Basic Technologies and Models for Implementation of Industry 4.0

Karabegović, Isak

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Cloud Manufacturing System for Collaborative Process Planning

Mijodrag Milosevic[*1]

Abstract: *The tendency of accelerated development of Cloud technologies enables the development of distributed application systems, which overcome traditional physical and time limitations, with the help of which geographically dislocated users, systems, resources and services are connected. The creation of an efficient, flexible collaborative environment in the field of designing manufacturing process plans is made possible by the use of Cloud technologies as well as advanced technologies from the business domain of modern manufacturing enterprises. This environment enables collaboration of project teams based on the exchange of digital information, thus ensuring greater innovation and better quality, while reducing costs and time needed to bring a new product to market. The paper will present one such Cloud manufacturing system intended for collaborative design of process plans in manufacturing.*

Keywords: *Industry 4.0,cloud manufacturing, process planning, collaborative engineering*

1. Introduction

Frequent product-related changes result in the emergence of multiple product variants, and distributed collaborative engineering brings new tools and methods for more efficient work administration during all phases of the product life cycle, for different product variants and customer needs [1]. Using CloudManufacturingSystem (CMS), designers, engineers and experts canexchange and share tasks and knowledge on a global level. In modern conditions, the production of complex products is realized in a large number of enterprises based on the principles of distributed production. Enterprises are specialized in partial process plans. Complex products, consisting of a large number of parts, components and modules, are assembled into a functional unit in one enterprise, but their parts are produced in different parts of the world [2]. Therefore, improved coordination is needed between teams collaborating from different places on the same manufacturing project. Design of Manufacturing Process Plans (MPP) is one of the very important tasks to be solved in a distributed production environment, in which different enterprises participate in collaborative product development [3].Activities related to the design of MPP

[*1] University of Novi Sad, Faculty of Technical Sciences, Department of Production Engineering, Novi Sad, Serbia, E-mail: mido@uns.ac.rs

are most often implemented at the intra-enterprise level using the CAPP system. In doing so, procedures are applied and executed that take engineering drawings, lists of materials and other technological specifications as input information in order to identify and select main processes, resources, sequences, operations and other parameters that are necessary to transform the raw material into a final product. CAPP tools integrate decision-making mechanisms and knowledge rules and build the basis for defining MPP, but their integration with other functions in the enterprise, such as financial flows, production planning, management of production resources, quality control, procurement, etc., is not simple at all. Nevertheless, this integration is necessary in enterprises that participate in a collaborative process with other enterprises in order to accelerate the development of new products, where the main motive is competitiveness on the global market. A network of enterprises participating in collaboration that includes both suppliers and end users can be defined as an extended enterprise [4]. The purpose of this integration is to achieve competitive advantage by maintaining distributed collaboration throughout the organizational structure. The functioning of the expanded enterprise is based on the use of the Internet technologies, because in this way the infrastructure is provided, by means of which information is simultaneously available to all participants in the planning of the production process, be it designers, experts, production managers, production workers, etc. Therefore, in Industry 4.0 concept, new paradigms are being introduced that combine Internet technologies and manufacturing, such as Cloud Manufacturing (CMfg) [5] and Industrial Internet of Things (IIoT) [6]. However, from the point of view of designing MPP, integration is often slowed down by various limitations. These are the most common limitations in the integration of CAD/CAPP/CAM systems, as well as limitations regarding information on technological capacities and resources, which are necessary for dislocated experts to design MPP.These problems can be solved using cloud-based, distributed, flexible, open systems for designing MPP in a collaborative environment. A system for collaborative process planning must help users to define MPP with the required level of detail. A common scenario of an expanded enterprise is the case when there is one enterprise, which uses the production services of another, geographically distant enterprise, in order to produce the necessary quantities of products while meeting the appropriate quality, costs and delivery time [4]. It is common for the observed production enterprise to require the design of its MPP in a collaborative environment, with the aim of taking into account the knowledge and experience of people from production, so that the MPP is efficient. In order to achieve this, it is necessary to identify all collaborative activities and flows of information and knowledge and integrate them into a collaborative cloud manufacturing environment that enables good engineering communication and coordination.

2. Development of the Cloud-Based Collaborative Environment

A CMS for collaborative design of MPP should ensure effective cooperation of all relevant subjects participating in the immediate preparation and planning of production. The basic task of this system is the effective inclusion of appropriate human resources in the decision-making process when defining the MPP of making a certain group of products. However, considering that decision-making cannot be realized without adequate input of geometric and technological data, as well as data on immediate production conditions and resources, the CMS should also provide access to key data on the basis of which appropriate technological solutions will be reached. In addition, the system should enable the archiving of obtained solutions, with the aim of their future analysis and exploitation, as well as the generation of appropriate documentation. Bearing in mind that such a system is applied in conditions of distributed production, the imperative should be the application of modern information and communication technologies, i.e., above all, the application of Cloud technologies. The development of a system for collaborative design implies a preliminary analysis of the collaborative environment in which the planned collaborative activities are implemented.

