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# Using Prospective Ergonomics To Design Cooperative Digital Twin

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**Abstract.** In the context of Industry 4.0, the digital twin offers a wide range of usage and application for manufacturers. However, digital twin designers focus more on taskwork, despite teamwork, the process by which the human agent and the digital twin cooperate. In this proposal, we consider this cooperation through Human-Autonomy Teaming (HAT). To build this cooperation, it is necessary to identify needs centered on the human agent, rather than technical solutions, i.e., the means to achieve these needs. For this purpose, we propose a prospective method based on the HAT framework, enabling human agents to project themselves into the future and imagine cooperation with the digital twin. Applied to planning maintenance activity, we compared two ideation conditions: an opened-condition and a guided-condition based on the KHO-KHC model. Thanks to the pre-experience provided by the KHO-KHC model, we hypothesized that guided-condition ideation will enable the expression of needs rather than technical solutions. The results showed that the opened-condition ideation and the guided-condition ideation enabled human agents to think about their future cooperation with the digital twin. Nevertheless, the guided-condition ideation resulted in the expression of more needs than technical solutions. Conversely, the opened-condition ideation allowed the expression of more technical solutions than needs. The results are discussed in terms of methodological contribution to prospective ergonomics.

**Keywords:** Human-Autonomy Teaming, Prospective Ergonomics, Digital Twin

## 1 Human-Autonomy Teaming to characterize Cooperation between Digital Twin and Human Agent

In the context of digital transformation, the digital twin offers a wide range of digital services. As a result, a vast field of possibilities is emerging for manufacturers in terms of usage (Julien & Martin, 2021). Current definitions of digital twin vary around a shared concept: a link between a physical counterpart and a virtual entity that represents it. (Silva et al., 2021). Most research considers the digital twin as a virtual representation of the human agent, allowing activity supervision for the prevention of workplace accidents or MDSs (Greco et al., 2020). This perspective must be expanded to consider

a cooperative approach. In this way, the digital twin must be able to cooperate with the human agent for more efficiency in achieving their common goals (Pacaux-Lemoine et al., 2022). Human-Autonomy Teaming (HAT) provides a framework to think about this cooperation.

HAT can be defined as a socio-technical system in which at least one human and one autonomous agent interact interdependently over time to accomplish a common task or goal (Cooke et al, 2020). In order to characterize the cooperation between the two agents, Pacaux-Lemoine et al. (2022) identifies the "Know-how-to-Operate (KHO)" and the "Know-how-to-cooperate (KHC)". KHO refers to each cooperating agent's knowledge to solve a problem inherent to the activity, i.e., the taskwork. Through teamwork, KHC refers to knowing how to cooperate with its partner. These two attributes are necessary for each agent to cooperate efficiently (Table 1).

|                                                                                                                                                  |
|--------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>KNOW-HOW-TO-OPERATE (KHO): Specific knowledge to each cooperating agent</b>                                                                   |
| <b>Internal:</b> skills of each cooperating agent (i.e., expertise, experience)                                                                  |
| <b>External:</b> obtain information from the environment and acting of the process                                                               |
| <b>KNOW-HOW-TO-COOPERATE (KHC): Know how to cooperate with your partner</b>                                                                      |
| <b>Internal:</b> build a model and deduce your partner's intentions, analyze tasks, and identify cooperative organization, produce a common plan |
| <b>External:</b> understand and provide information to your partner                                                                              |

**Table 1.** KHO-KHC model

Envisioning the cooperation with the digital twin can prove complicated. Given the wide range of possible uses and definitions (Julien & Martin, 2021), the human agent may have difficulty imagining an artefact that doesn't exist, and therefore the needs that may be associated with it (Colin & Martin, 2019). Prospective ergonomics could provide a framework to envision this cooperation.

## 2 Prospective ergonomics to think the HAT

Prospective ergonomics completes the intervention modalities of corrective and design ergonomics, by aiming to anticipate future needs (Robert & Brangier, 2012). The applications of prospective ergonomics are varied: new uses for carpooling (Allinc et al., 2019), needs related to hydrogen as an energy source for housing (Martin et al., 2021) or new experiences in tourism (Brangier et al., 2019). These studies have in common the desire to encourage the ideation process, enabling the expression of future needs rather than technical solutions. Indeed, to grasp what is really essential for the deployment of a technology, the focus should be on the expression of needs, i.e., centered on human agent rather than technical solutions (Pilemalm et al. 2007; Loup-Escande et al., 2014). Furthermore, studies on the digital twin emphasize the need to integrate technical solutions at the latest stage in the deployment process (Hamzaoui & Julien, 2022).

