APPLIED WORK DOMAIN ANALYSIS: TRANSLATING KNOWLEDGE TO REPRESENTATION

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This paper describes a method for transforming knowledge elicited from real life applications into Rasmussen's Abstraction-Decomposition Space (ADS). The ADS is used to represent knowledge in a Work Domain Analysis (WDA), the first of five stages in a Cognitive Work Analysis. The WDA is highly conceptual and is mostly used by trained practitioners. There are many concepts and rules in the construction of the ADS. These make it difficult for practitioners to transform and map their data onto the two dimensional (2D) ADS. In Applied Work Domain Analysis (AWDA), we introduce a new dimension, cause-effect, thereby creating a 2D orthogonal space called the Motivation-Expectation Space (MES). The rules for constructing the MES are easier to apply than the ADS. After constructing the MES, practitioners can map information in MES onto the ADS.

INTRODUCTION

Cognitive Work Analysis (CWA) is increasingly used for modeling complex systems (e.g. Burns, Garrison, & Dinadis, 2003; Kuo & Burns, 2000; Sanderson, Wong, Choudhury, & Memisevic, 2003). Most of the analyses focus on the Work Domain Analysis (WDA), which is the first of the five phases in CWA (Rasmussen, Pejtersen, & Goodstein, 1994; Vicente, 1999). Many studies cover theoretical aspects of WDA (Hajdukiewicz & Vicente, 2004; Harwood & Sanderson, 1986; Vicente, 1995), and some authors have applied WDA for redesigning systems (Bisantz & Vicente, 1994; Naikar, Sanderson, & Lintern, 1999; Reising & Sanderson, 2002a).

Naikar, Hopcroft, & Moylan (2005) outlined a methodology for formulating a WDA. They proposed the following steps:

1. Establish the purpose of the WDA
2. Identify the project constraints
3. Determine the boundaries of the WDA
4. Identify the nature of constraints
5. Identify the potential sources of information
6. Construct Abstraction-Decomposition Space – iteration 1
7. Construct Abstraction-Decomposition Space – iteration 2
8. Construct Abstraction-Decomposition Space – iteration 3

This outline neatly summarizes Rasmussen's (1994) and Vicente's (1999) theories into a workable plan for practitioners and guides the (de)composition of a work domain. However, from Stage 5 (Potential sources of information) to Stage 6 (Abstraction-Decomposition Space) is a major conceptual step. To guide this process Naikar et al. (2005) broke down stage 6 into several sub-stages:

6.1. Identify Work-Domain Properties
6.2. Define the Levels of Abstraction and Decomposition
6.3. Develop a Sketch of the ADS
6.4. Evaluate which Cells of the ADS to Populate
6.5. Populate the Selected Cells of the ADS
6.6. Revisit the Data for the ADS

Naikar et al. (2005) suggested using the abstraction levels in Rasmussen's original work on nuclear power plants. This limits the analysis to five levels: (1) functional purpose, (2) abstract function, (3) generalized function, (4) physical function and, (5) physical form. Many researchers have adhered to this framework (e.g. Bisantz et al., 1994; Kuo et al., 2000; Reising & Sanderson, 2002b).

This paper discusses two intermediate representations for conceptualizing elicited knowledge and translating the knowledge into levels in the ADS (See Figure 1). The process of constructing and utilizing these representations is termed "Applied Work Domain Analysis" (AWDA). The first is the Motivation-Expectation Space (MES), where cause-effect relationships are included and coupled with means-ends relationships of the 2D Motivation-Expectation Space. The MES is an orthogonal representation of the links in the abstraction hierarchy, which we think makes it more concrete and comprehensible. The second is a Venn diagram which is used to illustrate the physical decomposition. The decomposition hierarchy is studied apart from the teleology space to capture the important links between the physical descriptors in the system. Users can update both diagrams simultaneously as they perform AWDA.

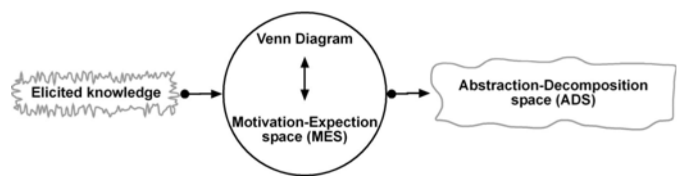

Figure 1 Applied Work Domain Analysis (AWDA) framework. AWDA uses Venn diagram and Motivation-Expectation Space (MES) to translate data from interviews, protocols, procedures, etc. onto the Work Domain Analysis' Abstraction-Decomposition Space (ADS).

