BEHAVIOURAL DESIGN APPROACH FOR IMPROVING MECHANICAL PRODUCT PERFORMANCE FORM DESIGN

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ABSTRACT: *The mechanical engineering problems today become more and more complex particularly in the area of new product development. Mechanical product design is usually performed simply taking into consideration system functions and structures, while users' behaviours in terms of using the system are generally not fully considered enough early in the design phase. This paper covers the multi-trade engineering design, and deals with the development of a behavioural design approach to help designers to optimize the product performance from design phase through taking into account utilization conditions and requirements. Product performance is defined as the way that the product performs its function with minimum of stops and of lost time*

KEYWORDS: *mechanical product design; user's behaviour; behavioural design approach; UML*

1 INTRODUCTION

Mechanical product design processes are often technology-centered and fail to integrate user's behaviour in term of using the product adequately. This problem is encountered along the whole life cycle of a project, and is especially noticeable during the early design phase. These behaviours take place all over the product lifecycle. In order to improve product performance, our research carefully thinks out a piece of research linking user centered and functional engineering design approached into an integrated package, and aims to better integrate product and user behaviour during the early design phase. Designers have been obliged to set aside their dreams of a 100% machine due to the vital requirement of the user to perform some definite tasks with machines. While machine productivity and utilization conditions are the main reasons for automating production systems, human intervention on such systems remains a critical need and the tasks performed by the user remain poorly defined at the design stage.
In traditional engineering design, designers normally take into consideration product functions and structures, while users' behaviours in terms of using the system are generally not fully considered enough early in design phase. A product's behaviour is studied only from a technical point of view in order to verify its reliability and potential problems in the detailed design phase. However, this behaviour is neither characterised nor studied from a utilization point of view. Nowadays, although designers increasingly have some understanding of user behaviour, they rarely pay much attention to the behaviour which derives from the structure (how the structure will move to fulfil the function), and behaviour which is fulfilled by the user (how the user will react to the machine).
It is known that the user's perception of a system is quite different from the designer's (Battini et al., 2011). Additionally, involving a range of users in design by adopting an inclusive approach has been identified as an important way through which companies can manufacture more successful systems [Gyi et al., 2010), (Huisg and Kohn, 2009). To separate system technology from user-related features, it is necessary to split the notion of system into two separate components: technical solutions and user-related features (Houssin et al., 2010). The strategy of knowledge management is not widely adopted for innovation in industries due to a lack of an effective approach of integration between user knowledge and technical knowledge (European Communities, 2009). Most current technical approaches stop at the functional level, without analyzing how the overall system (system-user) could behave in perform these functions.
Evaluating user's behaviour at design stage is of great importance to determine ways to improve a system's performance for its future version. Most of literature works do not consider safety constraints when human intervention is required for setting-up, operating and maintaining the system. As shown in figure 1 (Houssin and Coulibaly, 2014), the product lifecycle begins from design to destruction and includes utilization period with operational and failure, accidental and maintenance states. Three types of stops are noted: stop 1 after a pre-

ventive maintenance, stop 2 after a failure and stop 3 after an accident.
The objective of this paper is to propose an approach to help the designer optimize product performance enough early in design phase, taking into account use conditions and requirements. This approach is based on a Task Model and on the fact that the behavioural system (system and end-user) must be studied and defined in design phase. We focus on a production system design, and so, to complete the mechanical system design method, we propose a global view of behavioural design approach enough early in design stage.

