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Digital Manufacturing in SMEs based on the Context of the Industry 4.0 framework – one approach

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Abstract

Serbia is rapidly working on the development and implementation of digital manufacturing models in SMEs, through the national Industry 4.0 Platform. The aim is to create a pilot intelligent workshop which would be used to develop and showcase examples of best practice for digital manufacturing. Currently, most SMEs use CAD, CAM, ERP models, which form the basis for the development of the concept of digital manufacturing through cloud computing, BDA, IIoT and smart supply-chains, as elements of Industry 4.0. This paper gives a practical example of an SME with all the above-mentioned elements of digital manufacturing.

Keywords: Digital manufacturing, SME, case study.

1. Introduction and motivation

Industry 4.0 (I4.0) is a advanced model of automation of manufacturing systems, based on the connection and decentralized control of cyber-physical systems (CPS), using the Internet of Things (IoT) and support by cloud computing and artificial intelligence (AI) [1,2, 6]. I4.0 is a German manufacturing strategic initiative, aimed at the development of smart factories (SF), based on digital manufacturing (DM), which includes elements of I4.0. The aim of this paper is to show how a small and medium size enterprise (SME) in Serbia, develops and applies the concept of DM, as a basis for the application of the Industry 4.0 model in its business. The above example can be a good scenario for other SMEs in Serbia from the same industry, how to implement Project I4.0 in their environment. This paper has several sections: (i) how to start with digital production as a basis, apply the concept of I4.0 for SMEs, (ii) set the DM model for a specific SME, (iii) example of application for SMEs, with discussion and (iv) conclusions and future research.

2. Related works - literature review

The CPSs are one of key factory components based on the I4.0 concept. They are characterized by local information processing, autonomy but also network connection, in order to transfer information from it and use information from the environment for monitoring and control (PLCs (programmable logic controllers), SCADA (supervisory control and data acquisition), MES (manufacturing execution system), ERP (enterprise resource planning)) of the cyber physical production (CPM) [1]. For our research, presented in this paper, the concept of CPM for SMEs is important, for which a case study was done.

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A particularly important segment of the I4.0 application is for SMEs, where we have a new model of automation of technological systems, such as cloud manufacturing (CM). It optimizes the use of hardware / software support for: design and production of the intelligent products based on information technology (IT), automated and flexible connection of the production chains and their generation and interaction through new services and business models [2]. In our research, a model of automatic updating of engineering-production documentation (EBOM / MBOM) and plant-production documentation (ERP) is presented. These two units are interconnected through the manufacturing execution system (MES).

One of the important elements of the I4.0 in practice is the optimization and use of big data analytics (BDA), using artificial intelligence (AI) techniques and machine learning algorithms (ML) [3]. For the field of the production, which is the topic of this paper, ERP (especially intelligent scheduling) and predictive maintenance are the units where this concept is most applied, and some examples for the field of the ERP are given in this paper.

A particularly important segment of the application of DM in SMEs is the real-time work order management (MES) [4,5,9]. The essence is to get feedback information from the plant on the status of work order elements (MES), which in this model is achieved using the Digital Shadows (DS) model. The DS is a DM with one additional automated flow of information between the state of an existing physical object and a digital model, which means that, if the state of a physical object changes, then the state of the digital object automatically changes, but not vice versa [13]. In our case study, a MES model for SMEs is given.

The DM in SMEs are characterized by limited resources (which can be compensated through the CM model), as well as the diversity of customer requirements, which leads to a disproportionate complexity of the management systems and rapid response to these requirements [8]. For these reasons, it is necessary to take into account the stated characteristics when developing the DM model for SMEs, Table 1.

Table 1. The specific differences between various manufacturing system models (adapted from [8])

Characteristics	Manufacturing system (conventional)	Digital manufacturing (DM)	DM in SMEs
Decision-making unit number	Multiple units	Multiple units	Limited
Units association relation	Normative and long-term	Dynamic association	Dynamic association
Responsivity	Low responsivity	High responsivity	Very high responsivity
Control precision	Low control precision	High control precision	Very high control precision
Decision method	All in one decision	Distributed decision	Distributed decision
Optimize target	Local control and optimization	Global control and optimization	Global control and optimization

One of the most important stages of the digital transformation of an SME is the transition to a new business model of information system (ISs), whose framework is the I4.0 model, which was done in our example in the case study. The reengineering process (BPR), from the existing information system, which is characterized by: (i) lack of complete information, (ii) meet limited business needs, and (iii) lack of integration and business intelligence, static of the data and unused of it; the transition to an intelligent business information system, characterized by: (i) autonomous operation and hierarchical networking, (ii) dynamic data structure and their simulation for online operation, digital twin and digital shadow, and (iii) self-optimization (BDA).

