A PROTOTYPE OF A DOMAIN-SPECIFIC MODELING LANGUAGE FOR FORMAL SPECIFICATION OF A HUMAN WORKER

Dajana ANTANASIJEVIĆ*, Sonja RISTIĆ*, Marko VJEŠTICA**,
Darko STEFANOVIĆ*, Vladimir DIMITRIESKI**, Milan PISARIĆ***
* Department of Industrial Engineering and Engineering Management, Faculty of Technical Sciences,
University of Novi Sad, Trg Dositeja Obradovića 6, 21000 Novi Sad, Serbia, Tel. +381 021 450810,
E-mail: {narandzic@uns.ac.rs, sdristic@uns.ac.rs, darko.stefanovic@uns.ac.rs}
** Department of Computing and Control Engineering, Faculty of Technical Sciences,
University of Novi Sad, Trg Dositeja Obradovića 6, 21000 Novi Sad, Serbia, Tel. +381 021 450810,
E-mail: {marko.vjestica@uns.ac.rs, dimitrieski@uns.ac.rs}
*** KEBA, Industrial Automation, Reindlstraße 51, 4040 Linz, Austria, Tel. +43 732 730910, E-mail: pisa@keba.com

ABSTRACT

The application of innovative technologies that foster smart production resources' interconnectivity alongside the virtual space that facilities to support process simulation makes the technology factor become the center of Industry 4.0. The production process modeling and simulation can be used to facilitate flexibility and automation of a shop floor. In our previous research, we have created a Domain-Specific Modeling Language (DSML) named MultiProLan, aiming to create production process models suitable for the automatic generation of executable code that enables the automatic execution of production processes. As the next step, we have proposed research on a DSML language aimed at Industry 4.0 human worker modeling. Industry 4.0 still considers workers as a cost, while favoring technological aspects over the workers' wellbeing. Industry 5.0 complements Industry 4.0, focusing on a human-centric approach that puts core human needs and interests at the top of production processes. Based on our research proposal, here we present a blueprint of the HResModLan DSML prototype aimed at the formal specification of a human worker within Industry 5.0. Presented abstract and concrete syntaxes of the language are tested on a case study of a furniture factory to demonstrate whether they are a good base for the further development of the HResModLan language.

Keywords: *Industry 5.0, Industry 4.0, Human worker, Production Process Modeling, Domain-Specific Modeling Languages*

1. INTRODUCTION

Intensive digitalization and automation, reaching connectivity through the usage of cyber-physical systems in production processes, and emphasizing the interaction between machines, robots and humans, alongside the increasing customer need for highly customized products, led towards the fourth industrial revolution called Industry 4.0. It raises new challenges for future manufacturing, which are driven by four disruptions [1]: (i) data volumes, computational power, and connectivity; (ii) the emergence of analytics and business-intelligence capabilities; (iii) new forms of human-machine interaction; and (iv) improvements in transferring digital instructions to the physical world.

Industry 4.0 has brought many changes in production itself [2, 3]. Decentralized intelligence and management and different kinds of integration – horizontal integration, vertical integration, and integrated digital engineering – characterize Industry 4.0 [4]. There are a lot of research projects in the domain of smart manufacturing aimed at defining and implementing Industry 4.0 concepts [3]. However, some systematic literature reviews, like [5], note that there are not too many papers focused on the usage of information technology (IT) in production and management processes in Industry 4.0. They conclude that it is possible to identify the growth trend of the number of published papers in the area of Industry 4.0 in the period 2019–2020 compared to the period 2010–2012. Despite this growth, many research questions are still left unanswered, and many challenges are not yet addressed.

One of the important needs within Industry 4.0 is to enable manufacturing of different product variations without stopping production to achieve flexibility in manufacturing systems. One way to produce highly customized products with minimum idle time is by applying a higher abstraction-level orchestration that represents diverse scheduling activities, both batch product planning and operation scheduling, and allocating operation steps on resources [6]. In order to enable higher abstraction-level orchestration, in [7], we have proposed a framework for the formal description and automatic execution of production processes. The proposed framework is based on Model-Driven (MD) principles and a Domain-Specific Modeling Language (DSML) used to formally specify production processes, automatically generate instructions for smart machines or human workers, and gather feedback from them during the process execution. In [8], we presented a Digital Factory solution with an intelligent, real-time Orchestrator as its core component. An orchestrator is a software system that orchestrates a safe collaboration of all factory resources – humans, machines, robots – with the goal of producing a requested product. The production processes have to be formally specified to be processed by our Orchestrator, which in turn is responsible for the orchestration – matching, scheduling, and enriching the process – and for the execution of final production steps in a smart factory [8]. In the following phase of our research, we have developed the central artefact of the proposed MD framework – Multi-Level Production Process Modeling Language (MultiProLan) [9]. MultiProLan is a DSML created to model production processes within discrete product manufacturing. It enables the creation of both resource-agnostic (Master-Level – MasL) and resource-aware (Detail-Level – DetL) production process models that contribute to more comprehensible models and their reusability [6]. These models are suitable for the

automatic generation of executable code that enables the automatic execution of production processes within a simulation or a shop floor.

Human roles were changed during the industrial revolutions, but the most significant change in that segment occurred with Industry 4.0 [10]. Albeit some authors [11] state that the idea of Industry 4.0 is to minimize human work as much as possible and to replace it with robots, smart factories are not workerless production facilities. It is essential to enable fluent and safe cooperation of human workers with other, smart or legacy, resources [8]. With technological progress, new types of interactions between humans and machines, like the cooperation of machines with humans in adaptive production systems, arise [12]. Human's role is continuously changing, and automation is seen as a further enhancement of the human's physical, sensorial, and cognitive capabilities by means of human and cyber-physical systems integration. Industry 5.0 complements Industry 4.0, focusing on a human-centric approach that puts core human needs and interests at the top of production processes, looking forward to a vision of the co-existence of industry, society, and the environment. Romero and Stahre [13] introduce the concept of *Operator 5.0*, built upon the concept of *Operator 4.0* [12], as "a smart and skilled operator that uses human creativity, ingenuity, and innovation empowered by information and technology." The role of the human workers in Industry 5.0 gains the utmost attention and, among others, especially aspects like: skills, intellectual abilities, capabilities, limitations, motivation, and health and legal issues.