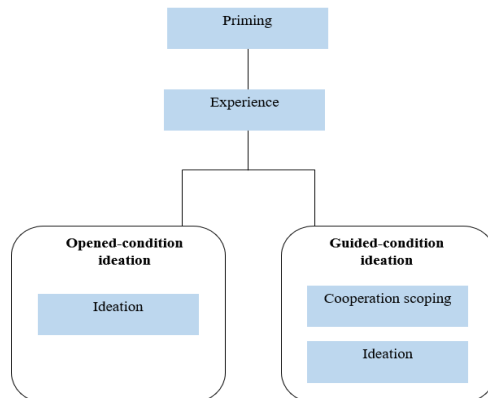
To express future needs, different methods have been used in prospective ergonomics, such as creativity sessions or ideation interviews (Martin et al., 2021). Considering cooperation topic, Barré et al. (2018) explored the improvement of ideation with a multidisciplinary design team considering their thinking styles. However, prospective ergonomics did not investigate cooperation between a human agent and an autonomous

agent such as the digital twin. Moreover, the theoretical framework of the HAT was not considered to support a prospective approach allowing reflection about future cooperation.

The aim of this paper is to develop a prospective method based on the KHO-KHC model, enabling human agents to envision their future cooperation with the digital twin. We hypothesize that a guided-condition ideation with the KHO-KHC model will enable human agents to pre-experience cooperation with the digital twin, encouraging the expression of needs rather than technical solutions.

### 3 Methodology

This proposal was conducted with SPIE Industrie, an integrator of solutions for the design and the maintenance of industrial installations. Therefore, our methodology was applied to the maintenance planning activity of an SPIE Industrie client, a major French railway company. Two methods were compared (Fig.1). Considering the scope of the industrial project, the sample of planning experts has been limited to future digital twin users.



**Fig. 1.** Methodology for expressing needs (3 phases for opened-condition ideation and 4 phases for guided-condition ideation).

#### 3.1 Study 1: Opened-condition Ideation

Nine planning supervisors have been recruited for this study. The first study mobilized an opened-condition ideation through a semi-directive interview, gradually projecting the participants into the future (Martin et al., 2021). The study consisted of a *priming phase* which introduced the planning context. Then, an *experience phase*, in which participants expressed negative and positive experiences regarding their maintenance planning activity. The *opened-ideation phase* consisted of the transformation and the preservation of these experiences as future ideas related to cooperation with the digital twin.

### 3.2 Study 2: Guided-condition Ideation

Five new planning supervisors have been recruited for this study. The second study also mobilized a semi-directive interview but thought a guided-condition ideation. The *priming* and *experience phases* were the same. These were followed by a *cooperation scoping*, i.e., a presentation of the KHO-KHC model. The aim was to present how cooperation with a digital twin might unfold in the future. For the *guided-ideation phase*, KHO questions were related to the digital twin's ability to gather information, analyze problems, make decisions and implement them. KHC questions were related to the digital twin's ability to understand the skills and intentions of the human agent, and to communicate information to him. Table 2 shows examples of KHO-KHC explanations during the cooperation scoping.

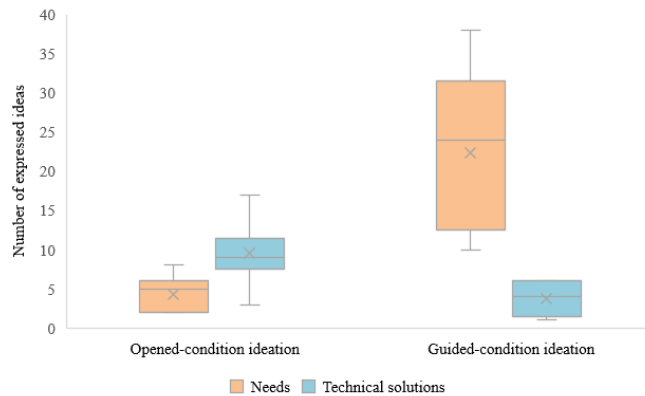
| KHO (internal and external)                                                                                                                    | KHC (internal)                                                                                                                                                                                                                  |
|------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| -The digital twin and you both have the skills and knowledge to gather information, analyze problems, make decisions and act on the situation. | -You have knowledge of the technology's skills, "I know the technology can do that".<br>-On the other hand, the digital twin can take your skills into account to adapt its help: "the digital twin knows that I'm capable of". |

