A Cloud-Based Process Planning System in Industry 4.0 Framework

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Abstract. When generating and optimizing process plans nowadays, new concepts and models which consider dynamic harmonization of all participants, systems and people involved in planning stages are applied. A number of systems and environments for distributed process planning that utilize various techniques of intelligent planning and collaborative technologies have been developed in the recent period. Today, a growing number of manufacturing companies adopt the principles of smart factory, also known as the Industry 4.0 concept with the focus on the effective integration of knowledge sources with a production process. This integration uses cloud manufacturing principles whose integral part is the cloud-based process planning. This paper will present such a system that utilizes cloud technology and services for defining process plans as well as expert heuristic knowledge for optimizing process plans and selecting the best solutions.

Keywords: Industry 4.0 · Cloud manufacturing · Distributed process planning · Knowledge sharing

1 Introduction

Industry 4.0 is aimed at creating smart factories where manufacturing technologies are upgraded and transformed by cyber-physical systems (CPS) [1, 2], the Internet of Things (IoT), and cloud computing [3]. Cloud computing represents a framework for the development of Cloud Manufacturing (CMfg) system or service which deploy and manage manufacturing information and sustainable management services for accessing and exploiting over the Internet. Cloud manufacturing represents an advanced production model that combines cloud computing, IoT, virtualization and service-oriented technologies. In this way, manufacturing resources are transformed into services which can be entirely shared and distributed. Industry 4.0 is widely considered as a key enabling technology for cloud manufacturing implementation. The advantages of cloud-based services in manufacturing use include:

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- Efficient resource utilisation and sharing,
- Rapid implementation,
- Frequent innovation,
- Cost savings,
- Scalability,
- Productivity gains,
- Quality and compliance, etc.

Cloud manufacturing integrates the continuous system for data management with the network of digital models, services and applications, including simulation and visualization. As shown in Fig. 1, the common services platform supports the service modules of machine availability monitoring [4], collaborative process planning [5, 6], adaptive setup planning [7], dynamic resource scheduling, process simulation and remote machining are built into the platform [4, 8, 9].

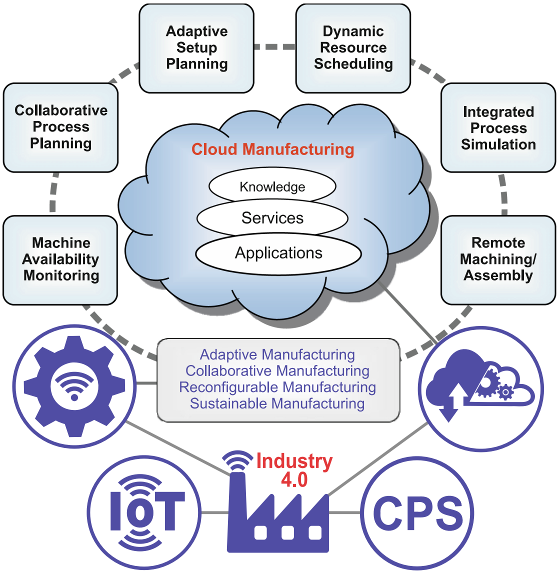

Fig. 1. A Cloud manufacturing platform in Industry 4.0 framework. (Adapted from [4, 8])