Motivation-Expectation Space

Figure 2 shows the basic block for constructing the MES. A new dimension, the cause-effect link is introduced. Operators often consider the effects of a failure. These effects are not guided by any purpose and thus do not fit in a means-ends relationship. A cause-effect link represents the operator's belief of what is taking place. Beyer (1981) termed such characteristics of decision-making "cognitive orientation" and the means-ends characteristics "motivational orientation" (Ford & Hegarty, 1984).

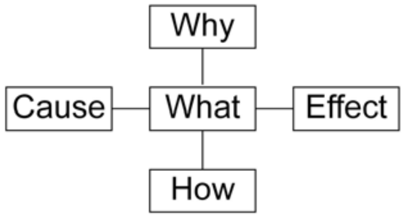

Figure 2 Motivation-Expectation space basic block. Moving left explains the cause of the an event; moving right states the effect of this event; moving up explains the rationale for having the event; and, moving down states the solution to the event.

If the operator's beliefs are established rules, the cause-effect dimension is effectively ADS's "Abstract Function" or "causal or intentional constraint" (Lin & Zhang, 2004). Cause-effect phenomena have been applied in other contexts with names such as cognitive maps, cause map, information map and belief net (Boland, Maheshwari, Te'eni, Schwartz, & Tenkasi, 1992).

In ADS, the two dimensions for classifying data are the abstraction and decomposition. Navigating vertically provides the why-what-how explanations of the system while navigating horizontally displays the spatial relationship between objects in the systems.

In the MES, the up-down navigation principal is similar to the ADS (See Figure 2). Moving up explains "what" is happening while moving down explains how it can be resolved. The left-right navigation presents the operator's view of cause-effect. Moving left will explain the cause of "what" is happening and moving right explain the effect of "what" is happening.

In our views, it is necessary to differentiate cause-effect from means-ends relation because the former is driven by expectations and the latter by purposes. By doing so, we form a joint representation of operator's motivation and the behavior of the technological system. Operator's reactions are guided by their goal for the task, as well as, the state-of-the-art they are working in.

Venn diagram

In the ADS, physical decomposition is represented with the means-ends hierarchy. In the MES, the physical descriptors are studied offline using a Venn diagram, where many different kinds of relationships and descriptors can be organized.

In the ADS, only hierarchical relationship between components is modeled – a component is a subset of a sub-system and a sub-system is a subset of a system (see Figure 3). For example, there are pumps and valves in a crude distiller. Pumps and valves are components and the crude distiller is a sub-system. A crude distiller contains many components (e.g. pumps, valves, etc) which are subsets of a sub-system. However, the simplistic model for classifying physical objects does not always work.

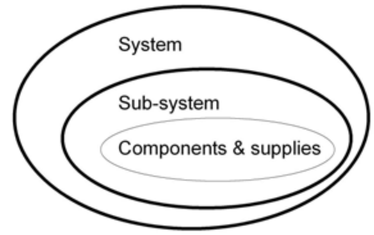

Figure 3 WDA Venn diagram of the hierarchical physical decomposition of a system.

Figure 4 shows the relationship between the objects in one case study. One example is the modeling of supplies. Bisantz et al. (1994) classified supplies under components in their ADS. However, supplies pass through the system at different decomposition levels and require different levels of troubleshooting. These details cannot be captured in the ADS.

Finally, it is necessary to establish the relationship between all descriptors for two reasons. First, it can be used to achieve independence between descriptors. Descriptors with similar meanings can be identified and discarded. Second, the descriptors can be ordered to fit the requirements of the context that is under investigation.

A CASE STUDY OF AWDA

We shall illustrate the use of AWDA using a case study of fault diagnosis performed by petrochemical operators. The data for the case study was collected from two sources: (1) interview notes elicited with the Critical Decision Method (Klein, Calderwood, & MacGregor, 1989) and (2) records of procedures. For illustrative purpose, the data was simplified. There were three steps:

1. Constructing the Venn diagram
2. Constructing the MES
3. Translating MES into the ADS

Venn diagram – gathering the descriptors

A platformer plant in an oil refinery was studied. From the transcript of the interview, descriptors of objects and action were extracted, and their relationships are represented in Figure 4.

AWDA utilized the Venn diagram to organized descriptors for MES. Object descriptors fell under three independent classifications: social, technical and measurement. The structure for social and measurement was simple for this case study. The technical descriptors were more challenging. Like with ADS, there was a hierarchy of information. In addition, supply was depicted visually as a flow through the system. Also, reactions were listed and differentiated from the components in the system.