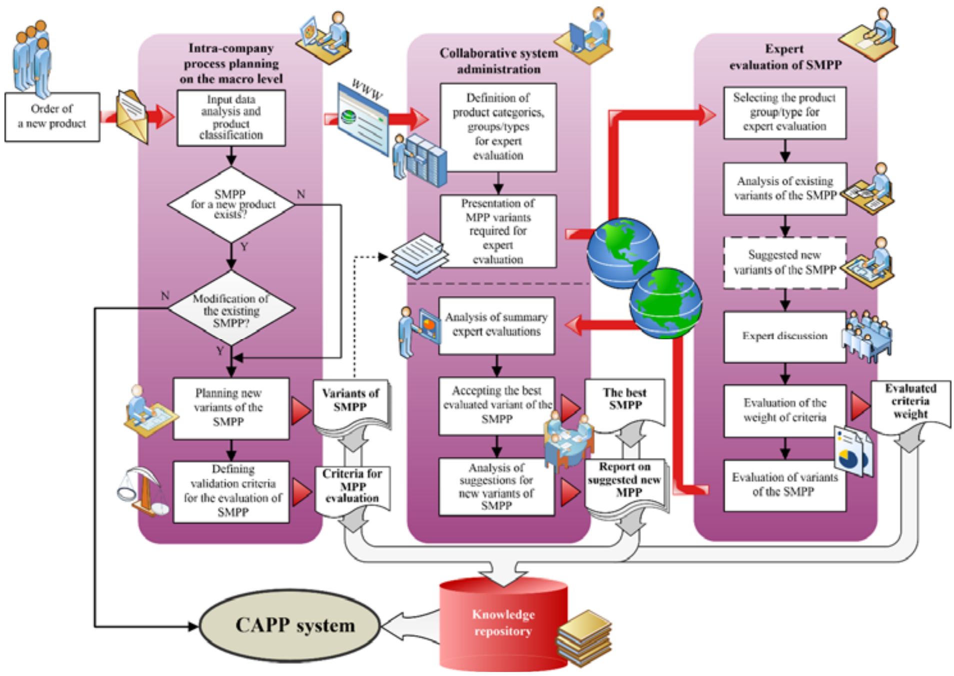

Figure 1.The collaborative environment for MPP [10,11]

One of the entities that initiates the collaborative process is an external enterprise that orders products from the parent enterprise that deals with production, but also with the preliminary design of MPP. The parent enterprise can function in conditions of distributed production, which implies physically separated elements of the production plant, that is, design departments. It goes without saying that this structure of the extended enterprise functions on the principles of e-Manufacturing[7], i.e., Cyber production [8] and that it is necessary to implement an appropriate collaborative system that enables immediate cooperation and quick transfer of necessary information between all segments of the enterprise [9]. The structure of the collaborative environment for MPP designing is shown in Figure 1. In this case, the CAPP system is partially based on a variant process planning technology that uses standard manufacturing process plans (SMPP).

2.1. Modelling of the engineering collaborative processes in the CMS

The presented collaborative environment includes a large number of subjects and factors that base their functioning on the application of the Internet and Cloud technologies [12]. Experts involved in the collaborative process must have access to all necessary data, regardless of their geographic location. Therefore, the CMS should be developed in such a way as to satisfy all the requirements of remote experts and engineers, but at the same time to enable efficient implementation and application within the parent enterprise. One of the basic tasks of the CMS is the collection of expert heuristic knowledge in order to expand the knowledge base for the automated design of MPP. In addition, the system must be reliable and provide adequate protection of data belonging to the parent or extended enterprise.

Bearing in mind the mentioned requirements, one of the primary stages in the development of the system is the observation of key actors in the collaborative environment, as well as their roles, that is, the tasks they perform in the collaborative process. Modeling and visualization of basic entities and processes in the system will be performed using UML, as a standard modeling language.

UML includes information about the static structure and dynamic behavior of the system. A system is modeled as a collection of discrete interacting objects. Static structures define the types of objects important to the system and its implementation, as well as the relationships between objects. Dynamic behavior defines the history of objects in time and the communication between objects to achieve certain goals. Representing the behavior of the system from different perspectives that are interconnected allows a better understanding of the system.

UML allows the construction of diagrams that model the system by describing:

- Conceptual elements (processes, system functions, etc.) and
- Deployment elements (program components, data schemes, etc.).