Within the cloud itself, products, processes and resources are modelled on the basis of real data. Planned products as well as their processes are being intensively verified and improved by using virtual models until they are fully developed. After all potential faults are removed, the models can be used in real manufacturing. The vision of the cloud-based concept focuses on the integration of available services and tools for planning and control of products at different levels of manufacturing and operational control within a factory. The cloud does not only contain datasets on models, processes and resources, but also the knowledge that is used in the process. As the knowledge within the cloud relates to different elements of manufacturing, it can represent a knowledge repository that includes explicit and implicit knowledge, procedural knowledge, rules, heuristics, expert analyses, decision support, etc. The knowledge has a dynamic character such as a production process - it is modified, complemented and corrected. Shaping knowledge in this environment is initiated by an intelligent system or a human. Industry 4.0 implies the implementation of Machine to Machine (M2M) communication which significantly reduces the direct involvement of a human in a manufacturing process. Given the tendency for cloud services to be autonomous and intelligent, in other words to represent smart objects, cloud-based manufacturing often utilizes multi-agent technologies and various methods of self-organization and coordination between agents [10–12] as well as function block-based methods [9, 13]. However, regardless of the use of intelligent services, it can be claimed that the influence of engineers and experts, i.e. people in process planning, is still very important [14], especially at the conceptual level. Expert heuristic knowledge is often impossible to fully simulate and represent with the help of existing artificial intelligence methods.

2 Cloud-Based Process Planning

Cloud-based process planning is a technology, in other words, discipline that provides a strategic approach for the development, implementation and optimization of all elements of a production process. That primarily involves the framework which combines digital product with digital processes and resources as well as the integration of a virtual model of manufacturing with a real physical model. Cloud-based process planning system should represent a set of distributed, flexible, open access and intelligent services for process planning in a collaborative environment and should help users to define process plans with required level of detail. These levels are known as meta, macro and micro process planning [15]. Meta or conceptual process planning is performed in order to determine manufacturing process and the machines that fit the shape, size, quality and cost requirements of the parts that are planned. Macro process planning is responsible for the specification of equipment, minimum number of process operations required for manufacturing a part, as well as the operation sequence. Micro process planning refers to the selection of tools, fixtures, generation of the tool paths in manufacturing process (e.g. machining process) and definition of other parameters related to the shop floor operations so that productivity, product quality and manufacturing cost remain optimal. Cloud-based process planning defines a framework that allows integration and coordination in the development of “smart products” and the exchange of information between entities which are parts of services, applications and experts. Collaborative connections are priority and with the development of new products, it is necessary to establish a collaborative process with both customers and suppliers within a common communication infrastructure [16]. In this scenario, defining process plans becomes one of the most important tasks.

3 Conceptual Model of the Cloud-Based Process Planning System

By analysing the necessary tasks of the modern collaborative environment for process planning within the Industry 4.0 and its main components, it leads to the conceptual model of the cloud-based system for process planning (Fig. 2).

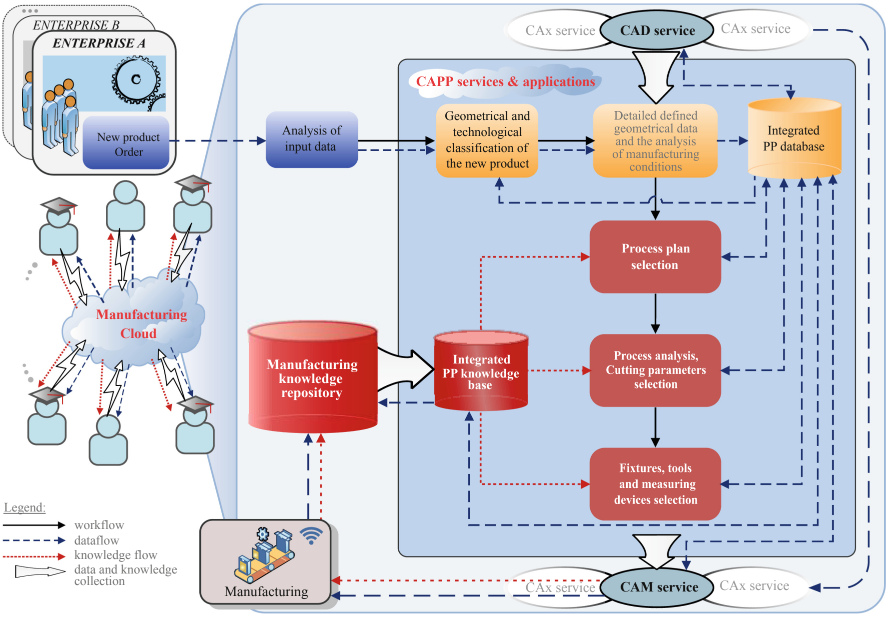

Fig. 2. Model of the cloud-based process planning system.