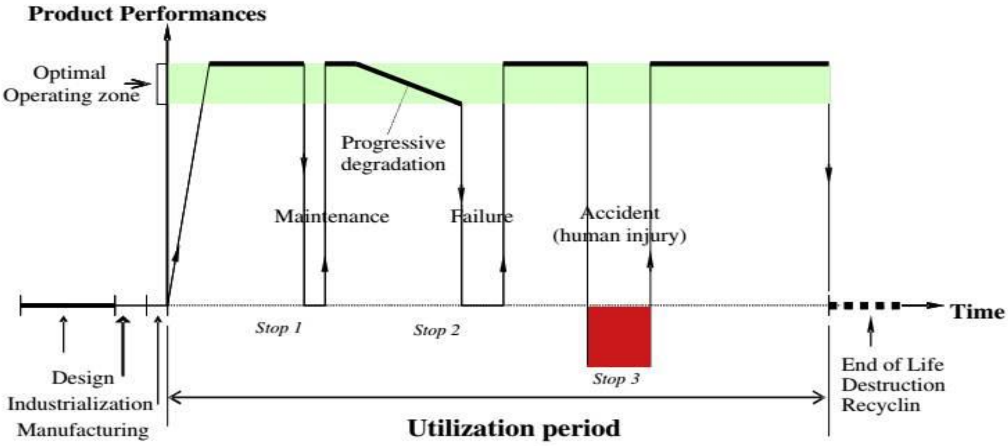

Figure 1: Product lifecycle events

2 THE BEHAVIOURAL DESIGN APPROACH (BDA)

The role of the designer has been changing with the developments in design practice. Now the role has shifted to the product development team, which has a significant role in making strategic company decisions, and is a creative force pushing innovation and raising the competitive capacity of a company (Valtonen, 2005). This new role also assigns the designer the duty of identifying user needs and of considering them while designing. Skepper et al. (2000) show that the engineers and designers had poor knowledge of both the formal design processes in use in their company and how to apply ergonomics principles.

2.1 Global View of BDA

After reviewing the relevant literature, we have concluded that the concept of behaviour has two aspects. The first involves behaviour which is carried out by the system according to its technical requirements (Gero et al 2004). The second involves behaviour which is carried out by the users of the system or the correlative working team.

We herein propose a behavioural design approach (which had been detailed in (Houssin et al., 2010) and (Sun et al., 2013) to integrate user and structure behaviour enough early in design phase. Behavioural design is an engineering design method based on multidisciplinary knowledge that takes into account, from its preliminary phases, the analysis and the specification of the utilization tasks necessary for accomplishing its function.
In order to implement a global view of the behavioural design approach at design stage, we must introduce a task model (to be operated either by the product itself or the user). We will adopt the definition proposed by Duursma (Duursma, 1995): the task is a goal to be achieved, which involves a determined change of an object's state which it is adopted also by (Hernandez 2005). In other words, behaviour is decomposed into tasks to be done by the system or the user. In the following section, we will present our task model integrated into our behavioural design approach.

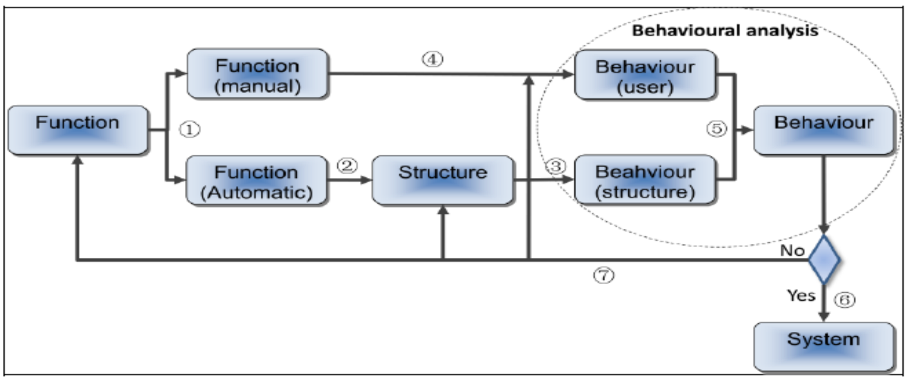

Figure 2: Global View of BDA (Houssin et al 2010)

2.2 Task Model

The task is a goal to achieve, which involves a determined change of an object's state (Hernandez 2005). In other words, the behaviour of the product presents all the tasks to be performed by this product. Moreover, we take into account those tasks to be performed by the end-user of the product to assure the performance demanded from this product. The conceptual foundations and structure of the task model is exemplified in figure 2 using the (UML) method. These tasks take into account the analysis and specification of the using conditions; that is to say, maintainability, user's safety, reliability and ways of system usage. Our approach is based on a "Task model" integrated into the Functional Analysis. During the design process phases, although system models are often primarily limited to geometrical aspects representing product-dimensioning and the associated functional surface qualities, they hardly or never take into account their behaviour and that of the future end-user and their interaction. In figure 3, we present our task model which is integrated in our behavioural design approach.

