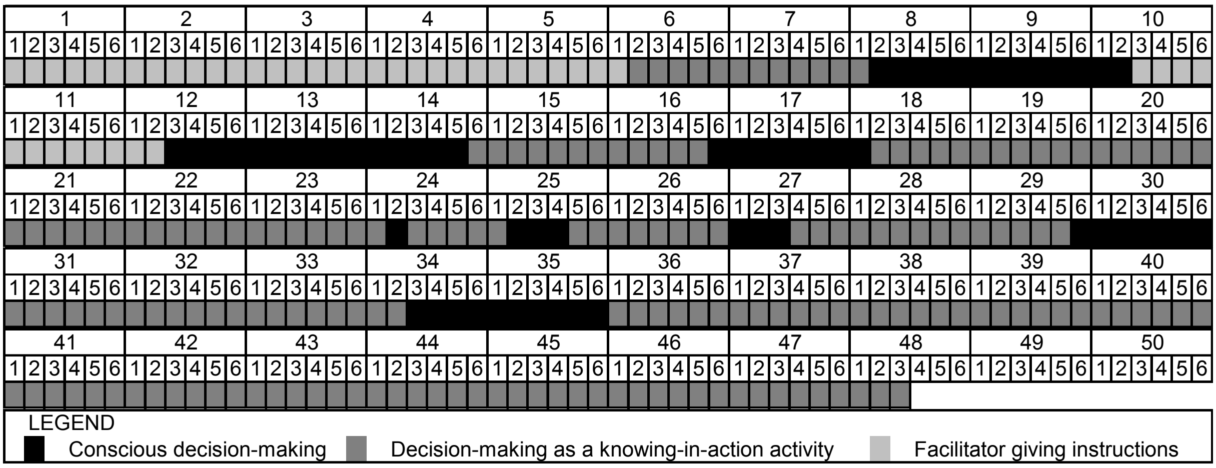
The action of arguing a decision is, therefore, a design action in which engineers discuss whether they should go or not for an idea, or about whether a concept is good or bad, or better or worse than another one, or about which concept they are going to select.

An argued decision is something that occurs in the conscious, and in team design it is uttered and can be coded. It can also be easily distinguished from other activities in a session.

For this reason, the coding system defined here is used only for those moments during which decision-making is taken to the conscious world. It should be pointed out that it is in these moments when designers feel that they need support, since in the rest of the process they trust on their own tacit knowledge and previous experience, i.e. in their knowledge-in-action. The objective, then, is to define a coding system that allows studying the role of knowledge in conscious decision making in conceptual design.

In Table 1, the alternation between conscious decision-making (highlighted black) and unconscious decision-making (highlighted dark grey) is represented. Five horizontal blocks, with three rows each, can be observed. The first row represents the minute in which the activity is taking place. For example, "8" represent what was going on during the 8th minute. The second row divides the minutes in intervals of 10 seconds. There are, obviously, 6 intervals in each minute. As it can be observed from the table, the total time that the engineers were recorded was about 47 minutes and 30 seconds, out of which 40 minutes and 20 seconds were dedicated to designing, the rest (7 minutes and 10 seconds) being dedicated to the instructions that the facilitator gave to the team. During 75% of the 40 minutes and 20 seconds of designing, engineers were observed taking decisions unconsciously, i.e., in a knowing-in-action activity. During 25% of the time, the decisions were taken consciously.

Table 1. Alternation between conscious decision making and unconscious decision making in the design experiment



The decisions that were consciously discussed in the design experiment are listed next:

1. Decide to go or not for a solution (during the 8th, 9th, 10th, 12th, 13th, and 14th minutes). The team does not finally utter a final decision about it, but since they never talk again about that solution, it is assumed that the group decided not to go for it.
2. Decide whether a solution is bad or not because it will damage the maps (during the 16th, 17th,

and 18th minutes).
3. Choose the best two among three alternatives (during the 24th minute).
4. Decide which parameters of the tube (colour, texture, size, etc.) should be made customisable (during the 25th minute).
5. Decide whether a solution is bad or not because it does not allow identifying the maps you have inside the tube (during the 27th minute). To solve this initially tentative decision, they do an activity that is later called in the coding system *biasing solving*, which means that they refine the solution to bias the decision. The final decision taken is that the solution is good.
6. Decide whether they can dispense with a lid or not (during the 29th and 30th minutes).
7. Decide to go or not for a solution because it is very similar to another one, which is, indeed, better (during the 34th and 35th minutes).
8. Decide whether to continue or not for a solution because it is too heavy and too sophisticated (during the 40th and 41st minutes).

