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Verification and validation of a Work Domain Analysis with turing machine task analysis

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ABSTRACT

While the use of Work Domain Analysis as a methodological framework in cognitive engineering is increasing rapidly, verification and validation of work domain models produced by this method are becoming a significant issue. In this article, we propose the use of a method based on Turing machine formalism named "Turing Machine Task Analysis" to verify and validate work domain models. The application of this method on two work domain analyses, one of car driving which is an "intentional" domain, and the other of a ship water system which is a "causal domain" showed the possibility of highlighting improvements needed by these models. More precisely, the step by step analysis of a degraded task scenario in each work domain model pointed out unsatisfactory aspects in the first modelling, like overspecification, underspecification, omission of work domain affordances, or unsuitable inclusion of objects in the work domain model.

1. Introduction

In recent years, numerous studies in cognitive engineering have been carried out in the application of a specific method named "Work Domain Analysis" (WDA) for designing human–machine interfaces and ergonomic work systems (for recent reviews see Read et al., 2012; Jiancaro et al., 2014). WDA aims at describing the functional properties provided by a work environment to specify the constraints that a work system must cope with. The output of a WDA is an ontological structured model depicting a work domain as a set of functional properties classified according to their abstraction level and their position in a structural decomposition of the work domain. The WDA has demonstrated its benefits in many fields of application like medicine, aviation, nuclear plants, or network management (Burns and Hajdukiewicz, 2013; Flach, 1990; Rasmussen, 1999; Vicente, 1999). Some of these works are themselves directly related to the development of industrial products. Nevertheless, most work domain models produced by this method have not been validated and verified. Verification and validation should be targets for enabling WDA to become a large-scale reliable method destined to the industry.

Our goal is to propose a formal method for verification and validation of a WDA model. Verification and validation are terms that should not be confused (Sargent, 2005). Verification is a demonstration of a correct use of the modelling formalism (Rykiel, 1996, p.232). It deals with building the model *right* (Balci, 1997). For instance, the debugging of errors in computer science is a verification process. Validation is rather "a demonstration that a model within its domain of applicability possesses a satisfactory range of accuracy consistent with the intended application of the model" (Rykiel, 1996, p.232). A validated model is a model considered acceptable for a certain use. Model validation deals with building the *right* model (Balci, 1997).

The next section presents the Work Domain Analysis method. Then, we consider the methodological resources currently available to verify and validate a model produced by this method. Afterwards, the Turing Machine Task Analysis method (TMTA) is introduced. The following two sections will be devoted to its application to the validation and verification of two work domain analyses: car driving and the supervision of an on board fresh water distribution system respectively. These two domains have been chosen because they belong to different kinds of work domains elicited by the literature in cognitive engineering, i.e. intentional or causal domains (Vicente, 1999). The car driving domain can be qualified as "intentional" since the human operator's intended actions are

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central to the events occurring in the work situation. The fresh water distribution domain can be qualified as "causal" since occurring events are less dependent on the human operator and more on the functioning of the system under control. Finally, we conclude with contributions and perspectives brought by the TMTA method.

2. Work Domain Analysis (WDA)

Work domain must be distinguished from task. While the former concerns objects over which control has to be achieved, the latter refers to goals, sub-goals and operations required to perform this control. According to Rasmussen (1987), work domain properties can be considered as a set of affordances for the human operators performing a task in the domain. This concept of affordance originally proposed by Gibson (1979) allows for envisioning human work as fundamentally based on environmental properties that support and constrain the deployment of human behaviours in the process of task achievement. Designing a WDA means to depict the work domain affordances. Concretely, this depiction generally requires documents about the work domain and interviews with experts who are able to elicit the different domain properties relevant to their work. The resulting model is typically represented by a matrix describing the work domain in terms of two hierarchies: the part-whole and the abstraction hierarchies (Fig. 1). The part-whole hierarchy presented in columns described the domain as a system composed of subsystems and components. It highlights the structural complexity of the domain as units embedded in each other. The abstraction hierarchy corresponds to the rows of the matrix and describes the domain through five different levels of abstraction. From bottom to top in the matrix, the lines represent the domain respectively as concrete forms, physical functions, generalized functions or processes, abstract functions and functional purposes. "Means-ends" relationships link the affordances of one abstraction level to another. Concrete affordances are means to reach more abstract affordances. Conversely, abstract affordances specify more concrete affordances necessary to reach abstract