In addition, UML is used at many different levels and in many stages of the development cycle. The basic diagrams provided by UML, which will be used here in the development of the CMS, are:

- Use case diagrams,
- Sequential diagrams,
- Activity diagram and
- Collaborative diagram.

The use case is a technique used to describe the possibilities of the planned system from the aspect of interaction between the system and the user. Use case diagrams are a way of presenting the functional requirements of a system and describe what the system does, not how. The main objectives of these diagrams are related to:

- Communication between the user and the development team,
- Deciding and describing the functional requirements of the system,
- A consistent description of what the system should do,
- System verification and
- Testing the system and checking the intended functionality.

Figure 2 shows a diagram of the use case of the CMS for the design of MPP, where the main actors, their basic roles and expected interactions in the system are presented. Four types of actors are foreseen in the system: product orderer, engineers, experts and system administrator. Each of these actors has intended roles within the CMS that interact with each other and can be shared and/or extended by other use cases. A detailed analysis of interactions over time between objects is shown by an interaction diagram. UML interaction diagrams show how objects in the system communicate with each other [13]. They show flows through use cases step by step, where you can see which objects are necessary to execute the flow, which actor initiates the flow, which messages are exchanged between objects, and what is the order of sending messages. One of the interaction diagrams is a sequential diagram that shows different processes or objects in the system that exist at the same time, as well as their interactions and the messages exchange with each other. In this way, the graphical display of user scenarios, i.e., objects, life lines, interactions and messages in the system is enabled.

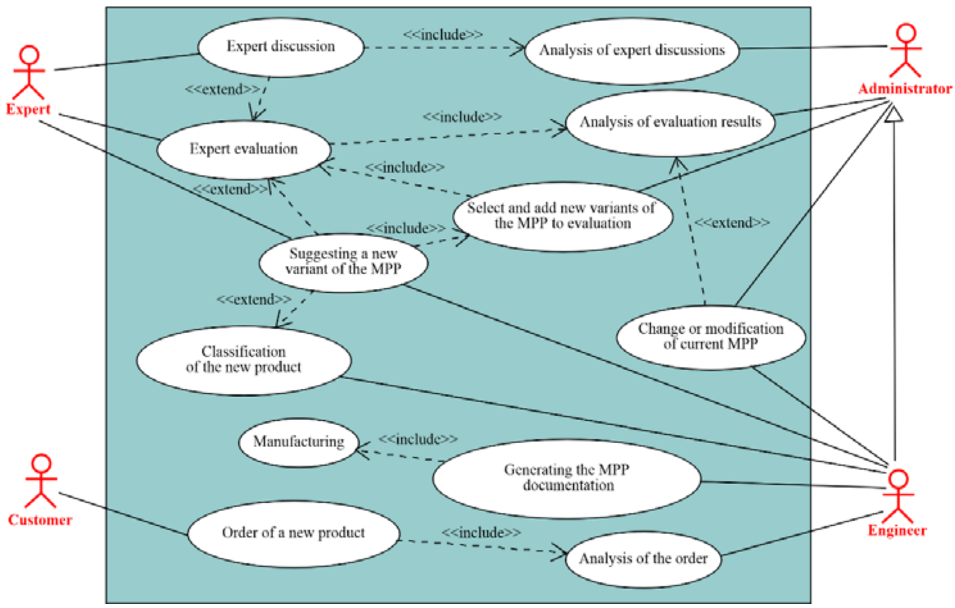

Figure 2.The main use case diagram for the CMS

UML interaction diagrams show how objects in a system interact with each other. They show flows through use cases step by step, where you can see which objects are necessary to execute the flow, which actor initiates the flow, which messages are exchanged between objects, and what is the order of sending messages. One of the interaction diagrams is a sequential diagram that shows different processes or objects that exist at the same time, as well as their mutual temporal interactions and the messages they exchange with each other. In this way, the graphical display of simple user scenarios is enabled. The elements of a sequence diagram are objects, life lines and symbols of interactions and messages.

Figure 3 displays a sequential diagram of collaborative design shown in accordance with the intended use case diagram. The process begins with the ordering of a new product by the customer, after which the technologist analyzes the order and creates variants of typical technological solutions. It is important to note that the collaborative design process can begin even without ordering a new product, if the development of a new product is one of the strategic goals of the parent enterprise or if there is a need to modify existing technological solutions. After that, the administrator selects the proposed solutions and enables their display in the web collaborative environment. Variants of technological solutions are available through the Internet to experts who are registered in the system, where they can propose new variants of MPP, discuss with each other and finally perform an expert evaluation. Expert evaluation consists not only of evaluation of criteria for evaluation of technological solutions, but also evaluation of the importance of individual criteria. The results of expert activities are available via the web to the administrator who analyzes them and generates reports. Engineers, i.e., experts within the enterprise, analyze these reports and make a decision on the choice of the current MPP that will be applied in the future for all products belonging to the observed group.