As a production resource, a human worker has to be orchestrated within a safe collaboration of all production resources, e.g., machines, robots, and other humans. In order to enable automated orchestration, a human worker has to be adequately modeled. Different conceptual modeling languages are used to model production processes like: Unified Modeling Language (UML) activity diagram, Business Process Modeling and Notation (BPMN), and Petri nets [7]. Nevertheless, all these languages are general-purpose modeling languages [14] and do not have adequate, specific concepts to model humans and their roles in production processes.

Being aware of the specific role of a human worker within a smart factory, in [15], we have proposed the research on a DSML aimed at human worker modeling in the context of Industry 4.0. The main goals of creating such a language are to enable the easier and more effective: (i) assignment of production process steps to adequate human workers; and (ii) requiring, selection, hiring, and development of employees. This paper represents an extended version of the conference paper [15]. In the meantime, we have created a prototype of a DSML, named Human Resource Modeling Language (HResModLan), aimed at human worker modeling, not only in the context of Industry 4.0 but also keeping in mind the Industry 5.0 production vision that respects the limits of the planet and the welfare of the industrial worker. The DSML prototype is the initial version of future HResModLan and, currently, covers only the concepts aimed at modeling a relatively small segment of the human resource problem domain. The presented results can be seen as a proof of concept for further development of HResModLan. We extend the conference paper [15] with: (i) the analysis of a selected segment of the human resource domain; (ii) the abstract and concrete syntaxes of created part of HResModLan; and (iii) a model of a furniture factory expressed by the concepts of created part of HResModLan.

Apart from the Introduction, this paper is organized as follows. Section 2 summarizes the theoretical foundations of the proposed research. In Section 3, we present the requirements for modeling a human worker as a participant in Industry 4.0/Industry 5.0 and the MD approach for the automatic execution of code generated from the models. The analysis of the human resource domain is discussed in Section 4, and the abstract and concrete syntaxes of the HResModLan language prototype are presented in Section 5. Conclusions and future work on human resource modeling in the context of Industry 4.0/Industry 5.0 are presented in Section 6.

2. BACKGROUND AND RELATED WORK

In the previous research we have conducted a systematic literature review (SLR) on human roles, competencies and skills in Industry 4.0 and the results are presented in [16]. The main conclusion based on that SLR was that there is a lack of research about the physical, mental and health features, capabilities, and risks in the context of human role and human resource specification within Industry 4.0/Industry 5.0. The theoretical foundations of the research proposed here are grouped into three fields: Industry 4.0 and Industry 5.0, Human Resource Management (HRM) in Industry 4.0/Industry 5.0, and Human resource modeling languages.

2.1. Industry 4.0 and Industry 5.0

Industry 4.0 is preceded by three industrial revolutions. The first one took place in the second half of the eighteenth century, and it sprang with new mechanical production facilities using water or steam power. The second industrial revolution began in the 1870s because of the electrification system and Taylor's work division with mass production and the usage of band conveyors. Finally, the third industrial revolution can be associated with the introduction of digital work, which took place in the 1970s.

Industry 4.0 involves industrial automation and the integration of new production technologies. Consequently, work conditions are improved, and productivity and quality are increased.

Smart factory integrates manufacturing assets with computing platforms and communication technology [17]. It is based on the rapid exchange of information and synchronization between production system resources. Technology has made possible new products and services that have generated significant transformations in both personal and professional life, emphasizing the interaction between machines and people [18]. It also has triggered changes in the workplace organization [19].

The interaction between humans and machines is very well known under the acronym HMI (Human-Machine Interaction). The interaction and communication between humans and machines have changed greatly over time. The history of HMI can be divided into four stages [20]. The first stage refers to the period from 1940 to 1955 when machines were mostly directed by humans or operated under human supervision. From 1955 to 1970, researchers began to model new machines and tools that were more adapted to humans. The next stage is related to the period from 1970 to 1985. A human began to be only a controller of many processes, that

is, a human was needed mostly to supervise the processes that take place through automated machines. From 1985 until today, this area has progressed a lot.

Industry 4.0 is mostly focused on the technical aspect of manufacturing and on its automatization, and less concerned with the human factor, society, and environment. Industry 4.0 vision of human workers replacement by robots is not sustainable. Various researches show the importance of humans in production processes and the need for their maximum involvement in work processes [12, 13, 21]. Industry 5.0 complements Industry 4.0 focusing on a human-centric approach that puts core human needs and interests at the top of the production process, looking forward a vision of co-existence of industry, society, and environment. The human worker within Industry 5.0 is not considered as a cost and human capital is valorized and appreciated. The focus of Industry 5.0 is on the development of human resources through continuous education, learning, and training [20]. Human needs have to be taken into account, as well as: human's physical abilities, competencies and knowledge, and emotional and physiological characteristics. For this reason, modeling languages aimed at production process and human worker modeling in Industry 4.0/Industry 5.0 should have concepts that are used to model all these characteristics.

2.2. Human Resource Management in Industry 4.0/Industry 5.0

Smart Human Resource Management (SHRM) or Electronic HRM (E-HRM) is closely related to Industry 4.0 and Industry 5.0 [17]. The shifting of HRM towards E-HRM brings several challenges, such as the selection and usage of new technologies and changes in organizational culture [22]. On the other side, it brings some benefits like more efficient attraction and talent improvement, as well as faster and better HR operations [23].