The core of this system is located in the manufacturing cloud and consists of various services and applications for process planning. Process planning system uses resources of the CAD service from the manufacturing cloud which results in the process plan as the basis for generating NC programs within the CAM service. Besides, different CAx services are simultaneously used in the development and analysis of product life cycle stages.

The module for generating process plans is not fully autonomous due to the reason that engineers and experts are also involved in the optimization of process plans [5, 6]. Human knowledge, experience and heuristics are used for evaluation and ranking of variants of process plans that are generated by CAPP services and applications. Parameters which represent equivalents of the quality of process plans are used for evaluation and multi-criteria ranking of process plans. Experts involved in the optimization are members of a virtual collaborative team and are enabled to work synchronously and asynchronously. Their common and final decision will be the best process plan for specific part family that will be used in manufacturing. Therefore, expert heuristic knowledge will become a part of a production knowledge repository within the manufacturing cloud, also known as the integrated process planning knowledge base (Fig. 3).

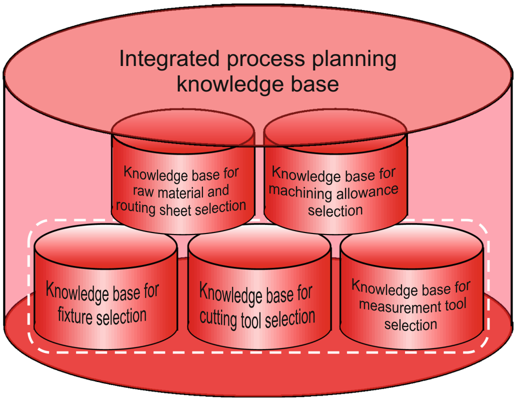

Fig. 3. Integrated process planning knowledge base.

The conceptual model shows the work, data and knowledge flows which represent links between services and applications. Using the dataflow diagram dataflows inside and outside the system can be graphically presented. This way shows the paths through which data groups flow as well as the elements between which the flow takes place. The elements of the graphical presentation of the dataflows consist of processes/ services, data warehouses and objects. Figure 4 shows the main (context) dataflow diagram that is further decomposed so that each function, process or a service at one level is represented with a new dataflow diagram at the next level.

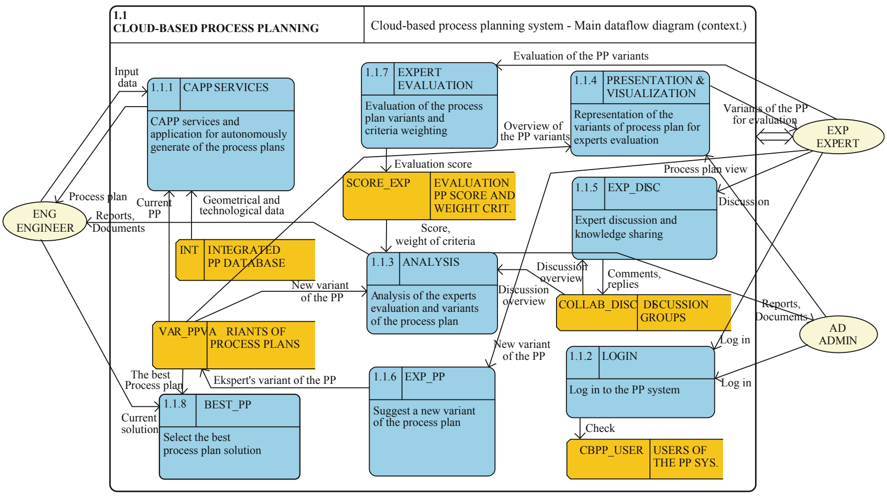

Fig. 4. Main dataflow diagram of the cloud-based process planning system.