**Table 2.** Examples of KHO-KHC explanations during the cooperation scoping.

## 4 Results

In the first study, 125 ideas were expressed. The opened-condition ideation was related to 86 technical solutions (Mean=9.56, Standard Deviation=3.81) and 39 needs (Mean=4.33, Standard Deviation=2.18). The left panel of figure 2 shows the variation in the ideas expressed among the nine interviews conducted.

In the second study, 131 ideas were expressed. The guided-condition ideation was related to 112 needs (Mean=22.40, Standard Deviation=10.74) and 19 technical solutions (Mean=3.80, Standard Deviation=2.28). The right panel of figure 2 shows the variation in the ideas expressed among the five interviews conducted.



**Fig. 2.** Number and type of ideas expressed according to the ideation condition.

To compare the differences related to idea type between opened-condition ideation and guided-condition operation, a Mann-Whitney U test was conducted. This test was chosen because the data did not meet the assumptions of normality required for a t-test. The results indicated that there was a significant difference between the opened-condition ideation and the guided-condition ideation regarding the needs expressed ( $U = 0$ ,  $p = 0.003$ ), and the technical solutions expressed ( $U = 43$ ,  $p = 0.011$ ).

This suggests that the guided-condition ideation had a significant effect on the expression of ideas related to needs. Considering KHO-KHC dimensions, table 3 shows the examples of verbatims expressed by the participants.

| Digital twin's KHO                                                                                    | Digital twin's KHC                                                                                                         |
|-------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------|
| - "The digital twin obtains information on the equipment's state."                                    | - "The digital twin should know my technical background: my degrees, my maintenance skills (i.e., mechanical, hydraulic)." |
| - "The digital twin analyzes maintenance interventions to adjust the maintenance plan."               | - "The digital twin knows my daily, monthly and annual priorities."                                                        |
| - "The digital twin proposes new maintenance task lists according to the equipment's physical state." | - "The digital twin considers my preferences when proposing solutions by asking questions."                                |

**Table 3.** Examples of verbatims expressed by the participants related to KHO-KHC dimensions.

## 5 Discussion

The methodology enabled participants to think about their future cooperation with the digital twin. Although the number of ideas expressed between open-condition and guided-condition ideation was fairly equivalent, we observed a statistical difference in the type of ideas expressed. The opened-condition ideation provided more technical solutions than needs. In contrast, the guided-condition ideation provided more needs than technical solutions. The results of the opened-condition ideation can be explained by a lack of framework simulating future activity with the digital twin (Anastrassova et al., 2007). The framework provided by the KHO-KHC model in the guided-condition ideation addressed this lack by proposing a context for thinking about future cooperation, and thus enabling participants to pre-experience cooperation with digital twin. The results can also be explained by the techno-focused profile of participants. Due to different thinking styles, Barre et al. (2018) show that the effectiveness of a method could be related to the participants' specialty (e.g., engineers or ergonomist).

The HAT theoretical framework appears to be a promising approach for thinking about future cooperation. Nevertheless, due to the scope of the industrial project, this methodology was applied to the planning maintenance activity with a limited sample. Consequently, we cannot conclude on the generalizability of the results. In order to validate our proposal as a prospective method, it would be valuable to replicate this study with more participants and varied profiles such as industrial designers or ergonomists (Barre et al., 2018). It would also be valuable to replicate this study in other fields investigated by HAT, such as healthcare or transport systems.

## 6 Conclusion

We aimed to propose a method allowing human agents to envision their future cooperation with the digital twin. The first method was based on an opened-condition ideation, giving greater expression to technical solutions. Based on the KHO-KHC model, the second method enabled the expression of needs, related to the human agent and its cooperation with the digital twin. Such a method will enable manufacturers to design a digital twin adapted to future needs. To deploy an effective HAT, future research may focus on digital twin's transparency.

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