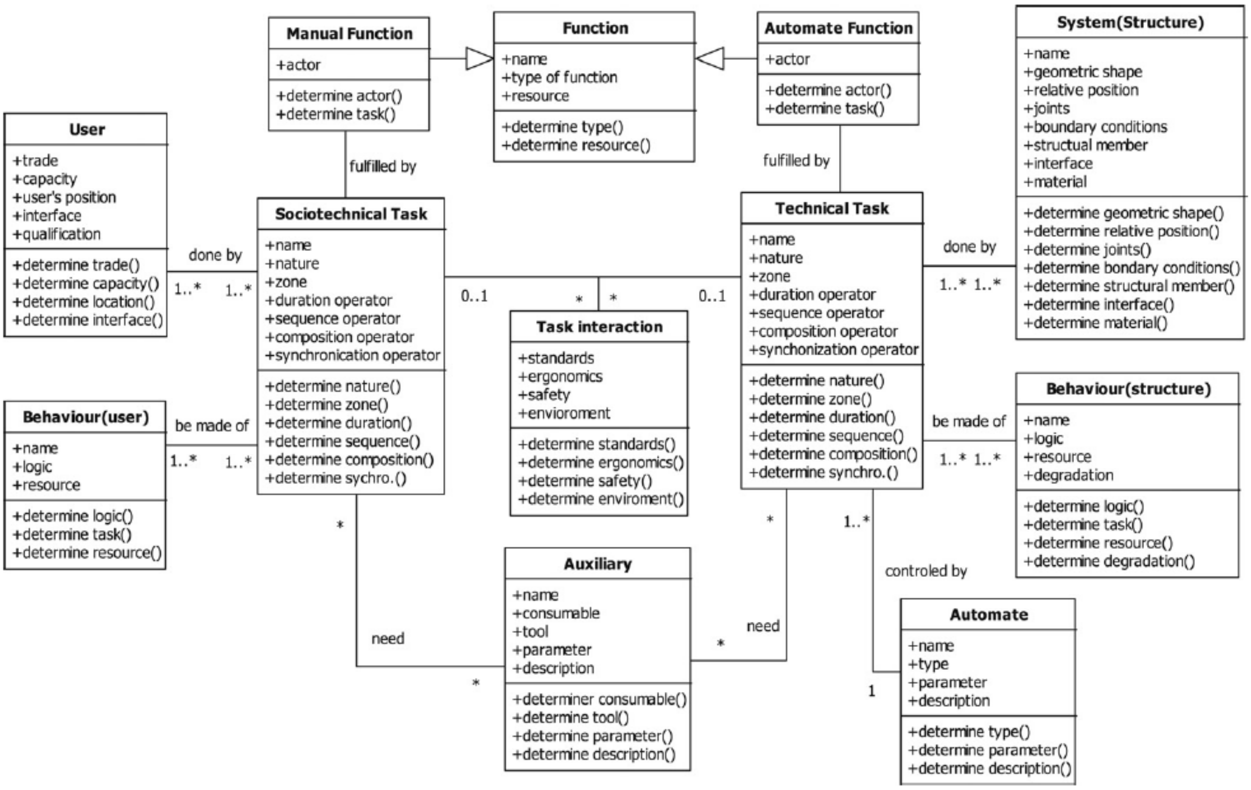

Figure 3: The global view of the Task model (Sun et al., 2013)

We thoroughly detail this concept and consider that it is composed of Technical Tasks and Socio-technical Tasks

- The Technical Tasks present all automated task required from the system. These tasks fulfill one or more system functions to be performed. It is presented and characterized in figure 4. We study what the effects of these tasks are on the product performance in use. Does it generate some dangerous phenomena, and for how long time, etc.?

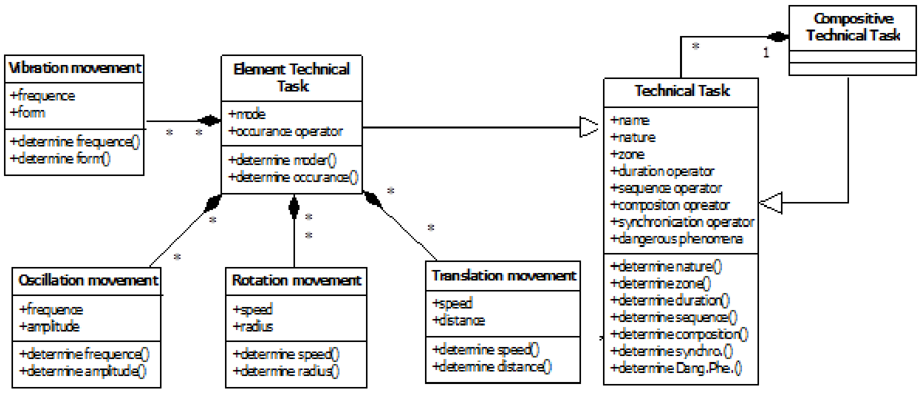

Figure 4: The "Technical Task" Concept (Houssin et al 2010)

