
Designing Human-Automation Collaboration for Predictive Maintenance

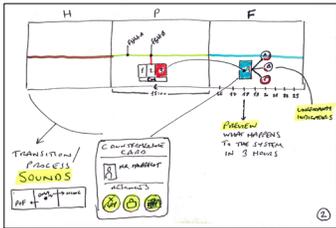


Figure 1: Early sketch of a design concept generated during a co-design session. The focus was on going back and forth between different time frames to preview the consequences of AI predictions.

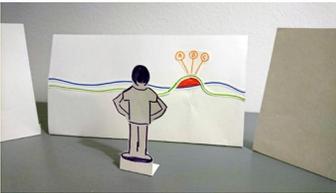


Figure 2: Image from an early sketch of the interface concept prepared with paper models that depicts the multiscreen interaction.



Figure 3: Snapshot from the implementation process of the design concept.

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DIS '20 Companion, July 6–10, 2020, Eindhoven, Netherlands
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ACM ISBN 978-1-4503-7987-8/20/07.
<https://doi.org/10.1145/3393914.3395863>

Abstract

Concerning the maintenance and upkeep of autonomous warehouses, contemporary developments in industrial digitalization and machine learning are currently fueling a shift from preventive maintenance to predictive maintenance (PdM). We report an ongoing co-design project that explores human-automation collaboration in this direction through a future scenario of baggage handling in an airport where human operators oversee and interact with AI-based predictions. The cornerstones of our design concept are the visualizations of current and predicted system performance and the ability for operators to preview consequences of future actions in relation to performance prediction.

Author Keywords

Autonomous warehouses; artificial intelligence; human-in-the-loop; co-design; data visualization; uncertainty.

CSS Concepts

• **Human-centered computing~Interaction design**

Introduction

Autonomous warehouses governed by artificial intelligence (AI) is a vision of the future of logistics that



Figure 4: Co-design sessions enabled collective exploration based on diverse areas of expertise. During roleplaying we used existing objects as props and improvised future situations.



Figure 5: The team members played different roles including those of non-human actors. This activity involved exploring multiple variations and generating new ideas.

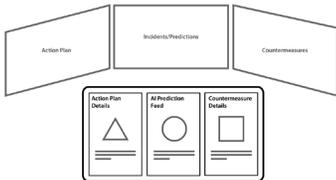


Figure 6: Design concept. Each screen can be manipulated via tablet. Suggested actions become activated when dragged to the *Action Plan* frame on the left.

currently attracts much attention, envisioning an AI that is capable of orchestrating the operations of a warehouse where multiple automated guided vehicles work on receiving, storing and delivering items. Concerning the maintenance and upkeep of such a complex technical installation, contemporary developments in industrial digitalization and machine learning are currently fueling a shift from preventive maintenance to **predictive maintenance (PdM)** [13, 14]. What this means is that traditional practices of scheduling inspection and maintenance based on time and usage templates are being supplanted with automated real-time monitoring and analysis of historical data to predict maintenance needs, promising to deliver better uptimes and longer component lives. It is clear that the current capabilities of AI technology already enable significant degrees of automation of operation and maintenance in the visionary context of an automated warehouse. It is equally clear that for reasons to do with reliability, accountability and big-picture judgment abilities, humans will need to be monitoring and intervening in operation as well as maintenance [1, 4, 7, 15, 19]. For the foreseeable future, we expect **human-automation collaboration (HAC)** to be the most fruitful design approach to the automated warehouse vision.

We report an ongoing project where design researchers in HAC work together with a company specializing in warehouse logistics solutions to explore these issues. The company is Toyota Material Handling in Mjölby, Sweden, coming from a long tradition of developing forklifts and other logistics equipment and currently exploring visions of autonomous warehouses. Our joint brief was to explore a future scenario of baggage handling in an airport, where automated guided

vehicles work in concert with human airport staff, security and customs officers, and other baggage handling technologies. One starting assumption was the existence of a control room with human operators planning and overseeing the operations of the integrated baggage handling system; another assumption was the existence of an AI module drawing on real-time and historical data to analyze the status of the various system components and predict maintenance needs.

The provisional knowledge contributions of our work so far are twofold: we present a design concept addressing some challenges in industrial HAC that we expect to be applicable in many similar design situations, and we report how this concept was attained using a co-design process based on co-production principles.