All the data used by CAPP services in the cloud are stored in the integrated process planning database (Fig. 5). That is a set of logically divided sets of data for different stages of process planning and defining routing sheets.

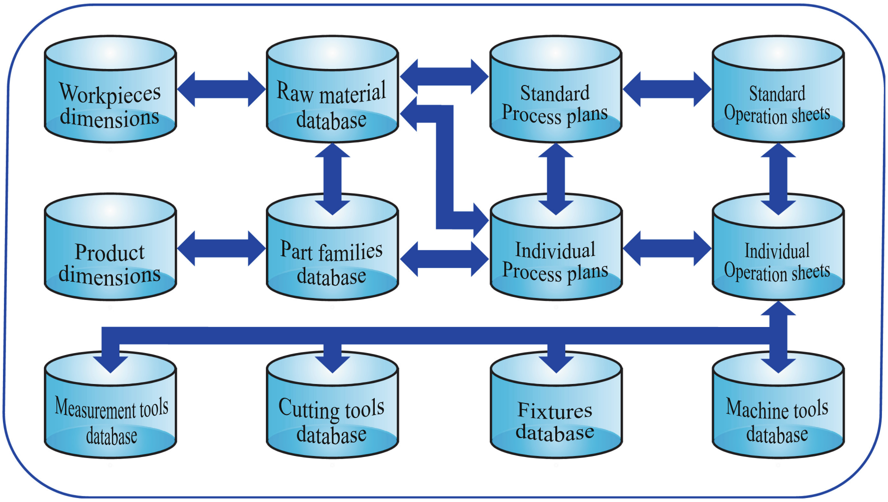

Fig. 5. Integrated process planning database.

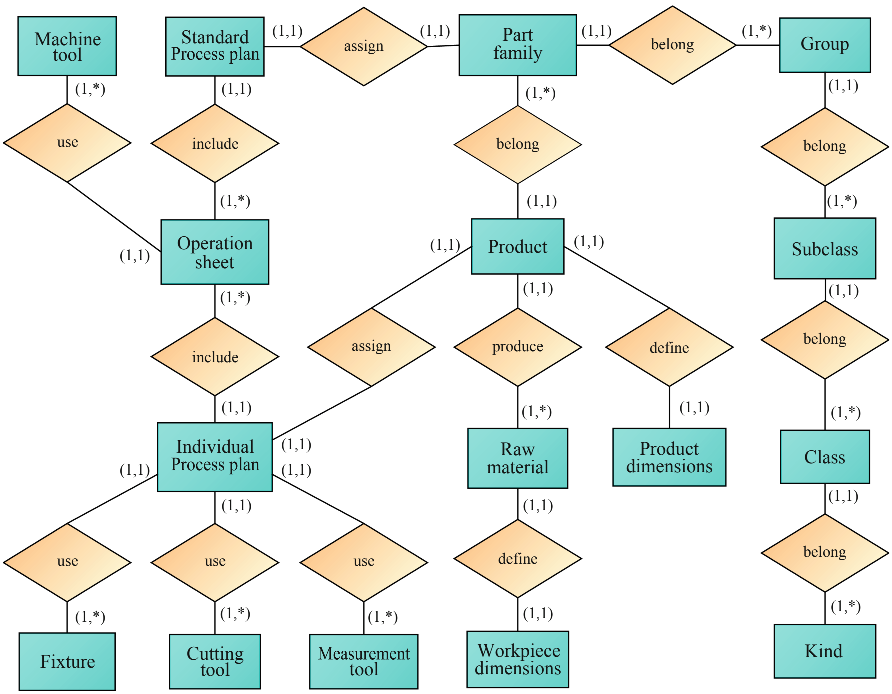

Fig. 6. Segment of the conceptual database schema.