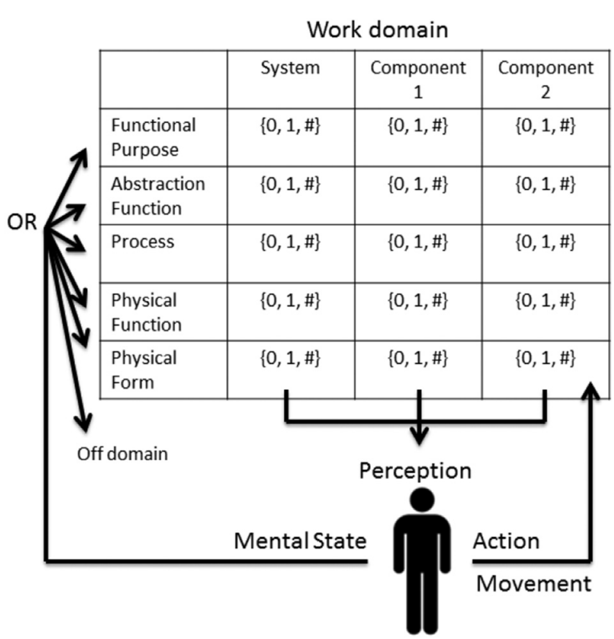

Fig. 1. Turing Machine Task Analysis. An agent operates in accordance with the affordance values (0,1,#) conveyed by the work domain.

affordances. The abstraction hierarchy highlights the functional complexity of the domain (Rasmussen, 1987; Vicente, 1999).

3. Verification and validation of a work domain model

Applied to WDA, the verification process deals with revealing whether the different properties of the work domain were properly located in the right cells of the work domain matrix according to their abstraction and part-whole levels. Verification is not a concern that has been studied yet in the literature on WDA. Somehow, verification can be processed implicitly during the design of a work domain model. The analyst, accompanied by experts, tested the internal consistency of the WDA matrix through inspection (Burns and Hajdukiewicz, 2013).

Validation of a work domain model means to assess whether the described affordances of the work area are the right ones and whether the accuracy with which they are described is also correct. To date, the only explicit method proposed for WDA validation is the mapping scenario technique proposed by Burns et al. (2001). This method relies on a mapping between a work domain model and task scenarios that have not been previously used during the Work Domain Analysis. In an illustration, the authors proposed that three human operators, who worked on the driving of a frigate, check their work domain model in accordance with an engagement scenario with an unknown contact. After being introduced to the WDA method, each expert described how the scenario referred to the work domain model step by step. At the end of each stage, discussion and comparison of proposals were guided by analysts. The experts said to be able to easily manipulate the domain model within this method. The main advantage of this method is to expose experts to the work domain model within the framework of a task scenario. Miller and Vicente (1999) used a quite similar approach to validate their domain model of a petrochemical plant. They used a degraded situation scenario, but they succeeded in completing this validation based only on the work domain knowledge held by one of the authors and without the help of an expert.

Some other works have attempted to propose some recommendations for the validation process. Naikar, Hopcroft, and Moylan (2005) advised using various kinds of experts to validate each level of abstraction contained in the model. Engineers can judge the physical aspects of the field. Operators would validate the intermediate levels of the abstraction hierarchy. Decision makers can analyse the functional purposes and the laws defining the abstract functions. However, such an approach is very cumbersome to implement. Another form of validation is the comparison of different models. This technique was explored by Burns et al. (2004), who conducted a comparison of separate but similar work domains: the redesign of a process control system on board a Canadian frigate and the design of a new class of military ship in the U.S. Navy. They reported that to really be able to make a comparison, two teams of analysts would be required to perform a work model on the very same work domain, but such a technique is also very expensive in time and effort.

The technique including all the above methods for validating a work domain model is the checking technique. Elements of the work domain models are checked by experts in reference to task scenarios, expert knowledge or other work domain analyses. In this set of methodological proposals, comparison with data coming from task scenarios can be considered as more rigorous and objective than those exclusively based on a subjective appreciation. A mapping scenario brings the work domain models together with the sequence of a real task. Nevertheless in task or incident scenario mapping, work domain elements can potentially be checked without being sufficiently specified to enable the triggering of the