Team members can propose new variants of MPP, discuss and finally perform an expert evaluation. The parent enterprise analyzes the evaluation results and makes a decision on the selection of the best rated SMPP for the families of parts that will be implemented in the intra-enterprise CAPP system and applied in production in the future.

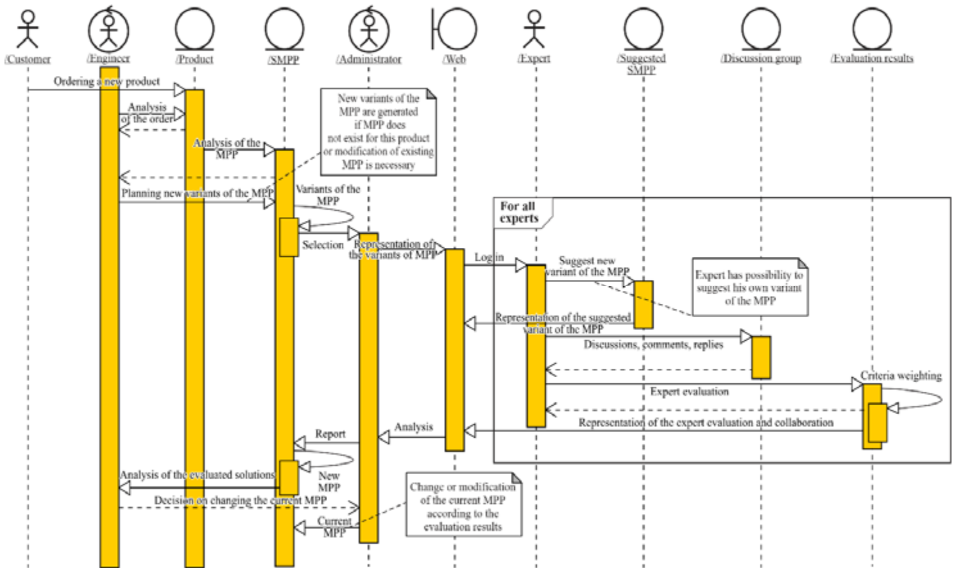

Figure 3.Sequential diagram of collaborative design of MPP

The role of the administrator in the CMS refersto the synchronization of the activities of the collaborative process, as shown in Figure 4. After logging into the CMS, the administrator can add new categories, types and groups of products, as well as variants of MPP that are intended for evaluation.

After the expert evaluation, the administrator analyzes the expert discussions and evaluation results and proposals for new SMPP. The evaluation can be monitored individually for each expert, or by analyzing the evaluations of all experts at the level of the observed product. The arithmetic mean method or the median method can be used to arrive at the best rated variant of a SMPP. On the basis of the performed analysis, a report is generated that will further serve the purpose of making a decision in the parent enterprise for possible changes to the existing MPP. In real manufacturing process, those solutions that are best evaluated or proposed by the experts, will be applied.

The sequence diagram shows the time-distributed administrator interactions within the CMS, as shown in Figure 5. The administrator logs into the system and adds new products, i.e., their variants of technological solutions intended for evaluation. Administration then refers to the analysis of expert profiles, discussions and results of expert evaluations. The proposed new technological solutions equally enter the variants of MPP for a certain type of product. Expert profiles can be deactivated by the administrator, so that their ratings are not included in the final summary analysis and do not affect the outcome of the assessment of technological solutions.