A model of the DM information system for SMEs is shown in Figure 1 [10].

In [10] it is stated that modern platforms for the development of enterprise information systems (EIS), such as Industry 4.0, can be a good approach for enterprise development? How? Using social networks, for example, customers define their requirements online, and the company should be ready to satisfy them, preferably immediately or as soon as possible. For that, he needs a new platform for EIS, and our research and example in this paper are on the way to such approaches.

The key elements of ISs in DM model for SMEs are [11,12]: (i) value creation. It is the driving force for the different stakeholders, that make on the core value added business process (innovation in design, planning, or/and manufacturing); (ii) information flows and business process connecting. The SMEs have to monitor the logical structure and flow of business information (request - acceptance - design - planning - production and delivery), through their integration, unambiguity and knowledge creation. But here the importance of interoperability must be emphasized, which is the most important element of this model, which in the DM model, i.e. I4.0, have to be realized; (iii) functional structure. The functional structure is the main form of ISs, based on an advanced management method, the functional structure resolves the enterprise operation management (integrates sub-information systems, and on the functional needs of the department and the cross sectors), and (iv) knowledge management and data stream.

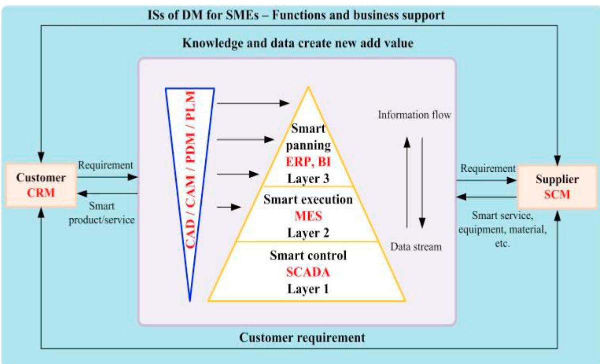

Figure 1. Framework of ISs in DM model for SMSs (adopted from [10])

A production in SMEs is faced daily with the creation of new knowledge, which arises from individual customer requirements for the product. The knowledge are: factual knowledge, conceptual knowledge, procedural knowledge, and metacognitive knowledge, so its processing and use is an imperative of this concept, because it is the basis for the development of SMEs. It is generated from a unique database, from data from the past and present.

This example also provided a framework for the development of our DM for SMEs, which was presented as case study.

In [9] the general framework of the NIST-defined smart manufacturing model is presented, which makes up the DM infrastructure that can be applied to SMEs, Figure 2 [9].

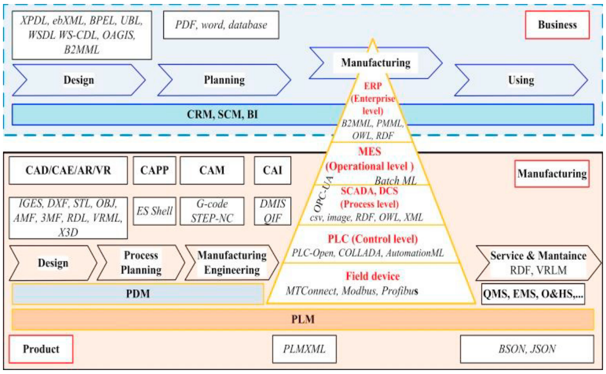

Figure 2. DM framework supports various data formats (adopted from [9]).

The general structure starts from three units, which can be recognized in conventional technological systems: (i) business (sales (CRM), procurement (SCM), general business functions (BI)), (ii) manufacturing, which includes engineering functions design (CAD / CAE / PDM), planning (CAPP / CAM / QMS / CAI), and production (with four levels of management (PLC, SCADA, MES and ERP), including maintenance and (iii) product, which integrates all digital lifetime information (PLM), including EOL (end of life). All three elements of this digital infrastructure are supported by different languages (XPDL, B2MML, LISP, PROLOG, ES Shell, ...) for modeling business and technological processes, and standardized formats (IGES, DXF, STL, ...) for data exchange in the digital platform that makes up the overall DM model.