The emergency of the smart industry, artificial intelligence (AI), and big data, to a great extent, affect HRM. New generations are joining the workforce, and HRM has to adapt [24]. There is a need for a new approach to the recruitment process that has to become more automated. Improved and virtual training possibilities would support employee development. Some authors discuss the possible application of big data in order to improve the identification of low performers [22]. However, these possibilities still have to be applied very carefully, considering the applicable legal regulation related to personal data protection and privacy. Furthermore, the human-robot collaboration makes teamwork more complex and difficult [25].

There is a strong need for HRM to support employees in collaborating with technologies [26]. The adoption of technologies is a challenging process. It can affect the workers' health and satisfaction [27]. Involving social robots can be one of the solutions to this problem [28]. Workers have to be prepared and empowered to cope with all challenges that arise in the technology adoption process.

The performance assessments, leadership promotion, and improved training possibilities, adapted to the new generation's needs and requirements, can positively affect employees' commitment [29]. Future HRM has to improve all of its major processes in order to adequately follow inevitable changes brought by Industry 4.0 and Industry 5.0.

The employees within Industry 4.0/Industry 5.0 are interested in doing high-value-added tasks and an organization supported by new technologies can enable the transition from repetitive tasks to high-value-added tasks [22]. A digital company has to update the skills of its employees, keeping in mind the new needs [30]. In the era when new professions emerge, competence management becomes a very important HRM tool. It is essential to identify a company's skill needs and map them with available individual and collective skills [31]. Giving human workers a crucial place within a company and empowering their involvement, interactivity, and continuous learning is one of the main characteristics of Industry 5.0.

2.3. Human Resource Modeling Languages

Modeling languages are needed to provide the appropriate notation for models' specifications. In the context of Industry 4.0/Industry 5.0 production process modeling approaches and languages are very important. There are numerous languages aimed at modeling different aspects of production processes. Bill of Materials and Operations (BOMO) [32] can be seen as an example of a traditional way to specify production processes. General purpose modeling languages (GPML), like Business Process Model and Notation (BPMN), are able to represent complex production process semantics and are extensively used in practice. However, according to [33] BPMN cannot be used to adequately model smart resources in general and human resources in particular. Ouyang et al. [34] argue that BPMN does not provide support for the full range of production resources. The authors present a conceptual resource data model that considers the various resource types (human and non-human) and their interaction. Some authors propose BPMN extensions to model several aspects of a human as a production resource. For example, Polderdijk et al. [35] extended BPMN to enable the modeling of human activities and physical risk features to simulate and depict the physical dangers that humans face as participants in production processes. In our previous research [6–9], we proposed a framework for the formal description and automatic execution of production processes within Industry 4.0. The framework is not based on a GPML nor on the extension of a GPML, but on a DSML aimed at modeling of production processes.

The role of human workers in smart factories is specific and they have to be seen from two perspectives: as a worker within the organization (organizational perspective); and as a human production resource (production perspective). Neither of the reviewed literature sources deals with these two perspectives in the context of Industry 4.0/Industry 5.0. That was the reason why we decided to create a new DSML HResModLan aimed at human resource modeling. Human resource models expressed by means of HResModLan will enable the automatic assignment of process steps of a production process to adequate human workers as well as the improvement of requiring, selecting, hiring and developing of employees.

3. A HUMAN WORKER SPECIFICATION – AN MD APPROACH

In our previous research [6–9], we have proposed an MD framework for the formal description and automatic execution

of production processes. The approach relies on the MultiProLan DSML that is aimed at modeling production processes. Production processes should be modeled independently from any production system, and production systems should be flexible enough to support various processes to increase the adaptability. On the one side, production process steps require the capabilities (that are independent of a production system) needed for their execution. On the other side, particular production system's resources may be seen as objects with their standardized interfaces that offer a set of capabilities they can perform. In order to separate production process models from a specific production system, MultiProLan enables the creation of models at two levels of abstraction – resource-agnostic and resource-aware levels. A resource-agnostic (Master-Level) production process model describes the requirements of its production steps like: the required capabilities needed for each process step execution, with constraints and parameters; input and output products of each process step with constraints and the material flow; control flows; collaboration between process steps; different process variations; and error handling [6]. A resource-aware (Detail-Level) production process model represents an enrichment of a resource-agnostic model with additional details specific to a particular production system that will execute the modeled production process. The enrichment may be done manually or automatically by means of a software component named Orchestrator. Both modes of enrichment perform matching between offered and required capabilities, thus matching process steps with resources that may perform them. After the matching process is finished, an instruction generator automatically transforms matched resources and process steps into instructions to execute operations.

In [15], we have presented the excerpt of the architecture of the MD framework for the formal description and automatic execution of production processes, extended with the components aimed at human worker specification.

Keeping in mind smart resources, MultiProLan is, at the moment, mostly focused on the concepts aimed at modeling machines' and robots' capabilities.

In [15], we have proposed research on a DSML language aimed at modeling human workers, as well as the adaptation of the existing framework for the formal description and automatic execution of production processes. In that way, the better integration of human workers and machines in the smart factory would be achieved due to the easier and more effective assignment of process steps to adequate human workers. In the meantime, we have created a prototype of a DSML, named HResModLan, aimed at human worker modeling not only in the context of Industry 4.0 but also keeping in mind the Industry 5.0 human-centered production vision. The DSML prototype is the initial version of future HResModLan and currently covers only those concepts aimed at modeling a relatively small segment of the human resource problem domain. In the following sections, we present: the human resource domain analysis, HResModLan abstract syntax, HResModLan concrete syntax, and a furniture factory human resource model expressed by the concepts of the HResModLan language prototype.