Segment of the conceptual schema of the integrated database that includes entities and relations is shown in Fig. 6. This schema is a part of manufacturing data repository and defines only the entities related to process planning. However, the data repository within the cloud manufacturing structure includes much larger volume of data from all stages of product life cycle.

4 System Architecture and Verification

Figure 7 shows the global architecture of the Cloud-based collaborative system for process planning. Architecture includes a CAPP server, a collaborative server and a database server.

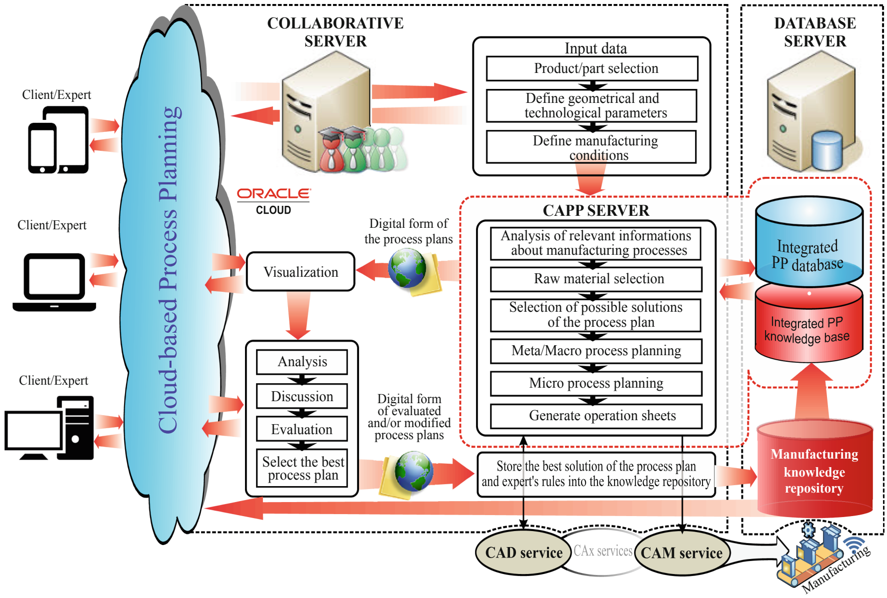

Fig. 7. Architecture of the cloud-based process planning system.

The use of a distributed CAPP server enables the automated generation of process plans on the basis of adequate input data. Functions of the CAPP server are based on the use of autonomous services and applications that are synchronized with the integrated knowledge base. Generated process plans are stored in the integrated database and the final evaluation is made by experts who in that way perform optimization of process plans.

Functions of the collaborative server are to exchange and share knowledge, offer users, primarily experts, insight into appropriate process plans as well as to process and store expert knowledge. With the help of the collaborative server, user requests are processed and forwarded to the database server. The task of these services is also a visualization as well as the realization of expert analysis, expert discussion and expert evaluation with the purpose of finding optimal process plan for observed conditions.

In order to address practical implementation of the proposed cloud-based collaborative system, the verification of the piston-cylinder assembly parts of the internal combustion engine was performed. The system involves the process plans for cylinder liners, ribbed cylinders and pistons. Previously, the part families manufactured within a real enterprise were defined in the system. By using the CAPP service, variants of process plans were generated at the meta and macro level. The expert team was formed and the proposed routing sheets were evaluated (Fig. 8).