Explorative Design Process

The collaboration between academic researchers and corporate R&D was set up as a **co-production** project, which generally implies three characteristics [8]. First, the partners commit to a common concrete goal — here, the design of an automated warehouse control room concept. Second, the recognition of partners' different agendas — the researchers aim to create and disseminate new knowledge, whereas the company is ultimately interested in future business opportunities. And finally, the notion of open IP — companies bringing existing IP to the table can protect it using NDAs and the like, but all new IP created in the course of the collaboration is free for partners to use as they see fit. Our mutual commitment to a co-production approach formed the basis for planning and executing a co-design process [11, 12] consisting of seven full-day sessions in as many weeks, with homework

Using Co-design for Exploring HAC

The topic of designing for HAC is attracting much recent attention and there is an emerging literature, much of which based on conventional data collection followed by analysis leading to a proposed design [2, 17]. Our work is an example of co-design, placing participants in the roles of actors rather than objects of study or providers of data. This is an age-old distinction in HCI and the differences between the two main approaches are generally well understood [5, 11].

What sets HAC apart from general HCI is the degree of agency and autonomy assigned to the non-human actors. We found that a co-design approach of bodystorming human as well as non-human roles enabled rapid exploration of a large space of possibilities for the behaviors and capabilities of "the AI." However, we acknowledge the need for co-design participants to have solid knowledge of AI/ML as a design material [6, 18] in order to avoid unproductive blue-sky speculation on what "the AI" could do.

between sessions including doing secondary research and validating the interim results with relevant colleagues. The co-design team was staffed with one product manager, three data scientists and one UX designer from Toyota, and led by one of the present authors who is a designer-researcher in interaction design.

The aim of the first session was to identify specific, actionable **challenges** in the general area of people and AI running an autonomous warehouse together. In the second session, we sketched a basic **scenario** based on an automated baggage handling system and then improvised roleplay [3] along the lines of the scenario to explore future situations and use cases (Figure 4). The session also included a remote interview with a process improvement engineer from an external company working in the domain of airport baggage handling, to learn more about the existing work practices and challenges. The third session comprised ideation through a quick cycle of divergence, synthesis and convergence, leading to five distinct **design concepts** (Figure 1). They were assessed in the fourth session with the help of a service and logistics consultant from the external company, leading to a decision to focus on two concepts for further development: first, to enable what-if preview of maintenance actions suggested by the AI, and second, to display current system performance along with ways to steer towards desired performance. To conclude the fourth session, we created a concrete scenario around the need for operators and AI to jointly plan and prepare the baggage handling system for momentary higher-than-normal performance. After the session, the co-design team leader developed the scenario into a complete **story** and two **storyboard sketches**.

The fifth session was devoted to bodystorming around the story (Figure 5), yielding a design concept that combined what-if exploration with the aggregated visualization of current and desired performance. The whole bodystorming activity [10] was captured in photographs, and the session ended by selecting photos and composing them into a photo storyboard [16] conveying the unified design concept. After the session, the team leader sketched an **interface design** (Figure 2, Figure 6) with interaction components and techniques inspired by the photo storyboard. In the sixth session, the interface design was assessed in a session with a higher-up Toyota representative as well as the service and logistics consultant who previously participated in the design process. The feedback was used in the seventh and final session to refine the interface design and the story. These concluding results from the co-design process were used as specifications for developing an **interactive demonstrator** [9] implementing the design concept (Figure 3) as described in the following section.

Design Concept

Lucas enters the control room at 6am. He picks up the tablet and fires up the baggage handling system on the three screens in front of him (Figure 7); everything looks normal. After a while, a prediction appears on the central screen indicating that there might be late passengers a few hours from now. The AI indicates that this event may delay three flights (F1, F2, F3) scheduled around that time. Lucas sees that the required performance is predicted to be higher than the available performance in the indicated time slot.

In order to see the range of actions the AI suggests to prevent the delays, he looks at the right screen where there are four actions to choose from (Figure 7). He

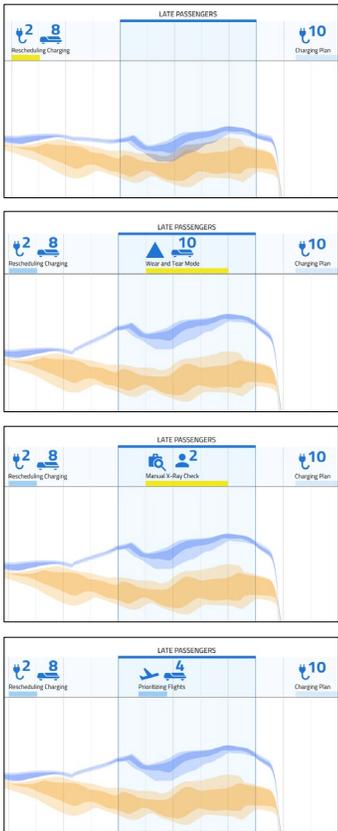


Figure 8a-8d: Lucas previews the suggested actions on the central screen. *Rescheduling charging* (a), *wear and tear mode* (b), *manual x-ray check* (c), and *prioritizing flights* (d).