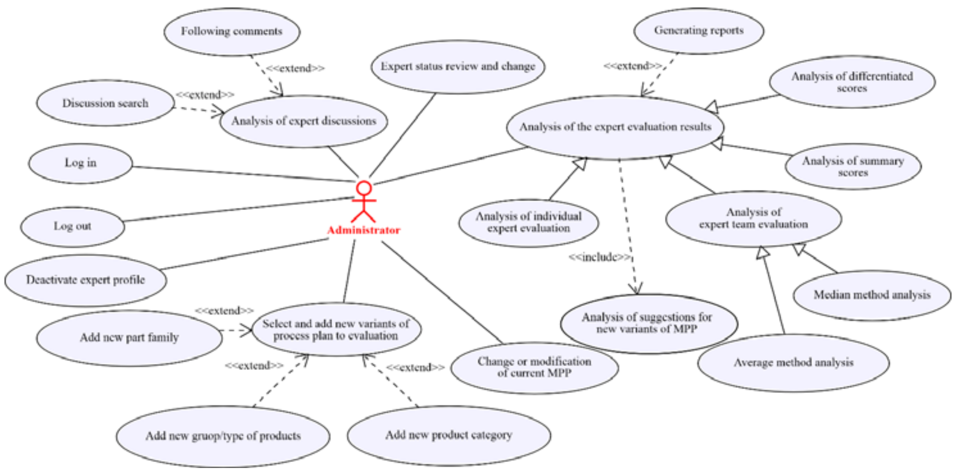

Figure 4. An administrator role in the CMS represented by a use case diagram

After analyzing the generated report, the administrator is enabled to change the current variant of the SMPP in the database, that is, the knowledge repository. From that moment on, for all new products that are determined by classification to belong to this type, the CAPP system will generate the MPP that was best evaluated by the experts.

The activity diagram represents a model of the dynamic behavior of the system. It describes the dynamics of the set of objects and the flow of the corresponding operations. In addition, the activity diagram describes logical procedures, business processes and business flows in the system. Figure 6 shows a diagram of the activities of the CMS, which consists of the corresponding activities and nodes where decision-making, branching or merging are performed. The diagram also shows the division of responsibility for each activity among three main executors: engineers, administrators and experts in three partitions or paths (swimlanes). The activities are arranged by paths, but there is a transition from one path to another.