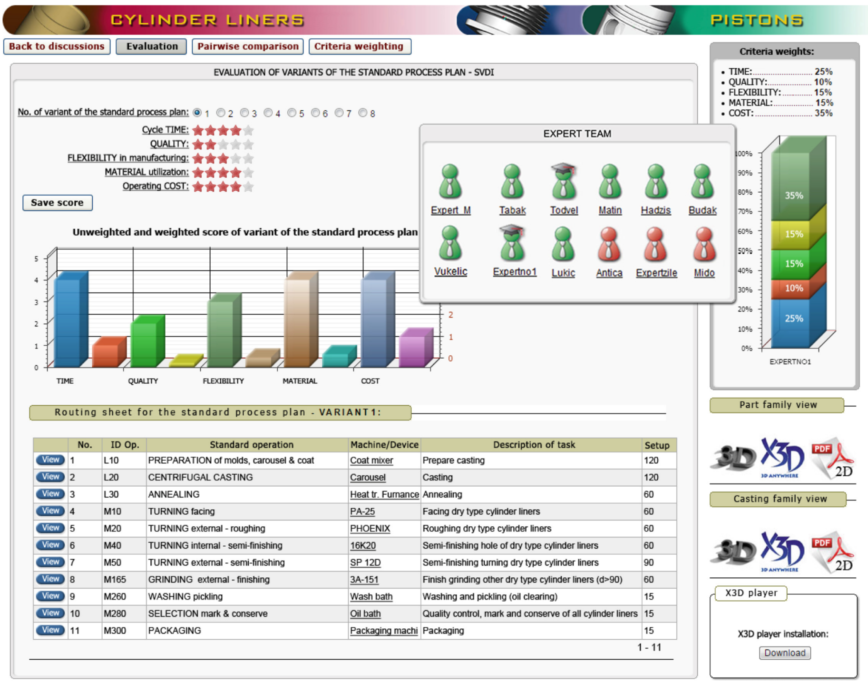

Fig. 8. Evaluation of the process plans routing sheet by the expert team.

Based on the evaluated criteria, the best solution was selected. This solution was further specified at the micro level where the focus was put on the definition of appropriate operation sheets (Fig. 9).

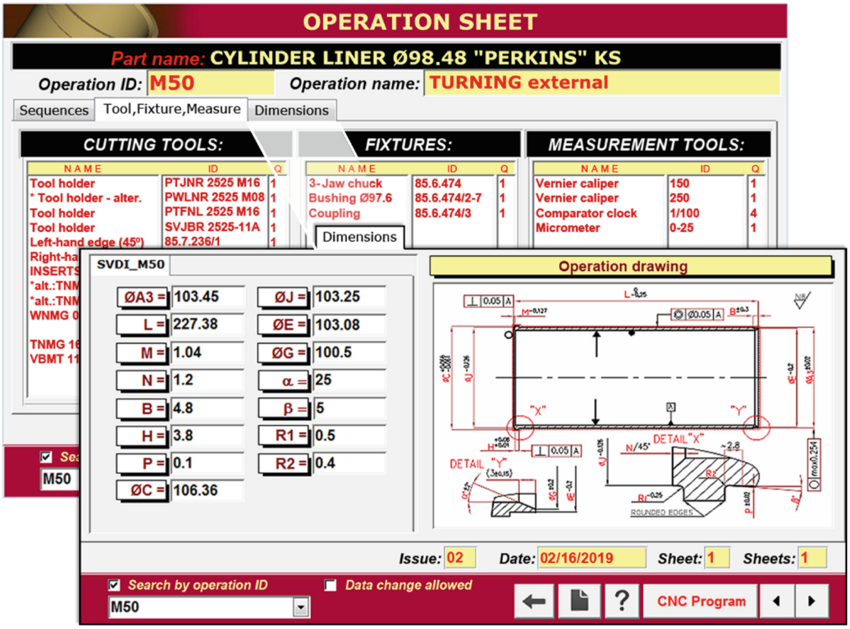

Fig. 9. A detailed operation sheet generated within the system.

5 Conclusion

Firstly, through the analysis of the given system, the significance of the use of cloud technologies in process planning and modern preparation of production were noticed. Thanks to novel technologies included in the Industry 4.0 framework, engineers and experts are able to create efficient virtual design environments that function globally within the manufacturing cloud.