4. HUMAN RESOURCE DOMAIN ANALYSIS

The first step of DSML development is to analyze a relevant problem domain. Here we use the Feature-Oriented Domain Analysis (FODA) method [36] and the standard FODA notation [33, 34] extended in a way to support feature and group cardinalities, making it possible to create cardinality-based feature models [38]. The organization feature (*Organization*) is the root of the FODA tree presented in Fig. 1.

Organizations can be of different organization structure types (*Organization Structure Type*), and they differ concerning the number of employees (*Organization Size*). Each organization has several organization unit types (*Organization Unit Types*). The organization, by the rule, has several, sometimes numerous, organization units (*Organization Unit*). Organization units that are legal persons are separated as the *Legal Person* feature. Only these organization units can act as employers, and they are composed of their employees (*Employee*) that can be production resources (*Human Production Resource*) or not (*Not A Production Resource*). All organization units (regardless of whether they are legal persons or not) can be composed of several workplaces (*Workplace*). An employee is assigned to a workplace. A human as a production resource can come from another organization (factory, company) as some kind of "workforce borrowing" between organizations within cross-organizational cooperation. Such a human worker is not employed within the organization to be modeled.

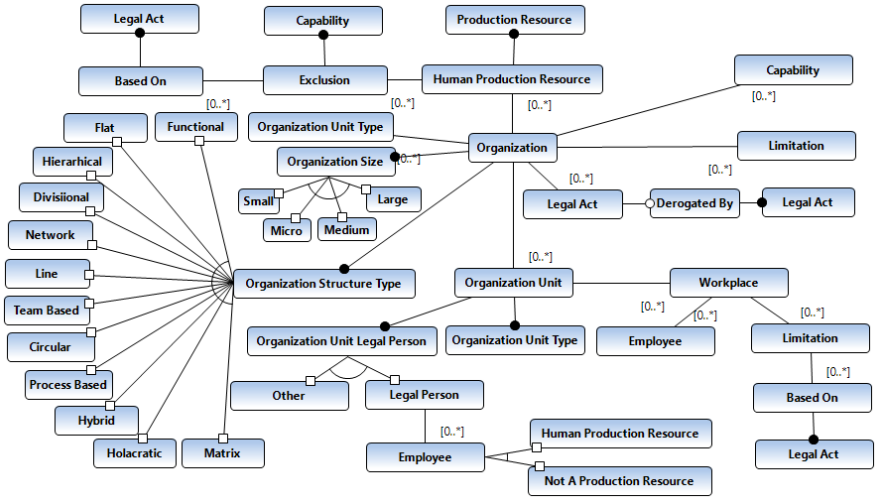


Fig. 1 An FODA model of Organization

Their engagement within the organization is not permanent, and for that engagement, they are paid by the organization that borrows them. Therefore, they are not recorded as employees of the modeled organization. For each organization, relevant legal acts (*Legal Act*) are specified, keeping track of derogated legal acts, too. A workplace can have some limitations (*Limitation*) that must be regulated by the legal acts, recording relevant articles and clauses (*Based On*). These workplace limitations indicate legal constraints concerning the possibility of somebody's assignment (employment) with the workplace. For example, persons under the age of 18 cannot be assigned to the workplace where night work is needed.

When it is about the production process execution, it is very important to record production resources' capabilities (offered capabilities) in order to enable matching between offered and required capabilities (by a production process step) within the orchestration process. Humans' capabilities are defined within the specification of a production system. Here, it is necessary to record the possible exclusions from defined human capabilities. For example, an employee can have a spinal injury and, for an interval of time, is not able to lift a heavy load. For a human production resource, these exclusions (*Exclusion*) are recorded alongside the relevant capability (*Capability*) and relevant legal acts (*Legal Act* and *Based On*) that regulate the allowance of these exclusions.

5. HUMAN RESOURCE MODELING LANGUAGE ABSTRACT AND CONCRETE SYNTAXES

In Fig. 2, the abstract syntax of the HResModLan prototype is presented. It is created by means of the Ecore meta-meta-model, which is part of the Eclipse Modeling Framework (EMF) [39]. The concepts presented in Fig. 2 are used to create models representing employees of the modeled organization, their workplaces, capabilities and exclusions. Atomic features from FODA model, representing one-of-many options of a variation point, like *Small*, *Micro*, *Medium* and *Large* leaves of *Organization Size* in Fig. 1, are represented as enumeration classes in the meta-model. Other features are represented by classes within the meta-model presented in Fig. 2. The composition association is used in the meta-model to represent the multiplicity *many* (*) of relationships between the features presented in FODA diagrams, like the relationship between *Organization* and *Legal Act* in Fig. 2.

We decided to create a graphical concrete syntax in order to make models easier to read for human resource managers, human worker supervisors, process designers, as well as human workers themselves. For that purpose, the Eclipse Sirius framework [40, 41] is used.

In Fig. 3, a model of a furniture factory, with its employees and production workers, is presented. The model is expressed by means of the HResModLan graphical concrete syntax.

All the way to the left in Fig. 3, there are three grey-colored rectangles representing organization unit types: Factory, Sector, and Department. Each organization unit is presented with a rectangle containing the icon of a building, which is different from the icon of buildings used to represent organization unit types. Rectangles representing organization units are colored in the same color that is used to color the corresponding organization unit type.

The organization unit Furniture factory is at the same time a legal person. Consequently, the rectangle that models it differs in a way that it has a different icon and a wider borderline compared to the rectangles that model other organization units.