- The Socio-technical or user Task represents the tasks requested from the user's product to fulfill the functions, which could not be automated. These socio-technical tasks could be carried out by one or more users (Work Team). Tasks could be performed in an intervention mode (manual mode, maintenance mode, setting-up mode, repairing mode, etc.). As described by Hedrick et al (Hedrick, Urbanic et al. 2004) each task could be simple or complex and characterized as in figure 5.

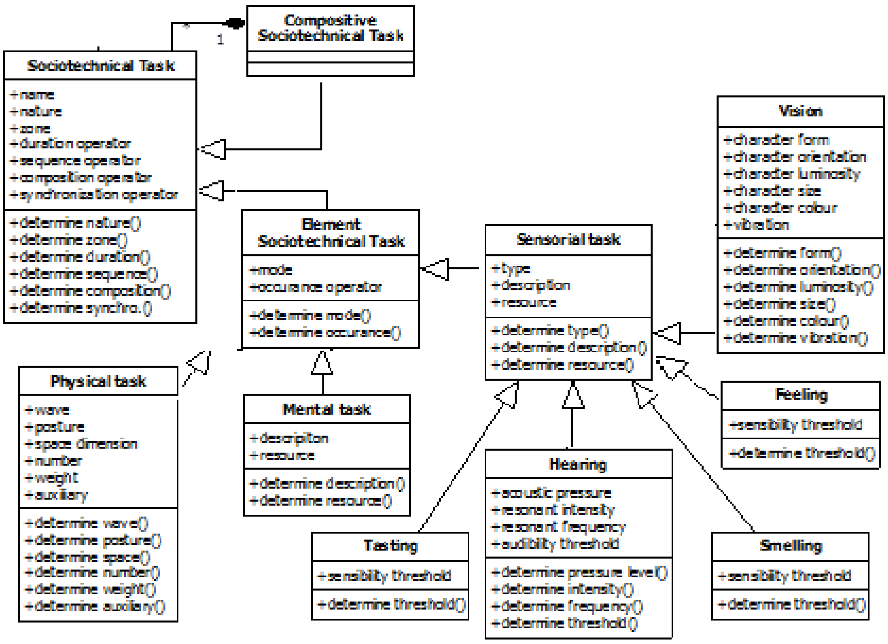

Figure 5: The "Socio-technical or user Task" Concept (Houssin et al 2010)

This model supports most of the parameters linking the environment and the use parameters. Some concepts in functional analysis are adopted here to make the better integration of the proposed behavioural design approach.

2.3 Task plans

From the perspective of safety, accessibility, usability, and ergonomics, user's behaviour is a subject to study the interactive relationship and function among user, machine and environment. It is the synthesis of the thinking, methodology and theory of user-machine engineering (Henderson and Bhatti 2001). Functional allocation and decomposition between user and machine, user machine interface, working space, and information transmission are defined as its research object. For these reasons, Task Plans framework is proposed as a useful tool to help designers to determine the task.

It is adapted from the concept developed by Houkes and Vermaas as part of their function theory (Houkes, Vermaas et al. 2002) , as shown in Figure 6.

- TP.1 designer defines the expected function which contains manual function and technical function. The Task Plans focus on manual function.
- TP.2 designer brings about his objective (manual function) he defines the ideal usage situation X.
- TP.3 designer believes that X′, satisfying the manual function, is the closest consistent and feasible approximation of X.
- TP.4 designer believes that a intended user who is following an suitable task plans P will lead to X′ using: 1) the artifact A_1 with functions f_{11}, f_{12}, …, satisfying manual function F_1; 2) the artifact A_2 with functions f_{21}, f_{22}, …, satisfying manual function F_2, etc.. The artifact here means the tools

used by the user or some sub-structure of the product to fulfill the manual function.