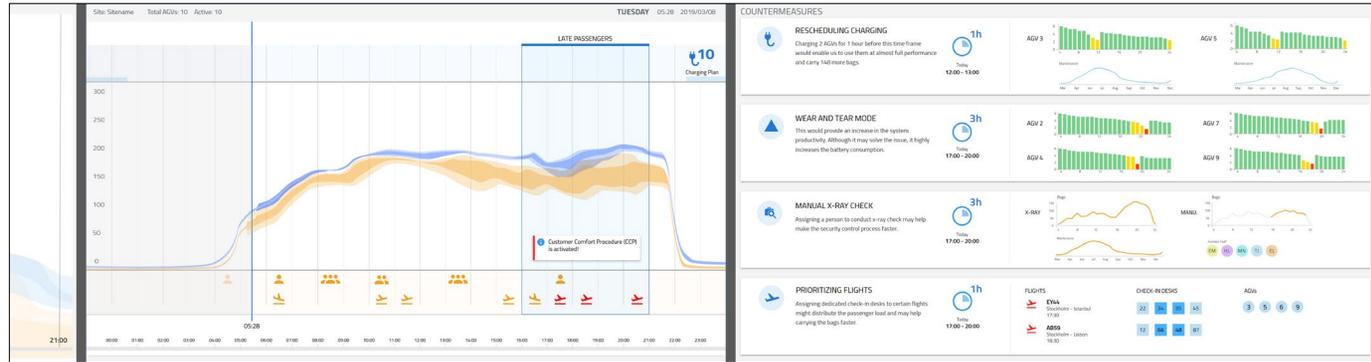


Figure 7: The central screen — *Incidents/Predictions* — displays a graph with two lines: the blue one represents the predicted available capacity and the orange one represents the predicted required capacity. The right screen — *Countermeasures* — displays possible actions that AI suggests regarding the incident in focus on the central screen. The left screen — *Action Plan* — displays the action taken that refers to the incident in focus (not fully shown in the figure). The tablet's screen is divided into three frames and each frame corresponds to the respective screens.

starts browsing the actions by tapping the first one and previews its consequences on the central screen (Figure 8a). The preview state does not prevent him from maintaining situational awareness as he can quickly go back to the present state by tapping the action again. He decides to activate this *rescheduling charging* action directly because it is a mechanical task that the AI is good at configuring. He does so on the tablet by dragging the suggestion to the *Action Plan* (Figure 6). Now the performance graph he saw earlier as a preview is updated.

He moves on to preview the next AI suggestion: *wear and tear mode* which demands too much resource for the moment (Figure 8b). Then he taps on the third one: *manual x-ray check* that is not preferable because it implies ordering the airport staff to do extra work (Figure 8c). The last action suggested by AI, *prioritizing*

flights, seems to raise the available performance to an acceptable level (Figure 8d). After some reconfiguration, he drags the suggestion to the *Action Plan* where it gets activated (also showing on the central screen). Thus, Lucas managed to raise the available performance to the necessary level and prevent the delays.

Concluding Remarks

The cornerstones of the design concept are the visualizations of **current and predicted system performance** (including the uncertainty of AI-based predictions) and the ability for operators to **preview consequences of future actions** in relation to performance prediction. We feel that this represents a fruitful approach to HAC in PdM, and we are looking forward to carrying out more extensive formative user testing and then refine the design concept accordingly.

ACKNOWLEDGEMENTS

We thank the co-design team members Boris Ahnberg, Emilia Johansson, Elisa Määttänen, Filip Nilsson, Gustav Sternelöv for their participation and generosity. We thank our research engineer Erik Olsson for his hardwork in implementing the demonstrator and Jonas Unger and Per Larsson for their technical supervision. This Visual Sweden project is funded by VINNOVA (grant number 2015-07051).

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