MPDesign: A Tool for Managing Task Requirements and Process Agent Characteristics in Manufacturing Process Design

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Abstract

MPDesign is a tool that supports the design of manufacturing processes as part of a Manufacturing Process Management System (MPMS). The tool helps collecting information on task requirements in terms of abilities and authorizations needed to perform these tasks, as well as the expected inputs and produced outputs of tasks. This information is cross-checked with information on the available human and robotic agents, which are potential actors for the tasks. The outcomes of the analysis can be exported and easily used in executable MPMS process models. They also provide immediate insights into the availability of the right resources and quality aspects of manufacturing processes. This allows factory managers to assign workers to tasks fitting their qualifications, allocate robotic agents to tasks which may be harmful to humans, and adequately plan upskilling of the personnel. At the same time, the tool verifies the integrity of the modelled process by analyzing the completeness of inputs and outputs and their proper flow.

Keywords

Task specification, actor specification, capability matching, manufacturing process, data-flow anomalies

1. Introduction

The work described in this paper is part of the EU-funded SHOP4CF project[2]. The SHOP4CF project aims to set up a new era of human-centered, digitalized shopfloor design and implementation to impact the industrial Europe of tomorrow. The project focuses on the development of a platform[3] with an open architecture that can support humans in production activities and provide basic implementation as a free, open-source solution. One of the key concepts in the SHOP4CF project is manufacturing process management (MPM), an extension of BPM concepts and technologies for the high-tech manufacturing domain. As part of these developments, the Manufacturing Process Management System (MPMS) has been offered. This system integrates business process management and manufacturing operations control. Moreover, MPMS orchestrates the manufacturing process across work cells[4] or production lines in a factory and operates based on executable business process models defined in BPMN. As such, MPMS requires information on task requirements, agent capabilities as well as information and material flow on the shop floor. [1]

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[2] https://shop4cf.eu/
[3] https://shop4cf.eu/marketplace/
[4] "A work cell is a method for arranging an organization's resources and processes in a manner that improves the quality and speed of a targeted output." Machine That Changed the World, James P. Womack, Daniel T. Jones, Daniel Roos, HarperBusiness, 1991

MPDesign has been developed to support MPMS with the orchestration of activities, by collecting, in a structured way, the relevant information on tasks and agents in a manufacturing process and using this information, on the one hand, to optimize the operational process design and, on the other hand to provide insights into the long-term strategy of the involved company with respect to human and machine resources. By using a conceptual, research-based data structure clearly defining and separating capabilities, official authorizations and skills, MPDesign extends the capabilities of the existing BPMS such as Camunda or Bizagi Studio.

The user of MPDesign provides information regarding tasks: the required abilities and authorizations of agents for a task as well as the inputs and outputs of a task. Similarly, information about the abilities and authorizations of both human and robotic agents is provided. It is also worth noting that the tool can be used at different levels of process aggregation: from processes in an individual work cell, through those of a production line, up to the end-to-end process of a whole factory.

MPDesign has been developed as an answer to the needs of manufacturing companies interested in an optimal allocation of both human and robotic assets as well as in creating safe, healthy and satisfying conditions for the workers. In standard BPMS, the matching is very basic and based only on organizational information such as position, role or department. MPMS extends this technique by matching tasks with appropriate, available agents during process execution based on specific task requirements and agent abilities [2]. This is also in line with the concepts presented in [3] [4] [5]. However, the procedure of providing the necessary data is quite cumbersome. Moreover, such runtime matching does not provide any additional insights into the strategic situation of the company. MPDesign facilitates collection of the required information, which can be easily exported and integrated into an MPMS executable process model. Even more important, it provides immediate insights into the current situation of the company in terms of completeness of resources. Insights on which agents can perform which tasks are provided in a well-structured way. This allows identification of bottlenecks, like tasks that can be performed by only few agents, operators that are capable of performing only few tasks and may need upskilling, and operators that can perform a wide range of tasks, making them especially valuable. Finally, the completeness of the task inputs and outputs is analyzed, ensuring the integrity of the process model.