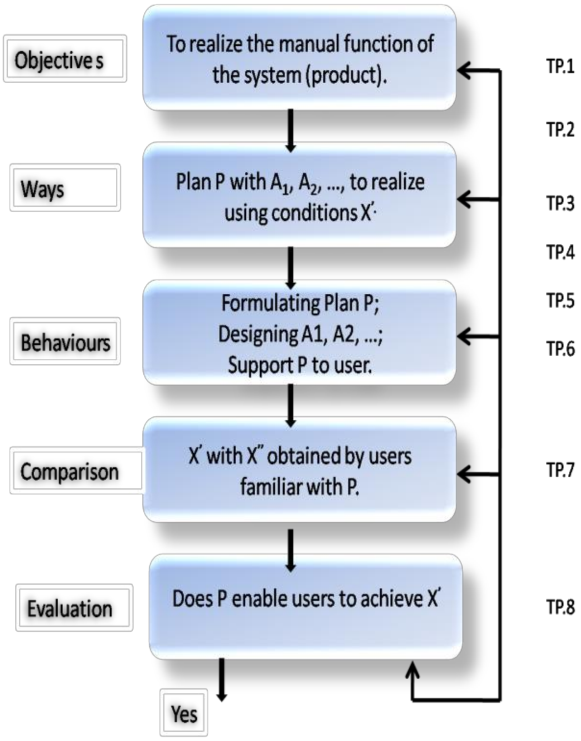

Figure 6: Task Plans (Sun et al., 2013)

- TP.5 designer constructs the use plans P to the intended users (from TP3 and TP4 by practical reasoning (Sandis al al 2009).
- TP.6 designer checks whether the resulting designs of A_1, A_2, etc. are consistent with P, and returns to TP4 or TP5 if this is not the case.
- TP.7 designer believes that X′ can or cannot be given rise to by intended users to whom P is supposed. This viewpoint is based on the assumption that some of these users go through a series of P′ and give rise to X′′, and on a comparison of X′′ with X′.
- TP.8 The designer arbitrate that his objective (manual function) to bring out X′ has been achieved or not. In the following stage, he can decide to repeat the entire design cycle, settle on another plan (return to TP.4), or repeat at least one design cycle (return to TP. 6).

In this section, we have proposed the global view of Behavioural Design Approach (BDA) integrated with the task model and task plans to realize the model mapping. At this step of our research, a combination of accurate industrial contexts allows us to define all the factors which are necessary to show and confirm the applicability of our approach. This means that a computer based system for supporting the engineering design based on the proposed approach is indispensable, and is more than a simple database. In the following section, a BDA system framework is developed in detail based on the integrated Behavioural Design Approach.

3 THE BDA SYSTEM FRAMEWORK

Developing the BDA system (Figure 7) for engineering design is a complicated assignment that includes not only the technical solutions, but also the user behaviour related to the system. It helps designers determine all the parameters of the structure task and the user task (zone, duration, sequence). These questions are classified at the task level (technical task and user task) and not simply at the function level as is the case in functional analysis. The target of the BDA system is "to help designers to analyse the interaction between user tasks and technical tasks to evaluate system performance and find potentially dangerous phenomena and zones."

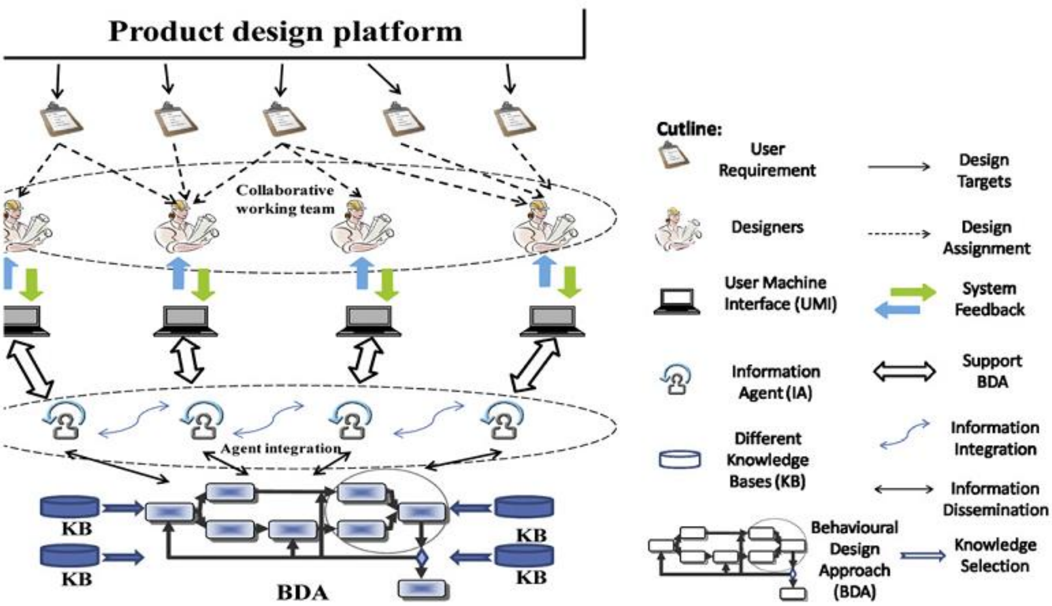

Figure 7: Framework of distributed BDA system for engineering design (Sun et al., 2013)