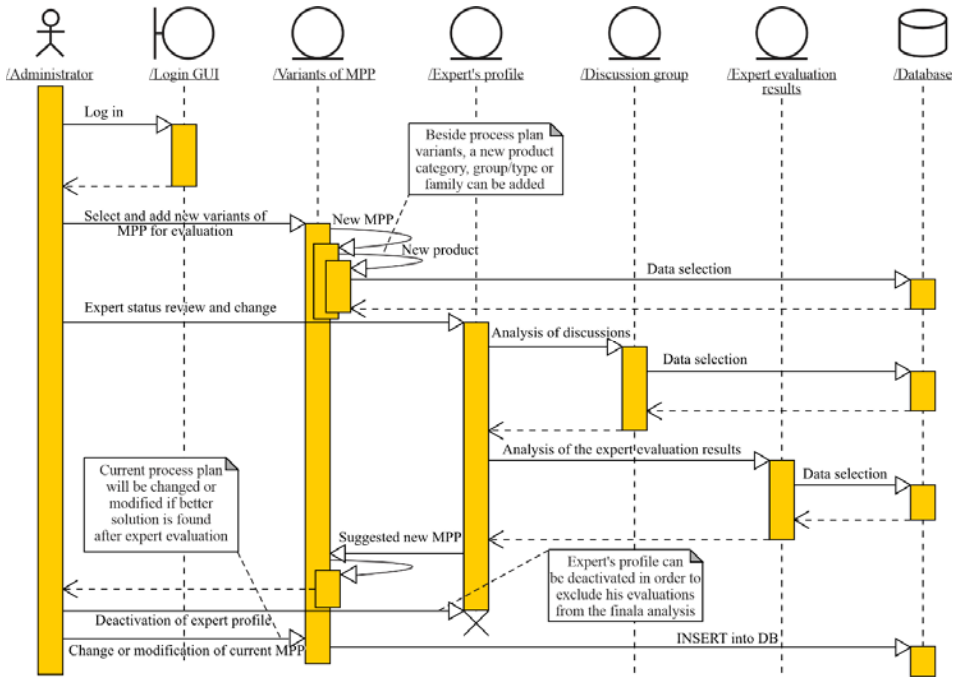

Figure5. Sequential diagram of administrator interactions in theCMS

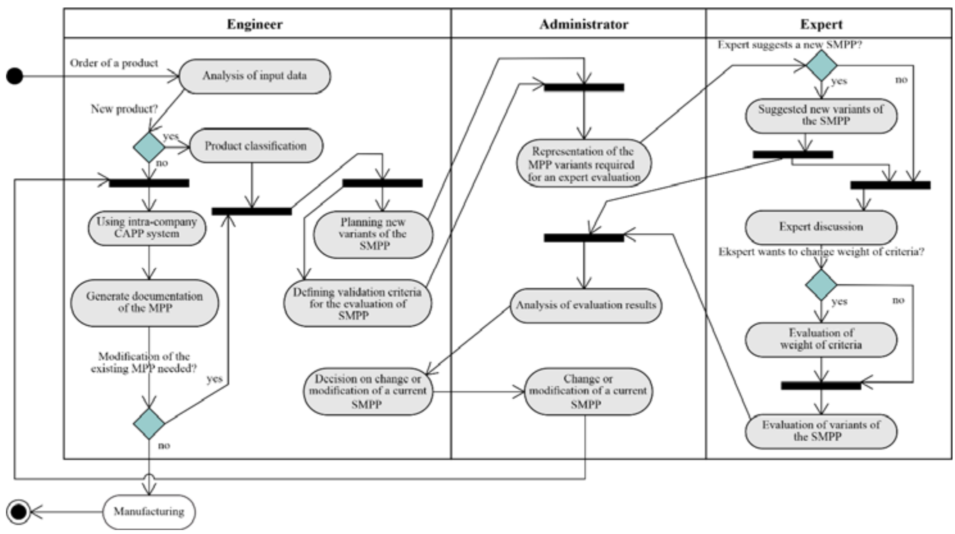

Figure 6. Activity diagram of the CMS

The diagram indicates that the engineer is responsible for the analysis of input data, product classification, the application of the CAPP system, as well as the design of new variants of SMPP. In addition, the engineer determines the criteria according to which the experts should evaluate the MPP and makes the final decision on the eventual change of the current SMPP after the expert evaluation. On the other hand, the administrator mediates between engineers and experts by analyzing their activities and makes the necessary changes in the CMS. The expert makes possible proposals for new variants of technological solutions, participates in the discussion, corrects the importance of the evaluation criteria and, finally, evaluates the proposed variants of SMPP.

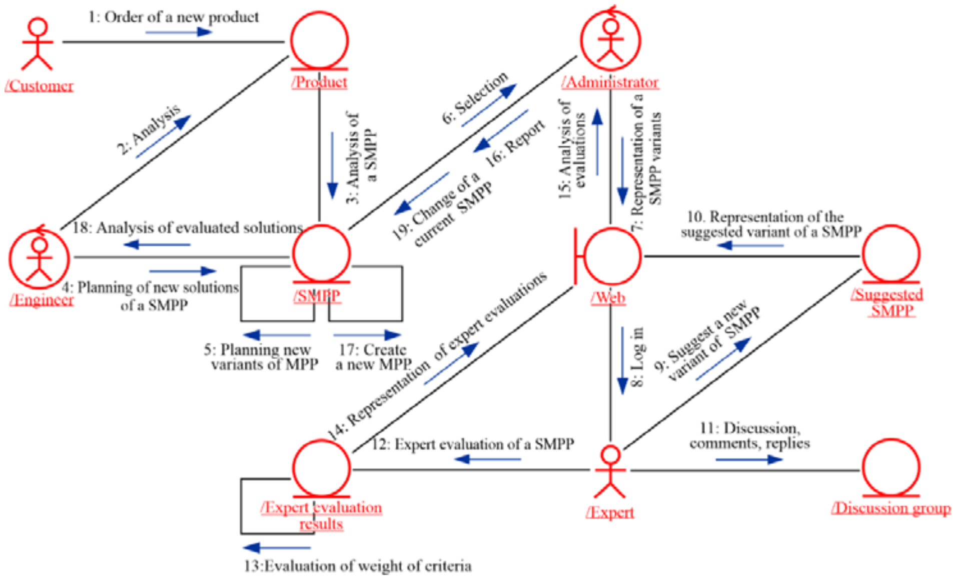

Figure7.Collaborative diagram of the CMS

Based on the presented sequential diagrams and activity diagrams, a corresponding CMS collaborative diagram can be defined, as shown in Figure 7. The collaborative diagram focuses on the interactions between objects in the system and defines their mutual relationships. The goal is to show the collaborative structure and organization of objects, that is, to show the messages that are exchanged between objects in the system.

By monitoring the order and direction of messages exchanged in the system, the flow of the collaborative process can be determined. The collaboration begins with the order of a new product by the external customer of the product, through the creation of variants of technological solutions and their expertise to the final analysis of the evaluated technological solutions and the modification of the current variant of the SMPP.

2.2. Model of the Cloud Manufacturing System

The core of this system is located within the parent enterprise A, whose primary task is related to the design of MPPfor products delivered by external enterprises B, C, etc. The parent enterprise bases its work on distributed design and production and may own enterprise A, in whose production plant direct production is carried out. In addition, bearing in mind the concept of modern distributed production, i.e., e-Manufacturing, it is envisaged that the parent enterprise will be integrated into a distributed network of enterprises, organizational units and experts participating in collaboration and using the Internet as an effective communication infrastructure. Therefore, it can be said that the planned CMS functions within the framework of the extended enterprise.

It is envisaged that the parent enterprise will use a specialized CAPP system designed to automate the design of technological solutions oriented to its own production program. In addition, it is understood that the parent enterprise, i.e., the extended enterprise, operates on the principles of competitive engineering, whereby different CAx systems are used simultaneously in the development and analysis of the phases of the product life cycle. The established model and the planned program solution of the CMS will enable the design of MPP both for the given technological equipment of the parent enterprise and for the technological equipment chosen by the experts, as participants in the collaborative process.