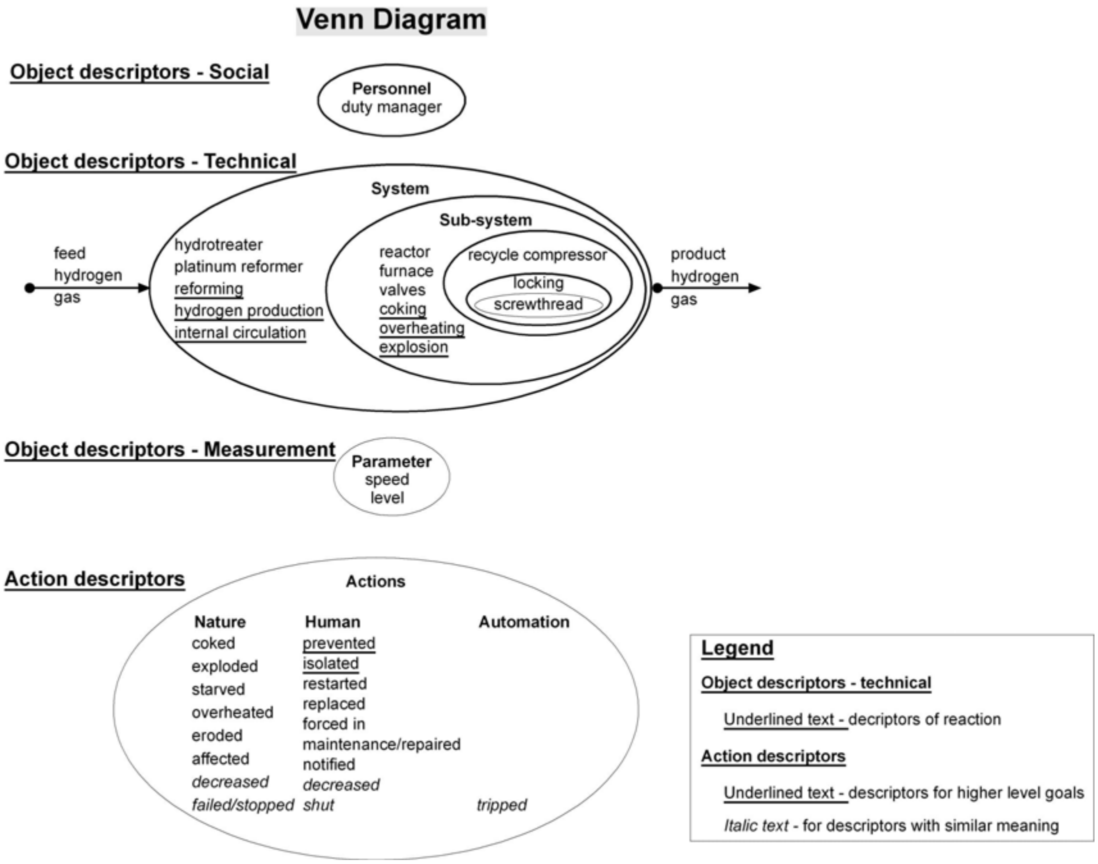

Figure 4 Venn diagram of descriptors in the MES for troubleshooting faults in a platinum reformer unit. The Venn diagram helps to structure and eliminate descriptors with similar meaning. The descriptors are ordered in four categories: Social, Technical, Measurement and Action. This list helps to standardize the order of describing a point in the MES.