4.4 Definition of the coding system

During conscious decision-making, designers have been observed doing mainly two things:

- Uttering decisions. The decisions are most of the time tentative. We will distinguish between tentative and validated decisions.
- Uttering knowledge. The knowledge is normally used to bias the decision towards one side. Sometimes the knowledge is tentative. Other times what they do is to validate knowledge or to access validated knowledge.

Besides uttering decisions or knowledge, the designers of this experiment have also been observed doing two more things: refining a solution to bias the decision towards one side, and posing questions whose answers will help to take the final decision.

Consequently, the coding system proposed here includes the six following activities, which are found during conscious decision-making:

- Tentatively deciding (TD). As suggested by Hansen and Andreasen (2003), it has been observed that engineering designers make tentative decisions based on the available information.
- Posing decision-oriented questions (PQ). In order to go from a tentative decision to a final decision, designers have been observed to sometimes pose such questions whose answers are expected to support a tentative decision.
- Validating knowledge or accessing already validated knowledge (VK). This is the action of accessing or creating knowledge that all the team members recognise as valid.
- Uttering tentative biased knowledge (TK). It implies uttering tentative knowledge that is biased towards a tentative decision.
- Biasing solving (BS). This is refining an already proposed solution in order to influence a pending decision.
- Deciding (VD). This is the action of confidently deciding whether or not to reject an idea, or stating whether an idea is better than another. The decision is considered valid.

5 STUDY OF THE RELIABILITY OF THE CODING SYSTEM PROPOSED

The reliability is studied with the help of a third person, who is an experienced researcher in the physical chemistry field. The coding system is considered reliable if the same results are obtained to a reasonable extent by other individuals. Other authors doing similar reliability studies obtained a percentage of agreement of 70% and 80% fits, e.g. [13], and solved the difference doing an arbitration discussion to create a better understanding of the data by discussing it among the coders. Here, it is necessary to study the reliability in two respects:

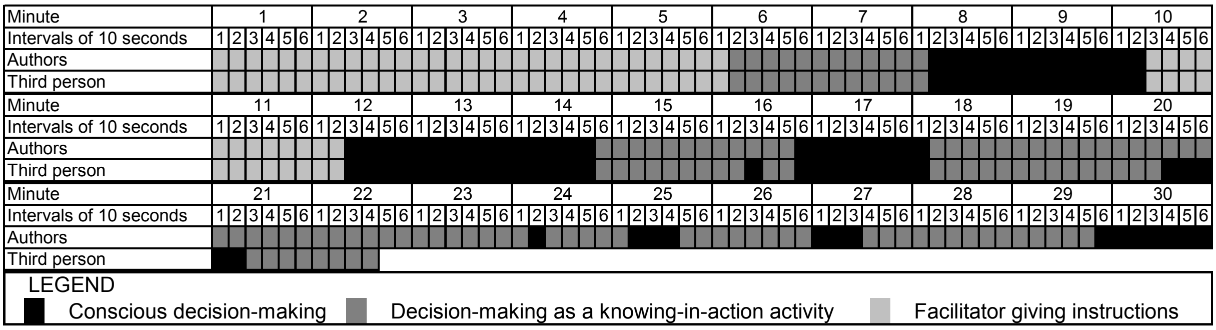
- On one hand, it has to be checked whether conscious decision-making can be differentiated from unconscious decision-making or not.
- On the other hand, it is necessary to study the percentage of disagreements in the coding of the activities.

5.1 Can conscious decision-making be easily differentiated from unconscious decision-making?

The third person was given explanations of the coding system and the experiment for about one hour. He was working on the identification of the conscious decision making and the coding system in the experiment for about 6 hours in a row. During his coding activity, one of the authors was sitting with him to solve potential problems with the understanding of the events in the video. He had a copy of the whole conversation transcribed, and some drawings that were made by the designers during the experiment.