2. Technical aspects

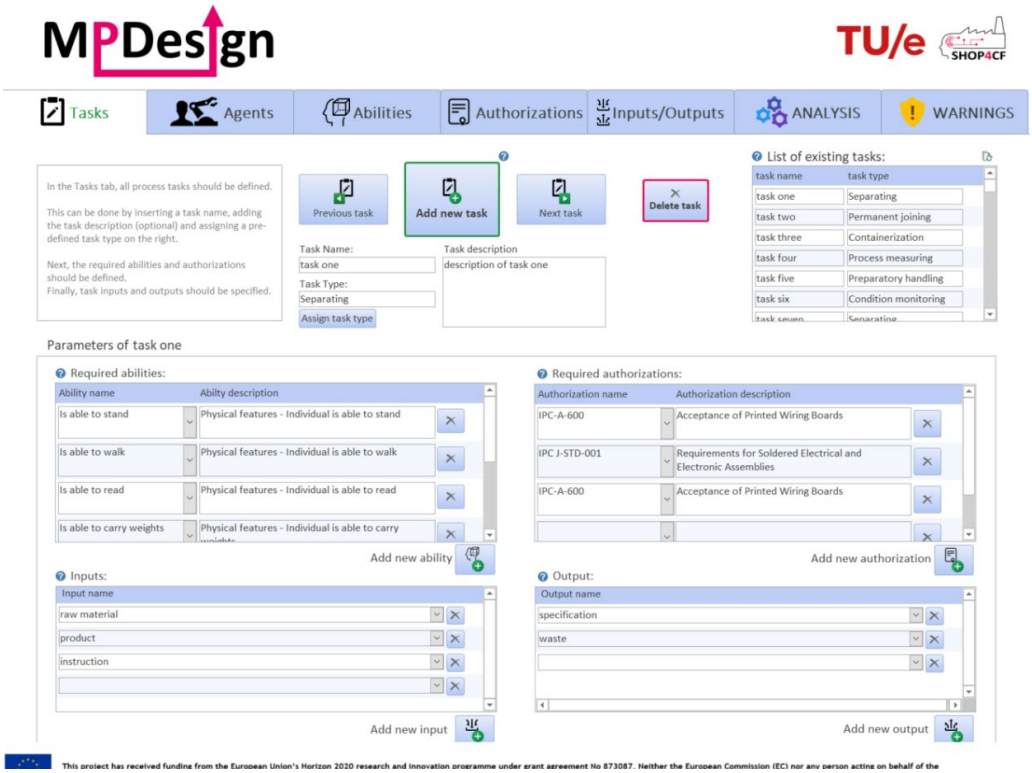

Figure 1. MPDesign GUI

The MPDesign tool is developed as an executable Microsoft Access application. The MS Access based frontend provides a user-friendly GUI with embedded help functionality. The outputs of the analyses are exported as standard Microsoft Excel spreadsheets allowing for easy processing.
Due to the availability of a free Access runtime environment the tool can be used without any costs. In order to perform the process analyses, the user needs to input the required information about the tasks to be performed and the available agents.

Defining a task (Figure 1) requires naming it, providing a brief description and assigning a task type. The task types follow the model defined in [2], which consists of three decomposition levels for the manufacturing activities. On the first level, the general types of Manufacturing Operations Management (MOM) (IEC62264-1) are defined: production, inventory, maintenance and quality. By choosing one of those categories, the user is directed to the second level of decomposition, which provides more detailed, but still clustered types of tasks (e.g., the inventory group consists of packing, storing and transporting actions). The last, third level, details manufacturing activities even further, so each task can be easily assigned with the type (e.g., for packing (on level 2) the following options are available: Individual packaging, Containerization).
Moreover, four characteristics need to be defined for each task – the Required abilities and Required authorization that are needed to assign the task to an agent, as well as the task Inputs and Outputs.

MPDesign is equipped with predefined collections of abilities and authorizations that are most commonly used in the manufacturing industry. Also, an exemplary list of task inputs and outputs is provided to give the user guidance on what type of information is required.
The list of authorizations is based on certifications in the manufacturing domain [6] and has been verified in practice using the SHOP4CF use cases. For the abilities, a distinction is made between the abilities of human agents and robotic agents. The robotic attributes are based on the list defined in [2]. We have proposed to structure the human attributes into three groups: physical features, abilities without certification and norms. This approach was inspired by [7] and was enriched with conclusions of the MPDesign validation with SHOP4CF use cases.

The physical features describe human capabilities, which can be limited due to permanent or temporary impairments (e.g., mobility limitations or injured limbs), making some of the tasks impossible to perform. Modelling those ensures that workers with temporary or permanent disabilities can also be assigned to meaningful and fitting tasks. Furthermore, an initial list of abilities without certification is defined to capture additional, self-declared skills of workers on the shop floor, such as proficiency in using certain software and equipment. Lastly, a set of norms is provided to determine which tasks can be assigned to human operators without breaching any safety and health regulations, like maximum carried weight, time spent in an uncomfortable position, etc. These norms are based on advised values for humans, and such an explicit cross-checking helps in identifying tasks which need to be performed by machines.

Altogether, the abilities and authorizations are used to determine which actor can be assigned to which task. In order not to limit users to such a predefined set of attributes, new authorizations and abilities can be easily added, and the preview of defined features is available in separate tabs accessible from the main menu of the MPDesign tool.

In the final step of defining the task, a set of inputs and outputs must be assigned to it. The inputs and outputs are use case-specific as they depend on what is manufactured in a process. Therefore, each analyzed process requires its own set of inputs and outputs. To make the definition more user-friendly, an exemplary list of inputs and outputs has been provided.

Once the tasks are defined, the data about all the available agents need to be provided. The agents are defined by their name, brief description and type – either human or automatic. Similar to the tasks definition, a set of abilities and authorizations exhibited by an agent needs to be indicated.