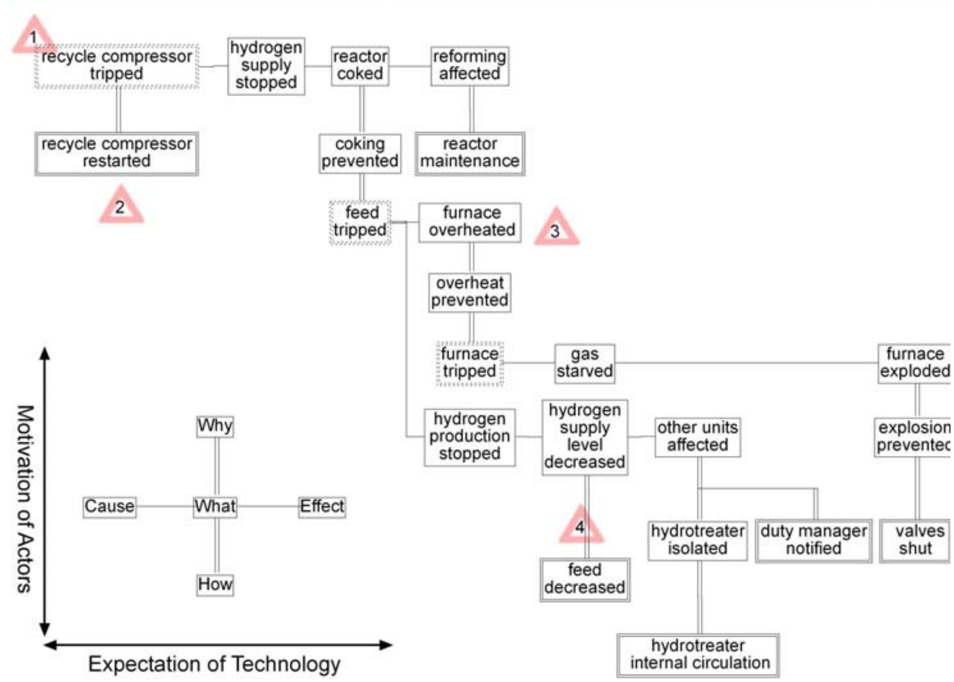

Figure 5 Motivation-Expectation Space of a case in a petrochemical plant. The horizontal dimension shows the operator's belief of the system while the vertical shows his behaviour to counter his predictions. The triangles shows the missing gaps where further knowledge needs to be recorded. The actions with the double dotted outline are actions taken by automation, while the ones with the double outline are actions taken by the operators.

In addition to objects, actions descriptors were also necessary for describing a point in the MES. Descriptors with the same meaning, e.g. maintenance and repair, were represented alongside. Redundant descriptors were removed after consideration. The descriptors were also classified by acts of nature, human and automation. Top level actions were underlined and similar actions with different actors (e.g. failed, shut, tripped) were represented in italic.

Motivation-Expectation Space

In the MES, moving left describes causal constraints while moving down describes the means for resolution (see Figure 5). One can start at the top right corner (recycle compressor trip). When the compressor trips, there will be no pressure difference to circulate the hydrogen. When the hydrogen is not circulating, chemical bonding does not take place. The reactor is saturated with the feed (hydrocarbons) and excessive coke is deposited on the reactor (coking). These links describe a natural course; they take place without an actor.

If too much coke is deposited on the reactor, the reactor will not provide the ideal condition for reforming. Major maintenance will have to be scheduled. To avoid the coking and maintenance, designers program the hydrocarbon feed to trip when the compressor trips. In the vertical dimension, we move downwards and find the actions needed to counter the predictions. Let's say that they predicted that coking will take place. To resolve the problem, they need to prevent the coking by tripping the feed.

Like with the ADS, the advantage of the MES is that the reader can start from any point and still make sense out of it. A person starting from "Feed trip" can move up the ladder and understand that the feed is tripped to prevent coking. He can also move right and understand that the effect of the trip is an overheating of the furnace and a stop of hydrogen production. An individual, who possesses knowledge of the AWDA building blocks in Figure 2, will be able to navigate and understand the MES.

The MES also allows an individual to identify gaps in the story. These are flagged with triangles in the MES. Researcher can ask the operators these questions to fill in the gaps.

1. What causes a recycle compressor trip?
2. How do operators restart the compressor? What are the steps? Do they refer to procedures?
3. What happens when a furnace overheats? Is "furnace damaged" an effect of furnace overheating?
4. What's the rationale for decreasing the feed when there is low hydrogen supply? Is it affected by hydrogenation?