The distributed BDA system for aiding engineering design should contain the following major functional elements: design assignment, system feedback, knowledge selection, agent integration and information dissemination.
Compared to the conventional engineering design system, the BDA system first carefully works out a segment of research which links the user-centred and functional engineering design approaches into an integrated package. Designers can input the new user task by fulfilling various manual functions. In order to appropriately use knowledge to support the BDA system, it is critical to identify the user task context and structure task and to verify the adaptive usage of reliable knowledge. After identifying the context of diverse tasks, designers are encouraged to evaluate and comment on the values of task interaction based on the results of their interaction. In the meanwhile, task and knowledge usage is automatically recorded in the knowledge base to improve the traceability and trustworthiness of the knowledge elements belonging to the BDA system.
Because there is insufficient knowledge and capability for an individual designer to complete a whole engineering design project, it is necessary to associate various designers and experienced users in it. They are organized into a collaborative working team to reach design targets. Based on the Behavioural Design Model, the BDA system framework is designed by adopting the intelligent agent as shown in a figure 7.
On the product design platform, user requirements are analysed and assigned design targets and dispatched to a coordinated working team. The designers collaborate with each other to fulfil the dispatched design targets. Each designer uses task integration knowledge and information through a user machine interface with the support of the CAD and BDA systems. The information agent provides BDA supporting programs such as accessing, searching, compiling, task comparisons and visualizing structures derived from the CAD system. It keeps track of the designer's operations and communication with other agents in the agent integration process with respect to the agent requirements. The knowledge base accesses agent information for storing and iterating relevant knowledge.
The BDA system framework is a comprehensive and collaborative implementation of the behavioural design model, which demonstrates how a collaborative working team can be supported by the behavioural design approach for mechanical engineering design. The collaborative working team and user machine interface construct the user-centred layer where use conditions and knowledge creation are performed by the user. The information agent integration is compiled in the computer aided layer where the behavioural design approach is supported. The knowledge base stores the iterating information accessed by the agent integration.

4 SOFTWARE PROTOTYPE (BDAS)

According to the analysis of directions of the system and its development environment and tools, BDAS (Behavioural Design Approach Software) is initially developed in a straightforward way, where the client and administrator are installed at the same machine. This software assists the designer to take into account and to respect standards, safety and ergonomics legislations. From one side designer opens a *SLDASM* from the *SolidWorks* library and then use BDAS calls it. Designer matches the structure (CAD model) to a task from a data base. If there is no task match the new structure, designers input the new task with all needed attributes which is corresponding to the new structure. From other side, designer inputs manual functions which are derived from the Functional Analysis (the manual function fulfilled by the user, because of the cost or the difficulties related to automation); Information Agents receive the information and then transfer them into Function Base; BDA system make an analogy between Function Base (manual) and Social Task Base (user); the task are divided into new and existed tasks; as shown in Figure 8.