The subsection 3.2 presents some examples of our research, which relate to previous considerations.

3. Problem description and model formulation

3.1. Basic framework

When we consider the detailed structure of the Industry 4.0 model, we can conclude that there are forty-five elements, which are applicable in large organizations. Our research shows that this model for SMEs in the field of manufacturing should have between fourteen and twenty-two elements depending on the type of manufacturing that SMEs are engaged in. For the organization from the example in this paper, that number of elements is 22.

Our research shows that MES is a key element for the development of the DM model, as a basis for I4.0 in SMEs. In the context of I4.0, the framework, today's trends for development and implementation, as well as the functions of MES are [11,12,13]: (i) completion of the technical-technological information on the product (EBOM, MBOM), (ii) macro and micro production planning and scheduling (ERP), with their online monitoring and re-scheduling of work orders (records of lots, orders and resources), by applying the advanced optimization algorithms, (iii) collection and exchange of the production data, coordination and monitoring of the production quality compliance, at the CPS level, including QMS, EMS, ..., (iv) managing the resources required for all types of data, which are necessary to calculate the optimal production plan online, (v) monitoring and managing the content of the intranet at the plant level, (vi) coordinating vertical and horizontal integration in the CPM model, (vii) monitoring the efficiency of production, with visual and graphic exchange of information, (vii) predictive and corrective maintenance, monitoring and emergency management (viii) statistical analysis and synthesis of big data sets, with the provision of additional services based on them, and (ix) exchange of information with supply chains (SCM) and product life cycles (PLM).

3.2. Case study

As it following real examples of DM from SMEs are given, in the text that follows. How to establish and operate a digital chain in SMEs, which includes elements (Table 2) are most important.

Table 2. The elements a digital chain in SMEs

Design, construction - CAD, CAM, CAE, CAI CAD bill of parts, 3D model - BOM Manufacturing technology, 3D model, Simulation - CAM, CAI CAD bill of parts, CAPP bill of parts - EBOM Monitoring of the change process, ... Quality, Quality Control Plans, FMEA, Procedures ... Certification, regulation, traceability - QMS, EMS, ... Maintenance planning and management - AR / VR	**PDM**
CAM bill of parts - MBOM Procurement and Supplier Management - SCM Customer Relationship Management - CRM Employee resource planning - HR Work order, Production planning and monitoring (scheduling) - ERP Inventory management, warehouse operations (materials, tools, ...) Packaging bill of parts Delivered bill of parts Service management Monitoring of products in exploitation Accounting, finance	**mMES/ mERP**

The request for product offer is generated in the CRM (customer relationship management) module, after accepted by the customer translates into a request for production and planning orders as part of the system - business information system - Iss (CRM module (purchase order / delivery note created directly in ERP). Thus, it becomes part of a unique database system (DB), so the designer, based on standard dimensional parameters of previous projects, automatically generates a typical or special CAD model (3D model of the part, component (structural, quantitative, modular)) - EBOM. In the next phase, the designer generates a typical CAM technology for the CAD model, which includes: the sequence of manufacturing operations + cutting tools, as well as cutting parameters + machine tools (3D machine model - digital twin) - MBOM. After the CAM documentation, the system in the next phase generates a CAQ (quality control plan for the part, as part of the ISO 9001 model). In the next step, mERP (mini ERP - for SMES) forms a set of work order: sheet of tools and fixture, sheet of heat treatment, sheet of quality control, calculates the costs in plant, gives the plan of final control. The SCM module defines the procurement and quality control plan of input materials and raw materials and thus forms a unique system of the digital chain model for the product that will be made in the planned quantity with a defined deadline, which is included in an unique system of classification of the business factors. The PDM system is now in full application, which means that a system for product variants and projects has been established. It is possible to place it on the cloud, and it is possible to expand it to a PLM system that would at this moment move from the product level to the digital level of the production program, also to the cloud. The ensuring traceability and tracing errors is done backwards, through delivery requests and work orders, through mERP, because in it they are connected through levels (higher and lower). The MES system works online, because a digital chain of production monitoring is provided. This means that the mERP system is monitored online, so the business plan is made on an annual basis, the production and delivery plan on a monthly basis and the term production plan on a weekly basis, Figure 3.