The CMSconceptual model includes two basic groups of experts who participate in the collaboration process:

- Engineers and experts belonging to the parent enterprise and
- Dislocated engineers and experts who are in the organizational structure of the extendedenterprise.

Engineers and experts within the parent enterprise participate in production planning based on the needs of external enterprises, in proposing new technological solutions, as well as in interaction with CAPP and other CAx systems used in design and analysis, as shown in Figure 8. On the other hand, dislocated engineers and experts participate in evaluating proposed solutions, but also in improving existing ones and proposing new, in their opinion, better technological manufacturing processes. The knowledge of all actors in the collaboration is collected and organized in a knowledge repository that is available not only to production but also to organizational structures, i.e., enterprise management. The acquired knowledge will also be used in the application phase of the specialized CAPP system during the automated design of technological solutions for future new products.

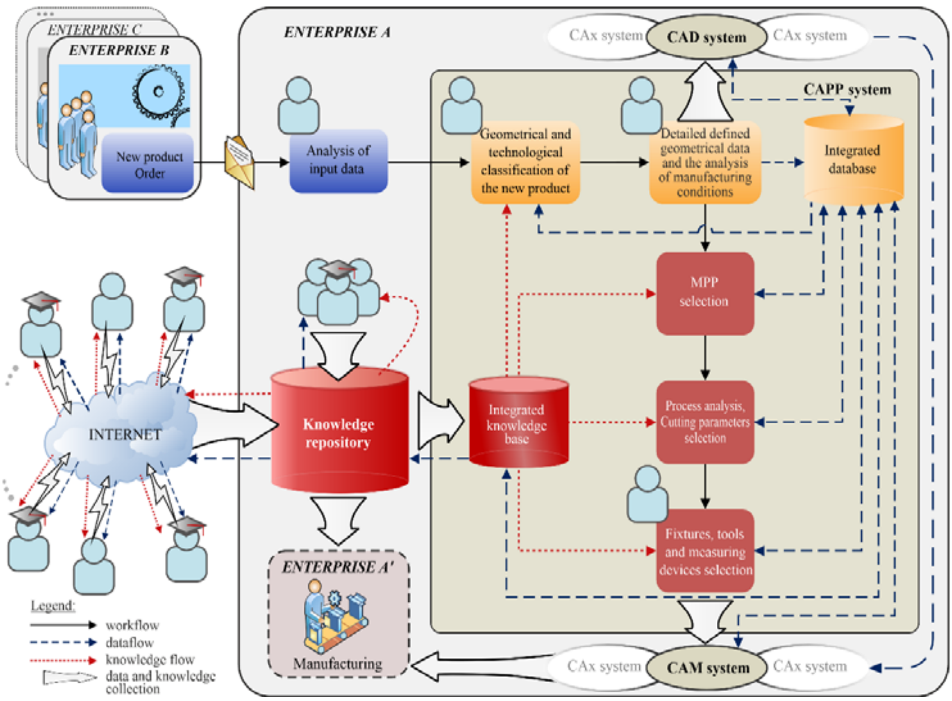

Figure8. Model of the CMS for manufacturing process planning

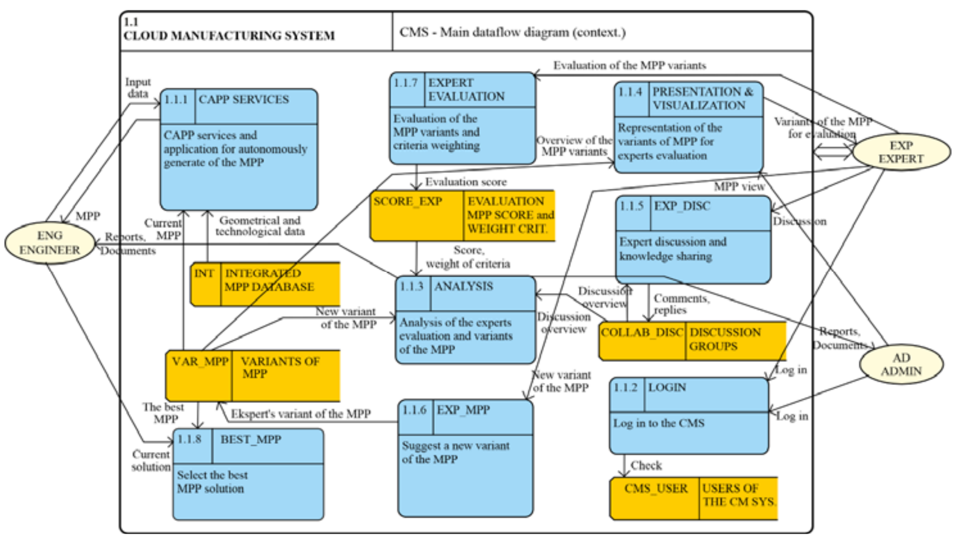

Figure9. Main data-flow diagram of the CMS

The information infrastructure in a CMS includes various flows of information and knowledge, as well as procedures for gathering engineering and expert knowledge, as shown in Figure 9. It is clear that the development of the model structure requires the application of a modern system for managing, organizing and distributing data. In addition to the need for dynamic manipulation of complex information structures, the database system must also enable adequate protection of information that represents a business secret at the level of the extended enterprise.

3. CMS Architecture and Verification

Figure 10 shows the global three-tier architecture of the CMS for designing MPP. The architecture, in addition to clients, i.e., experts, includes a collaborative server as well as a database server.

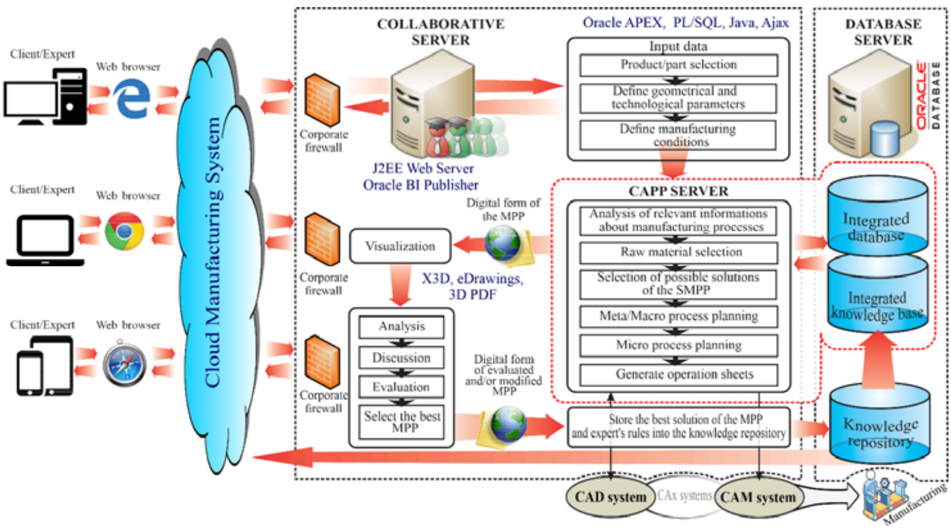

Figure10.Three-tier CMS architecture