After providing all the required data on tasks and agents, the process analysis can be performed. The MPDesign cross-checks the abilities and authorizations between the tasks and the agents. The matching is based on exhaustive comparison of agents and tasks. As a result, the following tables are created and displayed (Figure 2) :

- lists of tasks that can be performed by individual agents,
- lists of agents that can perform individual tasks,
- list of tasks with requirements that cannot be fulfilled by any agent,

- list of agents unable to perform any tasks.

Moreover, the inputs and outputs assignments are verified to ensure the integrity of the modelled process. Our approach is based on the data flow analysis method presented in [8] and adapted to the manufacturing domain. This involves identifying the following flow anomalies:

- inputs that are not generated by any previous task (which needs to be provided as external sources) - cf. absence of initialization anomaly from [8]
- outputs not used by any task in the process (that should correspond to the process final products, but may also be a redundant subproduct) - cf. inevitable redundancy anomaly from [8]
- identical inputs used by more than one task (potentially two tasks attempting to use the same depletable resource)
- identical outputs generated by more than one task (erroneous identification of physical subproduct) - cf. multiple initializations anomaly from [8].

All the generated tables can be then easily exported to a standard Excel spreadsheet where they can be further processed, e.g., to identify the bottlenecks in abilities and authorizations guiding future hires and purchases but also helping in upskilling workers whose current skillset makes them vulnerable.

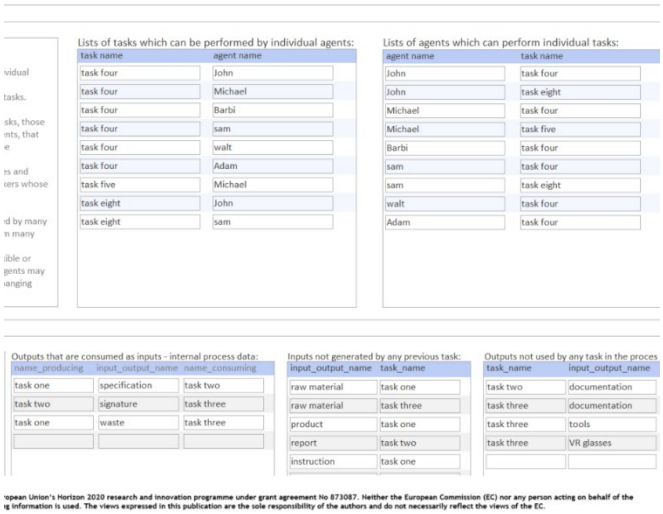

Figure 2. Exemplary results of the process analysis in MPDesign

3. Validation

MPDesign has been verified using the industrial scenarios of the SHOP4CF project. For each element in the tool (sets of attributes, types of tasks and agents etc.), it was checked whether the element complied with the use cases.

Firstly, the task types defined in the tool have been verified for completeness. Each task in SHOP4CF use cases was analyzed and linked to a specific type of manufacturing operations (according to the model in [2]). This procedure has ensured that all tasks of the tested scenarios could be assigned to a type. We plan to enrich the information on task type with its basic representation in Business Process Model and Notation (BPMN). As all the use cases are related to the manufacturing domain, the final list of task types is limited to the industrial environment. However, the list can be extended in a later version to multiple application domains.

Similarly, the predefined abilities and authorizations have been cross-checked against the requirements of tasks identified in each of the SHOP4CF pilots. While all the tasks present in the SHOP4CF pilots were successfully covered, it cannot be ensured for other manufacturing subdomains not represented by the SHOP4CF use cases. However, as mentioned earlier, the tool does not limit the user to predefined abilities and authorizations. This means that users can insert abilities and authorizations that are applicable to their processes.

The correctness of the actor-task matching and inputs-outputs integrity checks has been verified through a series of exhaustive tests. A test case, covering plausible combinations of capabilities, authorizations and requirements had been engineering to support validation. The cases involved tasks that could be performed by a single agent, a number of agents, all agents and no agent at all. Similarly, agents who can perform no tasks, one task, several tasks and all tasks were created. Additionally, we analyzed skills, capabilities and authorizations which on one hand were required by all tasks, individual tasks, several tasks and no tasks at all.

4. Maturity and availability

The MPDesign is ready to use and freely available for download in the GitHub[5] repository as an executable Microsoft Access application. The tool is accompanied by a screencast[6] and a user manual making it immediately ready to use. In case the user does not possess a viable Access license the freely available Microsoft access runtime environment[7] may be used. MPDesign is licensed under the Creative Commons Attribution-ShareAlike 4.0 International License.

5. Conclusion

The MPDesign tool provides valuable support in designing manufacturing process models. Its outcomes can be used to facilitate the proper matching of actors and tasks during the execution of the models. Even more importantly, the tool provides immediate insights into the quality, readiness, and availability of human and robotic actors. With these, factory managers can ensure proper assignment of workers based on their skills and plan upskilling processes to ensure continued employability and productivity of their staff.

The tool is ready to use and made publicly available. The future work involves extending MPDesign to take into account not only the task requirements matching but also the workers' preferences, thus enhancing its positive impact on job satisfaction even more.

Finally, even though MPDesign was initially developed in order to support MPMS, the usage of the tool can also be beneficial for any business process outside of the manufacturing domain with minor adaptations.

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