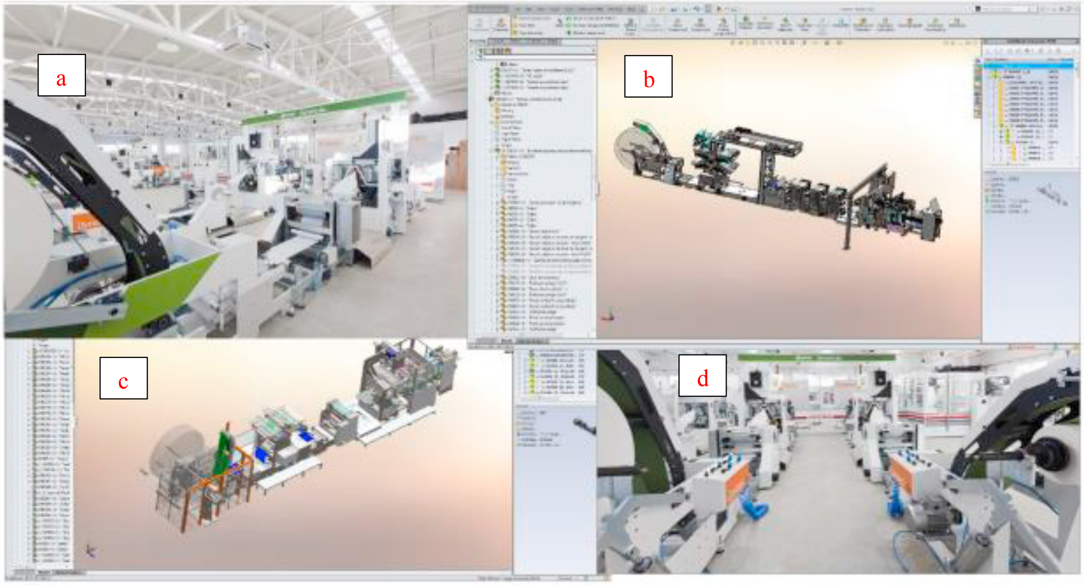

Figure 3. An example of PDM output for SMEs in the DM model - a) real machine in assembly and trial operation, b) 3D model - EBOM, c) digital twin machines, d) machine in exploitation - MES.

The following example is part of the mMES (mini MES for SMEs) module - MBOM technology component for parts of product from Figure 3, Figure 4.

Figure 4 shows a dialog box within which technological operations are defined with their order and execution times. All information is actually entered on a 3D model of the projected part or assembly. A characteristic of this approach is that this information is transmitted by copying 3D models, which significantly reduces the time of technology development in new constructions. This approach makes sense for companies that produce products to customer order or that configure products to market demand, where the product itself has a large number of components that are variable from project to project.

Although this approach can be used with simpler products with fewer parts being produced, in these situations it is not crucial for user productivity.

An extremely important aspect of mMES is the online monitoring of all elements of the work order, Figure 5.

MES software automatically reads the information of approved items from the PDM / PLM system for the management of the construction and technological documentation (EBOM / MBOM) and it always contains the current version of the information needed in production.

MES software has two modes of operation, one is based on printed work orders where scanning the bar code of the technological operation initiates the process of monitoring production through a web application and second, if necessary, the process of recording control characteristics of parts based on prescribed AQL. The application also records information about the operators, machines, measuring and control accessories used for a specific item and a specific work order.