The collaborative server has the function of enabling users, primarily experts, to see appropriate technological solutions, and also to enable the processing and storage of expert knowledge. The collaborative server accepts user requests and forwards them to the database server. These requests may refer to the display or writing of the corresponding data organized in the repository. Using the CAPP server, the automated generation of MPP of product creation is carried out on the basis of adequate input data. The functions of the CAPP server are based on procedures within the integrated knowledge base, whereby data on the macro design of MPP are downloaded from the knowledge repository. In this way, it is possible for expert evaluations to directly influence the technological solutions generated in the CAPP server.

The CMS provides expert analysis, discussion and evaluation in order to find the best solution of the SMPP for the given conditions. Experts are not conditioned by owning any commercial system for designing and interacting with a collaborative environment.

Figure 11. Verification of the CMS implementation

In the practical application of the presented CMS, it was performed on parts of the piston-cylinder assembly of the IC engine, which includes MPP for production of the cylinder liners, ribbed cylinders and pistons, as shown in Figure 11. The corresponding families of parts that are produced within the real parent enterprise were previously defined in the preparation phase of the CMS.

4. Conclusion

The development of internet technologies enables designers to effectively communicate, collaborate, share and exchange various resources during the design process. Cloud-based design environments represent a new paradigm in modern product development. Such environments are often used in all segments of product life cycle management, since all product and process data can be represented in digital form. Given that the design of manufacturing process plans represents a very important phase in product development and production preparation, most of the presented research is focused in that direction.
In the paper, first of all, the importance of the application of Cloud technologies in the design of manufacturing process plans and modern preparation of production was observed. Thanks to new tendencies in the development of Cloud technologies, engineers and experts are enabled to create effective virtual design environments that function on a global level.The CMS enables dislocated development teams and experts from the field of MPP design to collaborate and exchange knowledge. In a collaborative process, experts can evaluate existing technological solutions, modify them or propose completely new MPP. In addition, the system enables the collection of expert heuristic knowledge into the appropriate knowledge repository at the level of the extended enterprise.

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