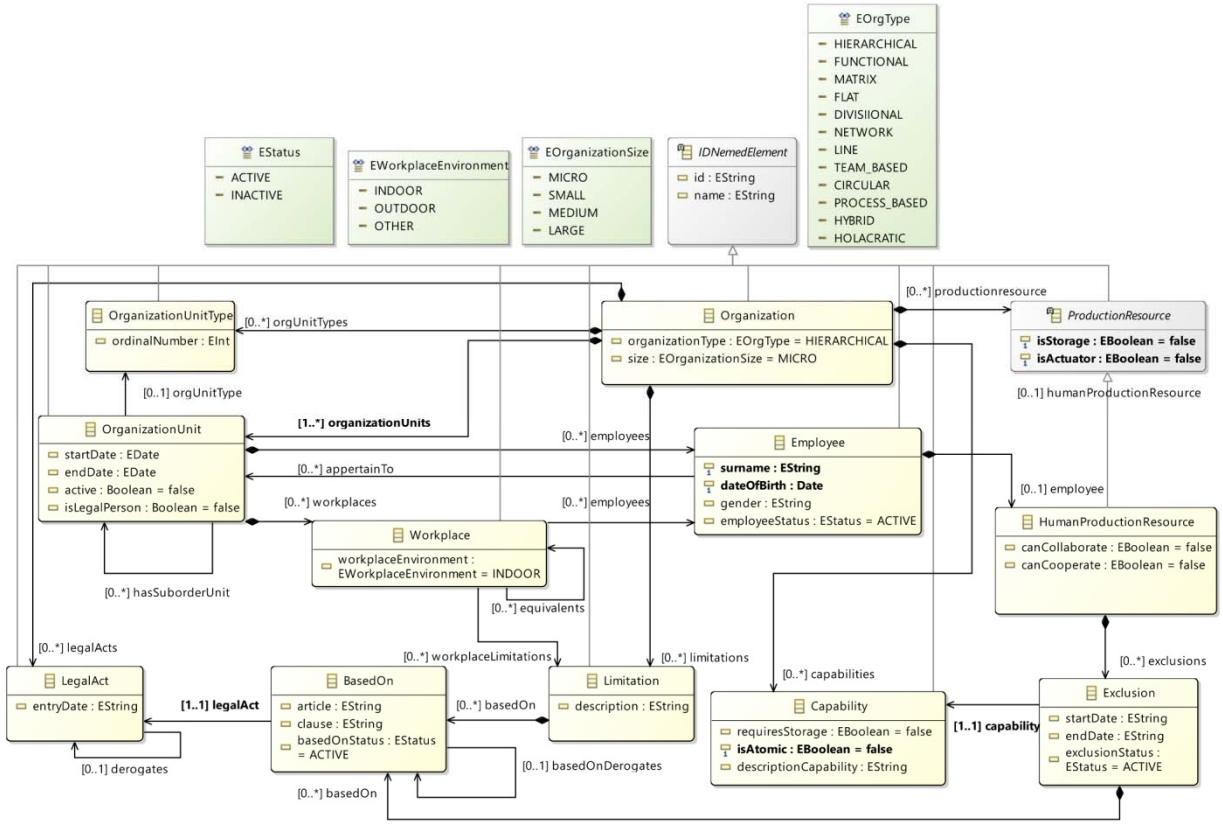


Fig. 2 The human resource modeling language abstract syntax

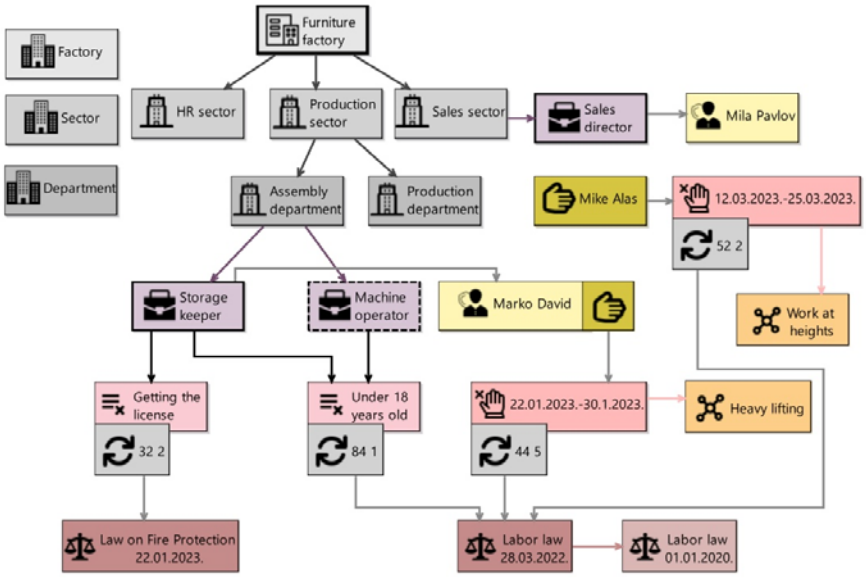


Fig. 3 A furniture factory model expressed by the concepts of HResModLan concrete syntax

Workplaces are represented with purple rectangles marked with the briefcase icon. Workplace limitations are represented with the light pink color and text icon with the × symbol. Light grey rectangles with two circle arrows as the icon represent an article and a paragraph of a legal act aimed at limitation regulation. For example, the Storage keeper workplace has two limitations. Namely, only adult persons (according to Labor law Republic of Serbia from 28.03.2022, article 84, clause 1) with the appropriate license (according to Law on Fire Protection Republic of Serbia from 22.01.2023, article 32, clause 2) can be assigned with the Storage keeper workplace.