The third person studied the first 22 minutes and 40 seconds of the experiment, which included the coding of 14 minutes and 30 seconds of designing, obtaining the result that appears in Table 2. There is a 93.1% (13 minutes and 30 seconds) of the time equally coded by the authors and the third person, and 6.9 % of the time (1 minute) coded differently. The author checked the codification of the third person and realised that the disagreements were due to the fact that the third person coded more times the design activities as conscious decisions than themselves (minutes 16th, 20th and 21st). Then, the author decided to give further explanations about the coding system to the third person to see if they could agree on the 100%, without letting him know what they had codified. The third person was asked to re-codify the experiment with the new insights, and the result was much worse than the first time. Then, the codifications were discussed and the third person commented that distinguishing between conscious and unconscious decision-making is difficult.

Table 2. Comparison of the alternation between conscious and unconscious decision-making as coded by the authors and by a third person



In spite of the negative comments from the third person regarding the reliability of the system proposed, it should be noted that a 93.1% match was obtained the first time, which is quite high compared to the percentage obtained by other authors [13].

5.2 Are the activities of the coding system unambiguously coded?

The reliability of the coding system for the two decisions considered conscious decisions by both, the authors and the third person, have been studied. The coded activities for the first decision last for 4 minutes and 40 seconds. Table 4 reflects the comparison between the codifications by the authors and by the third person. The coded activities for the second decision last for 2 minutes and 2 seconds. The percentage of agreements between the authors and the third person are shown in Table 3.

Table 3. Percentage of agreement/disagreement between the authors and a third person in the codification of two conscious decisions

	Agreement [seconds]	Disagreement [seconds]	Agreement (%)	Disagreement (%)
Decision 1	245	35	87,5%	12,5%
Decision 2	110	12	90,2%	9,8%
Total	355	47	88,3%	11,7%

The percentages of disagreement are not excessively high compared to what other authors have got. The differences between coders do not affect the model of decision-making proposed later.

Table 3. Comparison between the codifications by the authors and by a third person of the first conscious decision

Minute	8																													
Seconds	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
Authors											TD	TD	TD	TD	TD	TD	TD	TD	BS	BS	BS	BS	BS	BS	BS	BS	BS	BS	TD	TD
3rd person												TD	TD	TD	BS	BS	BS	BS	BS	BS	BS	BS	BS	BS	BS	BS	BS	BS	TD	TD

Minute	8																													
Seconds	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
Authors	TD	TD	TD	TK	TK	TK	TK	TK	TK	TK	TD	TD	TD	TD	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK
3rd person	TD	TD	TD	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK

Minute	9																													
Seconds	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
Authors	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK
3rd person	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK

Minute	9																													
Seconds	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
Authors	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	PQ	PQ	PQ	PQ	TD	TD	TD	TD	TD	TD	TD	BS	BS	BS	BS
3rd person	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	PQ	PQ	PQ	PQ	TK	TK	TK	TK	TK	TK	TK	BS	BS	BS	BS

Minute	10																													
Seconds	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
Authors	BS	BS	BS	BS	BS	BS	BS	BS	BS	BS	TD	TD	TD	TD	PQ	PQ	PQ	PQ	PQ	PQ	PQ	PQ								
3rd person	BS	BS	BS	BS	BS	BS	BS	BS	BS	BS	TK	TK	TK	TK	PQ	PQ	PQ	PQ	PQ	PQ	PQ	PQ								

Minute	12																													
Seconds	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
Authors																							TD	TD	TD	TD	TD	TD	PQ	TK
3rd person																							TK	TK	TK	TK	TK	TK	PQ	TK

Minute	12																													
Seconds	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
Authors	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK
3rd person	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK

Minute	13																													
Seconds	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
Authors	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	PQ	PQ	PQ	PQ
3rd person	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK	VK

Minute	13																													
Seconds	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
Authors	VK	VK	VK	VK	PQ	PQ	PQ	PQ	PQ	PQ	PQ	PQ	PQ	PQ	PQ	PQ	PQ	PQ	PQ	PQ	PQ	PQ	PQ	PQ	PQ	PQ	PQ	PQ	PQ	TK
3rd person	VK	VK	VK	VK	PQ	PQ	PQ	PQ	PQ	PQ	PQ	PQ	PQ	PQ	PQ	PQ	PQ	PQ	PQ	PQ	PQ	PQ	PQ	PQ	PQ	PQ	PQ	PQ	PQ	TK

Minute	14																													
Seconds	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
Authors	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK
3rd person	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	VK	VK	VK	VK	VK	TK	TK	TK

Minute	14																													
Seconds	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
Authors	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK										
3rd person	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK	TK										

LEGEND					
TD	Tentative decision	TK	Tentative knowledge	PQ	Posing questions
VD	Validated decision	VK	Validating knowledge	BS	Biased solving

6 ANALYSIS OF THE RESULTS FROM THE DESIGN EXPERIMENT

Once the conscious decisions were coded, the relationship between the different activities has been studied. As an example of the type of analysis, the first decision has been plotted in Figure 1. It is convenient to provide here the context of the decision. The team had been defining a solution (S1) for some minutes, when one of the team members proposes a second solution (S2). One of the other two members wants to reject the second solution proposed, and a decision of whether to do it or not is held. The drawings done of the solutions are shown in Figure 2. S1 consists of a tube in which maps are rolled up concentrically, and S2 is a tube in which maps are rolled up independently.