The implementation of autonomous intelligent services enables the automated generation of process plans, but the influence of humans within the process planning at the conceptual level still remains very important. Therefore, the presented cloud-based system offers dislocated development teams and process planning experts to collaborate and exchange knowledge. Experts in a collaborative process can evaluate existing process plans, perform their modifications and suggest entirely new process plans. In addition, the system provides collection of expert heuristic knowledge within an appropriate manufacturing knowledge repository at the level of a distributed enterprise.

References

1. Garcia, D.J., et al.: Sustainable manufacturing with cyber-physical discrete manufacturing networks: overview and modeling framework. J. Manuf. Sci. Eng. Trans. ASME **141**, 021013 (2019)
2. Majstorović, V.D., et al.: Cyber-physical manufacturing in context of industry 4.0 model. In: Lecture Notes in Mechanical Engineering, pp. 227–238 (2018)
3. Zhong, R.Y., Xu, X., Klotz, E., Newman, S.T.: Intelligent manufacturing in the context of industry 4.0: a review. Engineering **3**, 616–630 (2017)
4. Wang, L.: Machine availability monitoring and machining process planning towards Cloud manufacturing. CIRP J. Manufact. Sci. Technol. **6**, 263–273 (2013)
5. Milošević, M., Lukić, D., Borojević, S., Šimunović, G., Antić, A.: A model of collaborative process planning system (E-CAPP). Tehnicki Vjesnik/Technical Gazette **24**, 97–103 (2017)
6. Milosevic, M., Lukic, D., Antic, A., Lalic, B., Ficko, M., Simunovic, G.: e-CAPP: a distributed collaborative system for internet-based process planning. J. Manuf. Syst. **42**, 210–223 (2017)
7. Mourtzis, D., Vlachou, E., Xanthopoulos, N., Givehchi, M., Wang, L.: Cloud-based adaptive process planning considering availability and capabilities of machine tools. J. Manuf. Syst. **39**, 1–8 (2016)
8. Bi, Z.M., Wang, L.: Manufacturing paradigm shift towards better sustainability. In: Li, W., Mehnen, J. (eds.) Cloud Manufacturing: Distributed Computing Technologies for Global and Sustainable Manufacturing, pp. 99–119. Springer, London (2013)
9. Wang, X.V., Givehchi, M., Wang, L.: Manufacturing system on the cloud: a case study on cloud-based process planning. Procedia CIRP **63**, 39–45 (2017)
10. Wang, S., Wan, J., Zhang, D., Li, D., Zhang, C.: Towards smart factory for industry 4.0: a self-organized multi-agent system with big data based feedback and coordination. Comput. Netw. **101**(4), 158–168 (2016)
11. Leitão, P.: Agent-based distributed manufacturing control: a state-of-the-art survey. Eng. Appl. Artif. Intell. **22**(7), 979–991 (2009)
12. Sarkar, A., Šormaz, D.: Multi-agent system for cloud manufacturing process planning. Procedia Manuf. **17**, 435–443 (2018)
13. Givehchi, M., Haghighi, A., Wang, L.: Cloud-DPP for distributed process planning of mill-turn machining operations. Rob. Comput.-Integr. Manuf. **47**, 76–84 (2017)
14. Trstenjak, M., Cosic, P.: Process planning in industry 4.0 environment. Procedia Manuf. **11**, 1744–1750 (2017)
15. Siller, H.R., Vila, C., Estruch, A., Abellán, J.V., Romero, F.: Managing collaborative process planning activities through extended enterprise. In: Wang, L., Nee, A.Y.C. (eds.) Collaborative Design and Planning for Digital Manufacturing, pp. 153–185. Springer, London (2009)
16. Brettel, M., Friederichsen, N., Keller, M., Rosenberg, M.: How virtualization, decentralization and network building change the manufacturing landscape: an industry 4.0 perspective, world academy of science, engineering and technology. Int. J. Inf. Commun. Eng. **8**(1), 37–44 (2014)