Three persons are modeled in Fig. 3. Mila Pavlov is assigned to the Sales director workplace and she is not working in production. She is represented with a light-yellow rectangle. Marko David is assigned to the Storage keeper work place. At the same time, he is a human production resource, marked with a dark-yellow rectangle with the hand icon, added to the light-yellow rectangle. Mike Alas is coming from another organization for a fixed period to participate in the production process execution as a human production resource. He is represented only by a dark yellow rectangle with a hand icon, as he is not an employee of this furniture factory.

The exclusions for certain capabilities are modeled by light-red rectangles with the hand icon and the × symbol. Marko David has reported that due to the injury is not capable of lifting a heavy load in the period from 22.01.2023. to 30.01.2023. The exclusion is accepted and recorded based on the Labor law Republic of Serbia from 28.03.2022, article 44, clause 5. Capabilities are represented with light-orange rectangles with the five-circle icon. Actual legal acts are represented with dark-violet rectangles containing the scales icon. Derogated legal acts are represented similarly but light-violet colored. The arrow between legal acts indicates the derogate relation between them.

The models created using the HResModLan prototype contain the important information that will be used in the production process orchestration in order to make more effective assignments of process steps to adequate human workers. In that way, the better integration of human workers and machines in the smart factory would be achieved.

6. CONCLUSION

In the previous sections, we have identified and described the importance of modeling a human worker as a participant in Industry 4.0/Industry 5.0 and applying the MD approach for the formal description and automatic execution of production processes.

In order to enable automated orchestration, a human worker has to be adequately modeled. According to the preliminary literature review, different conceptual modeling languages are used to model production processes and their resources. Nevertheless, all these languages do not have adequate concepts to model humans and their roles in production processes. Here we present the DSML prototype, named HResModLan, aimed at human resource modeling in the context of Industry 5.0. The presented results can be seen as a proof of concept for further development of HResModLan.

The main strengths of the presented approach are that it: enables easier adaptation of machines and human workers to dynamic changes in production processes; improves the coordination of human workers and machines in factories; and enables automatic execution of production processes. Additionally, the possibility of human resource specification from two different perspectives will enable: support of Smart HRM; improvement of employees' health, satisfaction and commitment; new training possibilities; and more precise identification of needed company's skills and their mapping with available individual and collective skills. We use graphical concrete syntax that is intuitive and useful for potential users, like HR managers, human worker supervisors, process designers, as well as human workers themselves. At the same time, the graphical syntax may cause the main challenge of our approach and it is the scalability problem. At the moment we use different modeling layers, element-type filtering tools, zoom feature, and show/hide buttons to deal with the scalability problem. In our future work we will deal with the scalability problem considerably.

Our further research efforts are directed toward extending human resource domain analysis and further development of HResModLan. MultiProLan and HResModLan will form a family of DSMLs aimed at the formal description of production processes and production systems with their production resources. The extended architecture of the MD framework based on such a family of DSMLs will contribute to better and faster allocation of human workers, faster changes of documentation, if they are needed and better integration of human workers, human supervisors, and production processes. The framework will enable more adequate assignment of process steps to human workers, consequently lowering the number of errors, production time, better balancing of workers' workload, and costs. Adequate allocation of human workers can bring additional positive effects in the context of human workers' satisfaction, motivation, inclusion, health, and safety.

ACKNOWLEDGMENTS

This research (paper) has been supported by the Ministry of Science, Technological Development and Innovation through project no. 451-03-47/2023-01/200156 “Innovative scientific and artistic research from the FTS (activity) domain”.

REFERENCES

[1] PAÇAUX-LEMOINE, M. P. – BERDAL, Q. – GUÉRIN, C. – RAUFFET, P. – CHAUVIN, C. – TRENTESAUX, D.: Designing human–system cooperation in industry 4.0 with cognitive work analysis: A first evaluation. Cognition, Technology & Work, vol. 24, no. 1, pp.93-111, 2022. doi: 10.1007/s10111-021-00667-y.

[2] XU, L. D. – XU, E.L. – LI, L.: Industry 4.0: state of the art and future trends. International journal of production research, vol. 56, no. 8, pp.2941-2962, 2018. doi: 10.1080/00207543.2018.1444806.

[3] THOBEN, K. D. – WIESNER, S. – WUEST, T.: “Industrie 4.0” and smart manufacturing - a review of research issues and application examples. International journal of automation technology, vol. 11, no. 1, pp.4-16, 2017. doi: 10.20965/ijat.2017.p0004.

[4] CRNJAC, M. – VEŽA, I., – BANDUKA, N.: From concept to the introduction of industry 4.0, International Journal of Industrial Engineering and Management (IJIEM), vol. 8, no. 1, pp. 21-30, 2017.

[5] SPASOJEVIĆ, I. – HAVZI, S. – STEFANOVIĆ, D. – RISTIĆ, S., – MARJANOVIĆ, U.: Research Trends and Topics in IJIEM from 2010 to 2020: A Statistical History, International Journal of Industrial Engineering and Management (IJIEM), vol. 12, no 4, pp. 228-242, 2021.

[6] VJEŠTICA, M. – DIMITRIESKI, V. – PISARIĆ, M. – KORDIĆ, S. – RISTIĆ, S. – LUKOVIĆ, I.: Production processes modelling within digital product manufacturing in the context of Industry 4.0, Int. J. Prod. Res., pp. 1–20, 2022, doi: 10.1080/00207543.2022.2125593.

[7] VJEŠTICA, M. – DIMITRIESKI, V. – PISARIĆ, M. – KORDIĆ, S. – RISTIĆ, S. – LUKOVIĆ, I.: Towards a Formal Specification of Production Processes Suitable for Automatic Execution, Open Comput. Sci., vol. 11, no. 1, pp. 161–179, 2021, doi: 10.1515/comp-2020-0200.