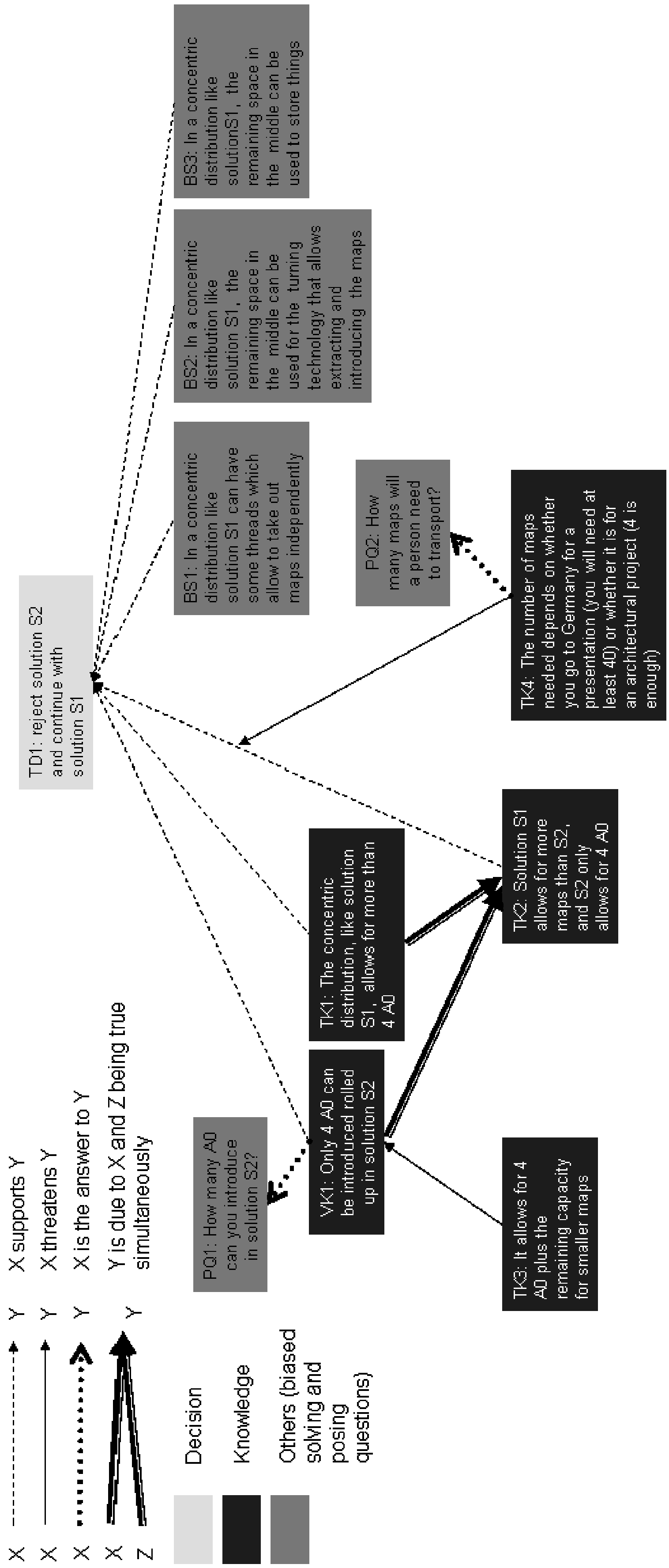


Figure 1. Types of relationships between the decision-making activities

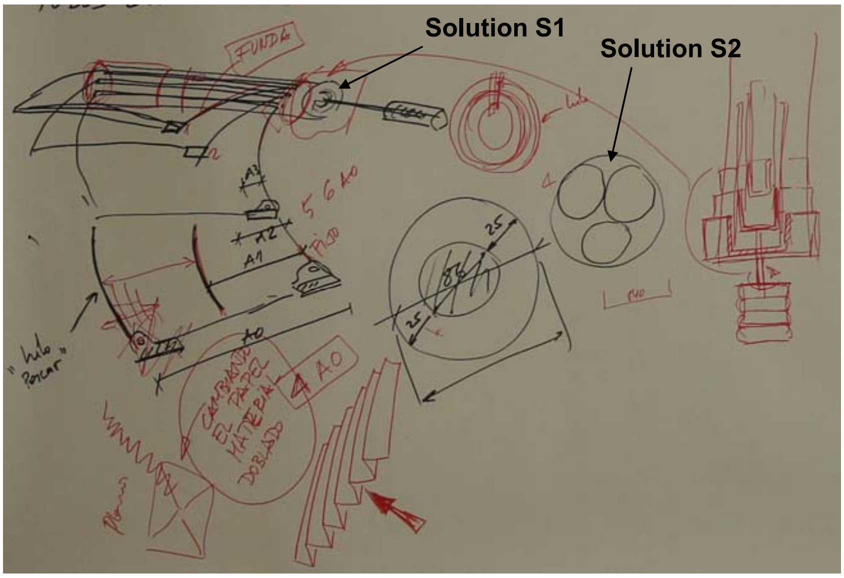


Figure 2. Solutions S1 and S2 discussed in the analysed decision

In Figure 1, the knowledge is highlighted black and the decisions light grey. The rest of activities are highlighted dark grey, which are in this decision: biasing solving (BS) and posing decision-oriented questions (PQ). The relationship between the activities are mainly of the following types:

- X supports Y. This happens when the objective of an activity is to support one of the options of a decision. For example, in Figure 1, the tentative decision of rejecting solution S2 is supported by the validated knowledge VK1, the tentative knowledge TK1 and TK2, and the biasing solving activities BS1, BS2, and BS3.
- X threatens Y. This happens when an activity, normally uttering tentative knowledge or posing decision-oriented questions, threatens a decision, other knowledge, or an assumption. Assumptions are normally hidden in the relationship between knowledge and decision, as shown in Figure 1 in the relationship between the tentative decision TD1 “reject S2 and continue with S1” and the tentative knowledge TK2 “S1 allows for more maps than S2, and S2 only allows for 4 A0”. The assumption hidden is that 4 A0 are not enough. This assumption gets threatened by the decision oriented question “how many maps will a person need to transport?”, whose answer threatens the assumption.

Other secondary relationships are:

- X is the answer of Y. Knowledge is used to answer the decision-oriented questions.
- Y is due to X an Z being true simultaneously.