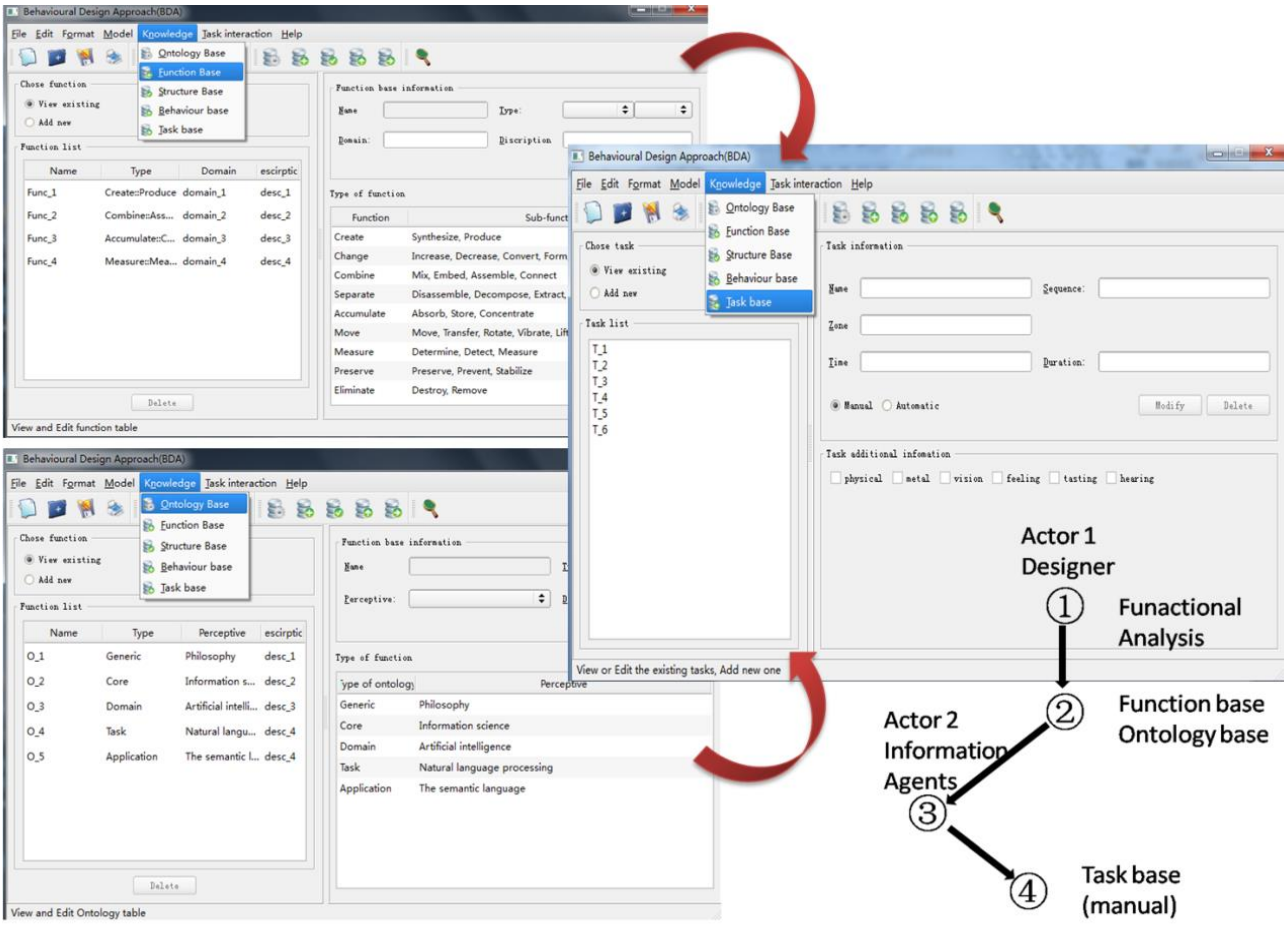

Figure 8: Analysis of manual function (user task)

If there is no task matches the new functions, designers input the new tasks with all needed attributes which are corresponding to the new functions. Designer have analysis of Structure Base (structure task) and analysis of Function Base (user task); and then the evaluation step occurs in the Task comparison step; as shown in figure 9.