[8] PISARIĆ, M. – DIMITRIESKI, V. – VJEŠTICA, M. – KRAJOSKI, G.: Towards a non-disruptive system for dynamic orchestration of the shop floor. In IFIP International Conference on Advances in Production Management Systems, pp. 469-476, 2020. doi: 10.1007/978-3-030-57997-5_54.

[9] VJEŠTICA, M. – DIMITRIESKI, V. – PISARIĆ, M. – KORDIĆ, S. – RISTIĆ, S. – LUKOVIĆ, I.: Multi-level production process modeling language, J. Comput. Lang., vol. 66, pp. 101053:1-101053:26, 2021, doi: 10.1016/j.cola.2021.101053.

[10] BORTOLINI, M. – FACCIO, M. – GALIZIA, F.G. – GAMBERI, M. – PILATI, F.: Adaptive automation assembly systems in the industry 4.0 era: a reference framework and full–scale prototype. Appl. Sci., vol. 11, no. 3, p.1256, 2021. doi: 10.3390/app11031256.

[11] GELLERT, A. – PRECUP, S. A. – PIRVU, B. C. – FIORE, U. – ZAMFIRESCU, C. B. – PALMIERI, F.: An Empirical Evaluation of Prediction by Partial Matching in Assembly Assistance Systems. Appl. Sci., vol. 11, no. 7, p.3278, 2021. doi: 10.3390/app11073278.

[12] ROMERO, D. – BERNUS, P. – NORAN, O. – STAHRE, J. – FAST-BERGLUND, Å.: The operator 4.0: Human cyber-physical systems & adaptive automation towards human-automation symbiosis work systems. In IFIP international conference on advances in production management systems, pp. 677-686, 2016. doi: 10.1007/978-3-319-51133-7_80.

[13] ROMERO, D. – STAHRE, J.: Towards The Resilient Operator 5.0: The Future of Work in Smart Resilient Manufacturing Systems. Procedia CIRP, Vol. 104, pp. 1089–1094, 2021. doi: 10.1016/j.procir.2021.11.183.

[14] KOSAR, T. – OLIVEIRA, N. – MERNIK, M. – PEREIRA, V. J. M. – ČREPINŠEK, M. – Da CRUZ, D. – HENRIQUES, R.P.: Comparing general-purpose and domain-specific languages: An empirical study. Computer Science and Information Systems, vol. 7, no. 2, pp.247-264, 2010. doi: 10.2298/CSIS1002247K.

[15] ANTANASIJEVIĆ, D. – RISTIĆ, S. – VJEŠTICA, M. – DIMITRIESKI, V. – PISARIĆ, M.: Towards a Formal Specification of Human Worker for Industry 4.0. In IEEE 16th International Scientific Conference on Informatics (Informatics), pp. 33–38, 2022. doi: 10.1109/Informatics57926.2022.10083444.

[16] NARANDŽIĆ (ANTANASIJEVIĆ), D. – SPASOJEVIĆ, I. – LOLIĆ, T. – STEFANOVIĆ, D. – RISTIĆ, S.: Human Roles, Competencies and Skills in Industry 4.0: Systematic Literature Review. In Central European Conference on Information and Intelligent Systems, pp. 359-369, 2021.

[17] KHALIFA, R. B. – TLIBA, K. – DIALLO, M.T. – PENAS, O. – YAHIA, N. B. – CHOLEY, J.Y.: Modeling and management of human resources in the reconfiguration of production system in industry 4.0 by neural networks. In 2019 International Conference on Signal, Control and Communication (SCC), pp. 246-249, 2019. doi: 10.1109/SCC47175.2019.9116104.

[18] SIMA, V. – GHEORGHE, I. J. – SUBIĆ, J. – NANCU, D.: Influences of the Industry 4.0 Revolution on the Human Capital Development and Consumer Behavior: A Systematic Review, Sustainability, vol. 12, no. 10, pp. 4035; doi: 10.3390/su12104035.

[19] GALLO, T. – SANTOLAMAZZA, A.: Industry 4.0 and human factor: How is technology changing the role of the maintenance operator?. Procedia Computer Science, 180, pp.388-393, 2021. doi: 10.1016/j.procs.2021.01.364.

[20] NARDO, M. – FORINO, D. – MURINO, T.: The evolution of man–machine interaction: The role of human in Industry 4.0 paradigm. Production & manufacturing research, vol. 8, no. 1, pp.20-34, 2020. doi: 10.1080/21693277.2020.1737592.

[21] IVANOV, D.: The Industry 5.0 framework: viability-based integration of the resilience, sustainability, and human-centricity perspectives. Int. J. Prod. Res., vol. 61,

no. 5, pp. 1683–1695, 2023, doi: 10.1080/00207543.2022.2118892.

[22] BONDAROUK, T. – BREWSTER, C.: Conceptualising the future of HRM and technology research. Int. J. Hum. Resour. Manag., vol. 27, no. 21, pp.2652-2671, 2016. doi: 10.1080/09585192.2016.1232296.

[23] SIVATHANU, B. – PILLAI, R.: Smart HR 4.0–how industry 4.0 is disrupting HR. Hum. Resour. Manag. Int. Dig., vol. 26, no. 4, pp. 7-11, 2018. doi: 10.1108/HRMID-04-2018-0059.

[24] SHAW, P. – VARGHESE, R.M.: Industry 4.0 and Future of HR. Journal of Management, vol. 5, no. 6, pp.96-103, 2018.

[25] FENG, Y. – RICHARDS, L.: A review of digital curation professional competencies: theory and current practices. Rec. Manag. J., Vol. 28, no. 1, pp.62-78, 2018. doi: 10.1108/RMJ-09-2016-0022.

[26] JØRGENSEN, K. M. – BOJE, D. M.: Resituating narrative and story in business ethics. Business Ethics: A European Review, vol. 19, no. 3, pp.253-264, 2010. doi: 10.1108/BJM-06-2017-0196.