7 PROPOSAL OF A MODEL OF DECISION-MAKING

The model of decision making proposed here is shown in Figure 3. It shows that in the context of a problem and a solution finding activity, engineering designers make tentative decisions based on tentative knowledge. Knowledge plays a fundamental role, since decisions become validated as the tentative knowledge does, and hidden assumptions are not proved wrong.

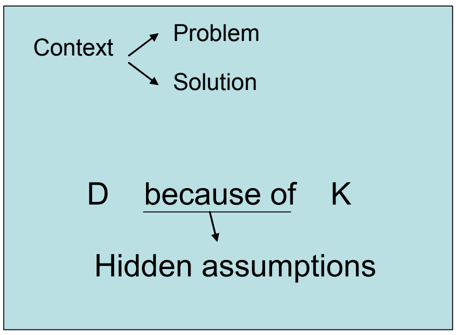


Figure 3. Model of decision-making in conceptual design

From the analysis of the decisions taken in the experiment, it has been found that three types of knowledge are mainly used in decisions:

- Knowledge about the product or the technology.
- Knowledge about the relationship between a tentative decision and a tentative knowledge.
- Knowledge about the design process.

7 RESULTS IMPLICATIONS

The implications of these findings are explained next.

To support designers in decision-making we have several options:

- To provide them with knowledge about products and technologies, or about the design process.
- To provide them with tools to validate knowledge or with validated knowledge.
- To provide them with tools that help them finding hidden assumptions.

To increase the traceability of decisions in a company, it is necessary to record:

- The decisions taken.
- The context of the problem being solved and the solution.
- The knowledge behind the decision taken, and de degree of validity (or certainty) of this knowledge.
- The assumptions made in the relationship between knowledge and decisions, if they can be externalised.

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