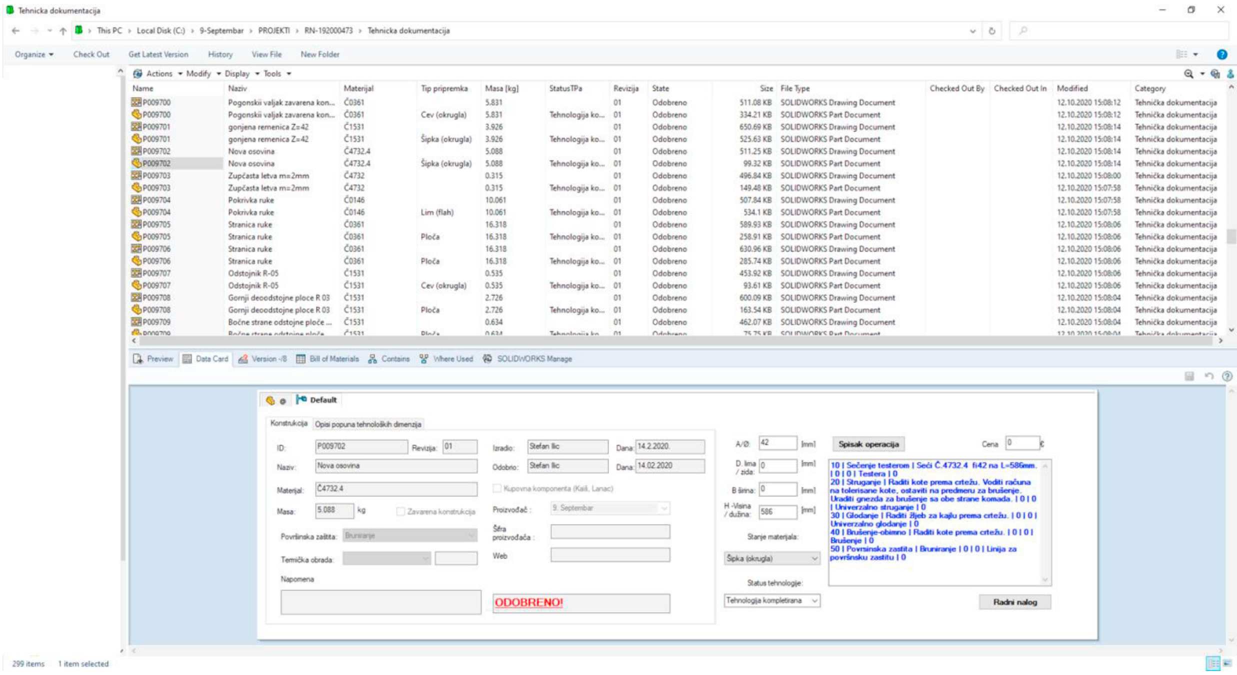

Figure 4. MBOM for the product

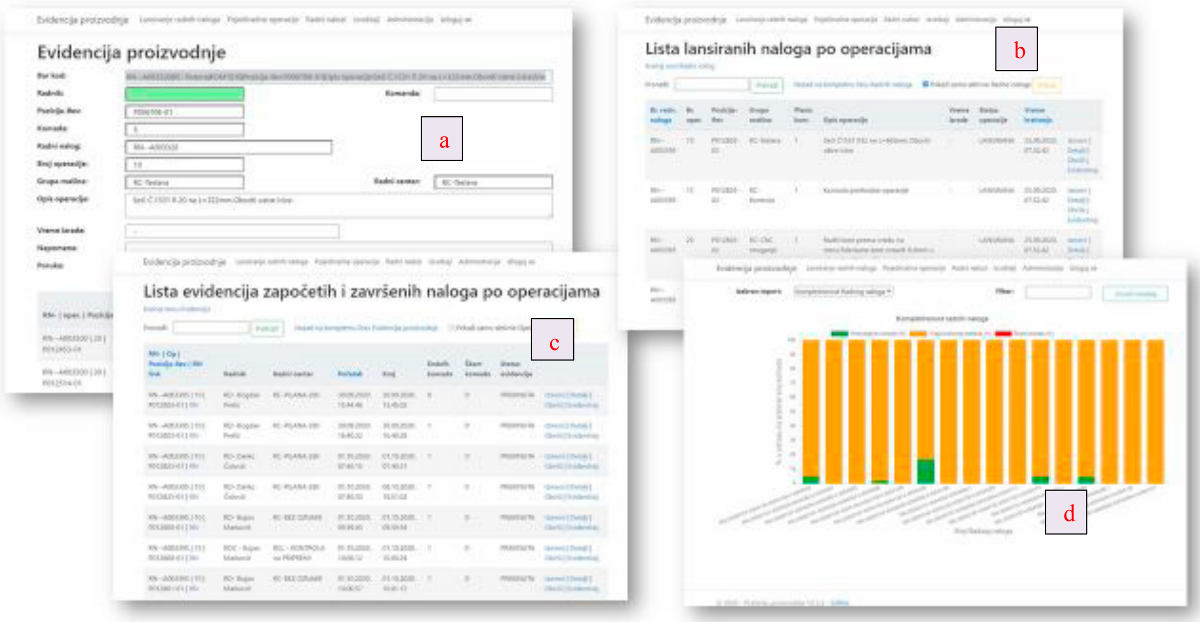

Figure 5. The work order monitoring - a) production records, b) list of the launched work orders by operations, c) list of records of started and completed work orders by operations, and d) histogram of completeness of the work orders