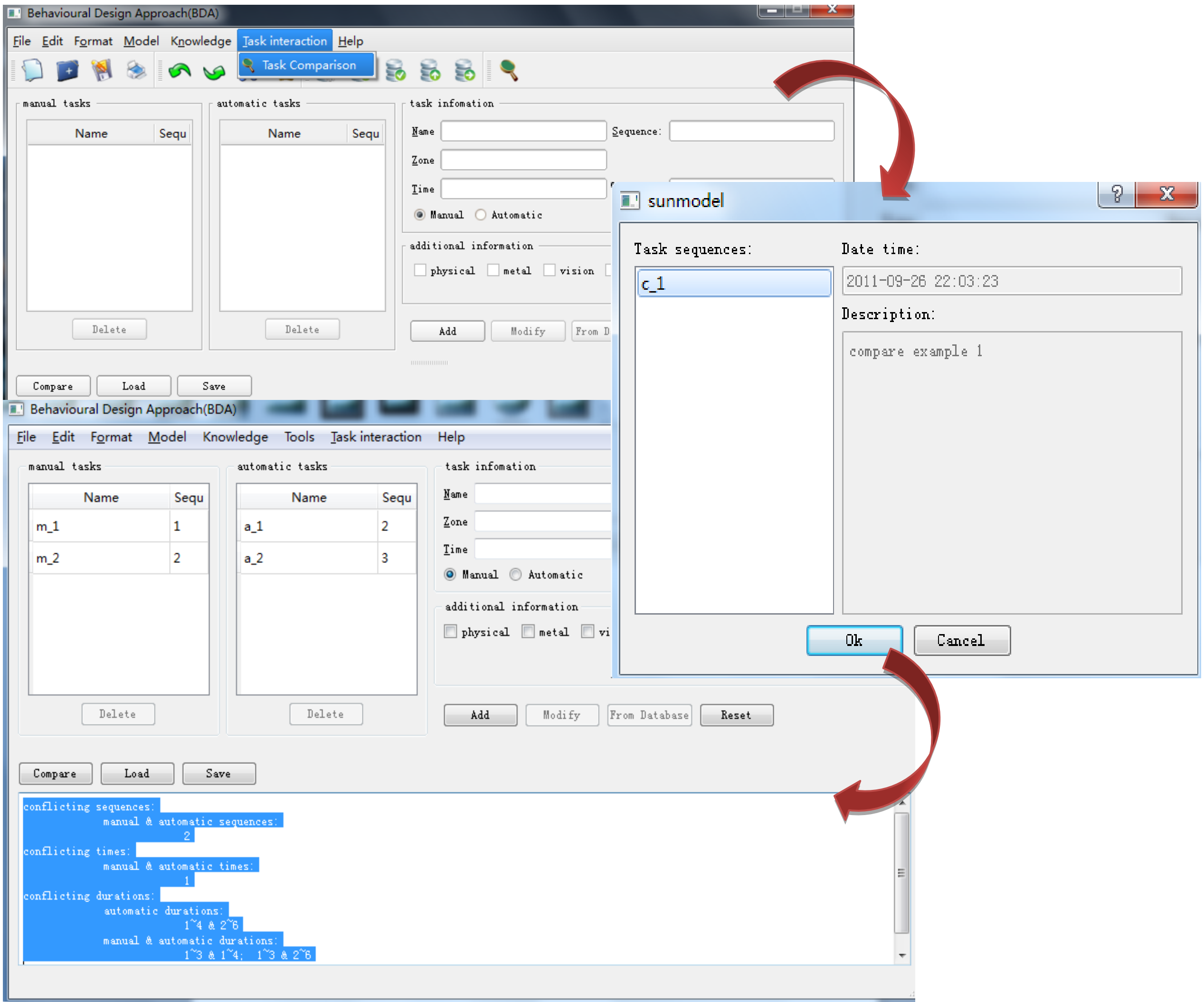

Figure 9: The evaluation of Task Comparison

If there is no problem in the interaction between user task and technical task, designer validate all and go on. If not, (for example hazard exists) the result is not acceptable, designer have to modify the solution, task, structure, etc. to cancel all causes that influence product performance (decrease the dangerous phenomenon and engendered hazard; long and difficult tasks; etc.).

5 CONCLUSIONS AND PERCEPTIVE

Both empirical and theoretical studies have shown that there is a need for design methods which focus on the user aspects of design activities. While machine productivity and use conditions are the main reasons for automating production systems, human intervention remains a critical need and the tasks performed by the user remain poorly defined at the design stage. This paper offers a suggestion for a design procedure to be used in the synthesis part of the design work. The procedure treats the artefact to be designed as a user-technical system instead of simply a technical system, making it possible to focus on the user aspects.

In this paper, we have presented the behavioural design approach which integrates the utilization tasks of products, and user behaviour from the design phase. We consider human tasks requirements as opportunities instead of as constraints. Thus, we are proposing that functional specifications be completed by behavioural ones.

The BDA system has been developed based on the model to support and allow a systematic utilization of the Behavioural Design Approach by integrating it into a designer's daily work. In the last section, a software has been proposed to exemplify the practical aspects of the Behavioural Design Approach. Although considerable endeavours have been made in this study to improve product performance during the design phase, there are still many problems demanding further research. The evaluation of the consequences of using our approach in the design process will also be further researched. Lastly, the integration of BDA with the method of Knowledge Management KM and TRIZ could be explored for the future innovation.

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