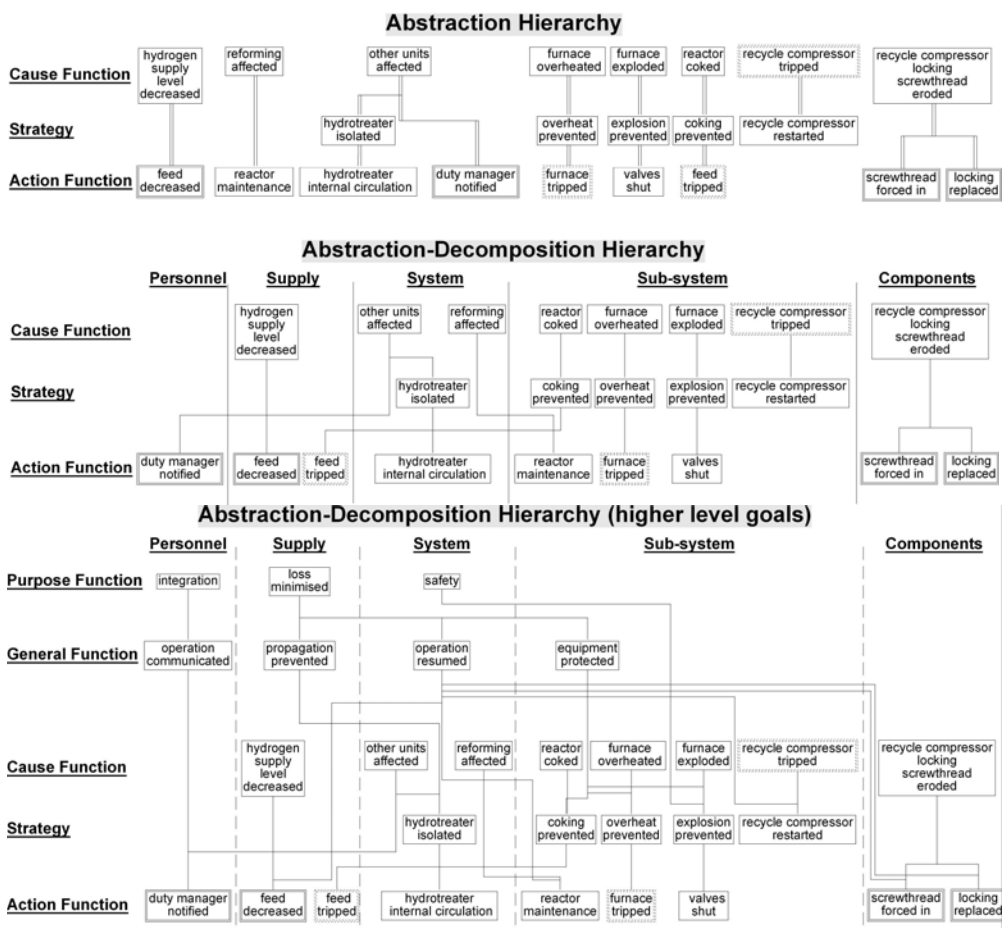

Figure 6 Top: Abstraction Space depicting the means-ends relationship. Middle: Abstraction-Decomposition Space depicting the means-ends and physical relationship. Bottom: Abstraction-Decomposition Space with higher level goals.

Mapping MES to ADS

In mapping from MES to ADS, the authors used three steps for the transformation. First, the vertical ladders in the MES were extracted and classified under three hierarchies (See Figure 6). The first row describes the cause function in the vertical chain. The second row refers to the strategies. The last row represents the action taken by the actors in the system. This is now an Abstraction Space.

Next, each point was shuffled with reference to the relationship set in the Venn diagram. Personnel and supply were placed to the left but users can refer to the Venn diagram for the actual relationship. This is an almost completed ADS.

Finally, two higher level functions were added to explain the purpose-directed behavior of the operators. At the highest level is the purpose function. In this case study, the goals of the operators when they handle an abnormal situation is the integration of the system, safety and loss minimizing. At the next level is a general function that groups and classify the strategies. This represents the completed ADS.

DISCUSSIONS

WDA is the refined representation of the AWDA. WDA provides the overview while AWDA gives the detailed information. Table 1 lists the differences between AWDA and WDA.

Table 1 Difference between WDA and AWDA

	WDA	AWDA
Users	Scientist, researchers	Human factors engineers Designers
Representation	Means-ends decomposition Physical decomposition	Venn diagram Means-ends decomposition Cause-effect
Information Structure	Hierarchy	Network with embedded Hierarchy
Boundaries	Bounded	Unbounded
	Event independent	Event dependent
Purposes	At the top as ends to the external environment	Embedded in the network

AWDA helps to structure information for formulating WDA. The ADS is a highly conceptual model. In conceptualizing a WDA there are many rules. Users need to have a strong theoretical foundation of the concepts before they can generate and apply a WDA. The proposed AWDA utilizes several of the concepts in WDA, it is however formulated so that it is easier to use.

AWDA representations retains more information than WDA-ADS. WDA categorized information and present it hierarchically. While this is good for generalizing behavior, it does not preserve the integrity of the information as good as AWDA's network of information. With the current state-of-the-art computing system, users can easily use search engine to pinpoint their interest and quickly identify the causes, effects, means and ends of a situation. With more details, it is easier for designers and engineers to utilize the data. The AWDA allows designers and engineers to get a good overview of the task.

AWDA can also be used as a knowledge elicitation tool as researcher can quickly identify gaps in the links. Expert operators often formulate short-cuts, which can be difficult to verbalize. The actions they take have become automatic and it is difficult to explain this knowledge (Rasmussen, 1983). AWDA facilitates rationalizing operator's line of thoughts. Boland et al. (1992) had used a similar representation for a software that aid distributed decision making.

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