One of the most important features of this concept (DM) in practice is online reporting, Figure 6.

All information related to product design projects, technological procedures and information on the status of work orders in production can be summarized on control panels in accordance with the wishes of users.

Control panels are updated in real time.

All the above examples represent good manufacturing practice according to the DM model, with elements of Industry 4.0, which raises the competence and competitiveness of domestic industry in the international market.

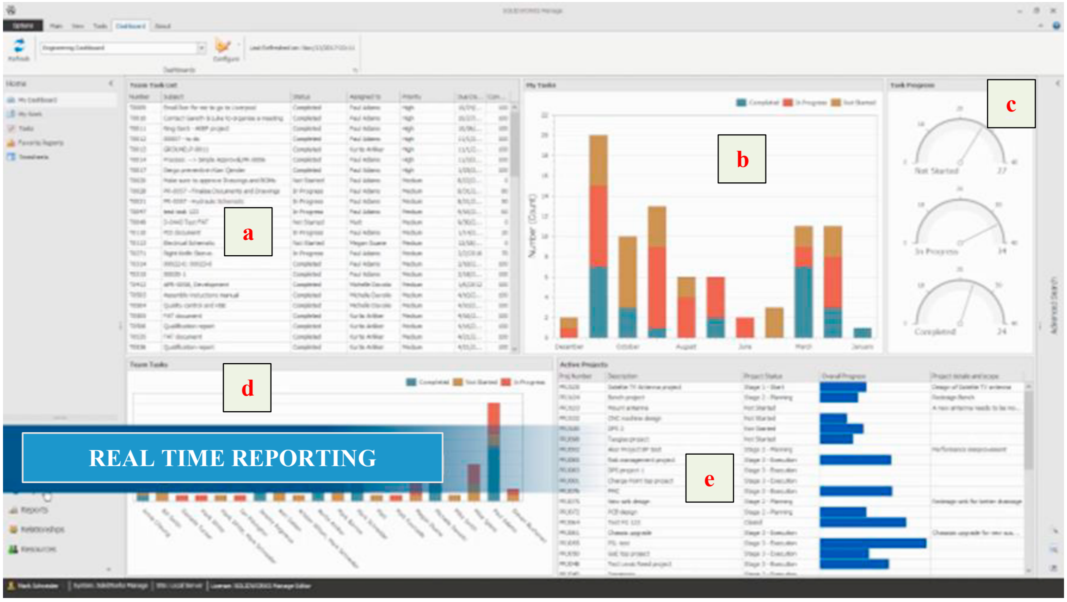

Figure 6. Real-time reporting - a) team list and their tasks, b) histogram of the state of execution of tasks per person, c) graphical presentation b, d) histogram of the state of execution of tasks per team, e) overview of projects and % of their execution.

4. Conclusions and future researches

In Serbia, the National Platform for Industry 4.0 has been created and adopted, which means that in the triangle: decision makers (government, ministries, economic associations) - scientific community (faculties, institutes) - economy (primarily SMEs) organized systematic efforts to implement Industry 4.0 [7]. On the other hand, the Faculty of Mechanical Engineering in Belgrade has organized five international Conferences on the Industry 4.0 Model for Advanced Engineering / Manufacturing - Industry 4.0 and Smart Manufacturing since 2015 and held 28 Panels about Industry 4.0. This has led to the fact that digitalization is an imperative of the moment in the development of the Serbian economy, and Industry 4.0 is the goal to be pursued. The considered examples in this paper are the best practice of DM, which is spreading more and more in Serbia. Currently, more than 20 SMEs are working on DM projects in their environment. The future MEF research in this area will relate to the application of the intelligent CAI model in DM, which was developed in the previous period.

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