[27] LIBERT, K. – MOSCONI, E. – CADIEUX, N.: Human-machine interaction and human resource management perspective for collaborative robotics implementation and adoption. In Proceedings of the 53rd Hawaii international conference on system sciences, pp. 533-542, 2020. doi: 10.24251/HICSS.2020.066.

[28] KNOD JR, E. M. – WALL, J. L. – DANIELS, J.P. – SHANE, H.M. – WERNIMONT, T.A.: Robotics: Challenges for the human resources manager. Business Horizons, vol. 27, no. 2, pp.38-46, 1984.

[29] JAWORSKI, C. – RAVICHANDRAN, S. – KARPINSKI, A. C. – SINGH, S.: The effects of training satisfaction, employee benefits, and incentives on part-time employees' commitment. Int. J. Hosp. Manag., vol. 74, pp.1-12, 2018. doi: 10.1016/j.ijhm.2018.02.011.

[30] EDVINSSON, L.: Developing intellectual capital at Skandia. Long range planning, vol. 30, no. 3, pp.366-373, 1997. doi: 10.1016/S0024-6301(97)90248-X.

[31] BONGOMIN, O. – GILIBRAYS OCEN, G. – OYONDI NGANYI, E. – MUSINGUZI, A. – OMARA, T.: Exponential disruptive technologies and the required skills of industry 4.0. J. Eng., pp. 1-17, 2020. doi: 10.1155/2020/4280156.

[32] JIAO, J. – TSENG, M. M. – MA, Q. – ZOU, Y.: Generic bill-of-materials-and-operations for high-variety production management, Concurr. eng., vol.8, no.4, pp. 297-321, 2000. doi:10.1177/1063293X0000800404.

[33] GARCÍA-DOMÍNGUEZ, A. – MARCOS, M. – MEDINA, I.: A comparison of BPMN 2.0 with other notations for manufacturing processes. In AIP Conference Proceedings, vol. 1431, no. 1, pp. 593-600, 2012. doi: 10.1063/1.4707613.

[34] OUYANG, C. – WYNN, M. T. – FIDGE, C. – TER HOFSTEDE, A. H. – KUHR, J. C.: Modelling complex resource requirements in business process management systems, In 21st Australasian Conferences on Information Systems, 2010.

[35] POLDERDIJK, M. – VANDERFEESTEN, I. – ERASMUS, J. – TRAGANOS, K. – BOSCH, T. – VAN RHIJN, G. – FAHLAND, D.: A visualization of human physical risks in manufacturing processes using BPMN. in: Lect. Notes Bus. Inf. Process, 2017. pp. 732–743, doi:10.1007/978-3-319-74030-0_58.

[36] KANG, K. C. – COHEN, S. G. – HESS, J. A. – NOVAK, W. E. – PETERSON, A. S.: Feature-Oriented Domain Analysis (FODA) Feasibility Study, Software Engineering Institute, Carnegie Mellon University, 1990.

[37] MERNIK, M. – HEERING, J. – SLOANE, A. M.: When and how to develop domain-specific languages. ACM computing surveys (CSUR), vol. 37, no. 4, pp.316-344, 2005. doi: 10.1145/1118890.1118892.

[38] CZARNECKI, K. – HELSEN, S. – EISENECKER, U.: Formalizing cardinality-based feature models and their specialization. Softw. Process Improv. Pract., vol. 10, no. 1, pp. 7–29, 2005. doi: 10.1002/spip.213.

[39] Eclipse Foundation, Eclipse Modeling Framework. https://www.eclipse.org/modeling/emf/ (accessed September 20, 2022).

[40] Eclipse Sirius Documentation. https://www.eclipse.org/sirius/doc/ (accessed September 20, 2022).

[41] VUJOVIĆ, V. – MAKSIMOVIĆ, M. – PERIŠIĆ, B: Sirius: A Rapid Development of DSM Graphical Editor, In IEEE 18th Int. Conf. Intell. Eng. Syst. INES, IEEE, Tihany, Hungary, 2014: pp. 233–238, 2014. doi: 10.1109/INES.2014.6909375.

Received April 12, 2023, accepted July 14, 2023

BIOGRAPHIES

Dajana Antanasijević is a teaching assistant and a Ph.D. candidate in Industrial Engineering/Engineering Management at the University of Novi Sad, Faculty of Technical Sciences. Her scientific research is focusing on meta-modeling, domain-specific languages, model transformations, modeling human in Industry 4.0/Industry 5.0.

Sonja Ristić currently works as a Full Professor at the University of Novi Sad, Faculty of Technical Sciences. Her research interests include Database Systems, Software Engineering, Model-Driven Software Engineering, and Domain-Specific Languages.

Marko Vještica is a teaching assistant and a Ph.D. candidate in Computer Science at the University of Novi Sad, Faculty of Technical Sciences. His research interests include meta-modeling, domain-specific languages, model-driven engineering, model transformations, production process modeling and Industry 4.0.

Darko Stefanović is a Full Professor at the University of Novi Sad, Faculty of Technical Sciences. His research interests include ERP systems, e-learning systems, e-government systems, data mining, and business process mining in production planning.

Vladimir Dimitrieski works as an assistant professor at the University of Novi Sad, Faculty of Technical Sciences. With a strong background in the domain of Industry 4.0, (meta-) modeling and data engineering, he has been a part of multiple national, international and industrial projects in these domains.

Milan Pisarić is a Ph.D. candidate in Computer Science at the University of Novi Sad, Faculty of Technical Sciences. He works as an Engineering Manager in KEBA Industrial Automation, on the application of modern technologies in the company's R&D and production departments.