Integrating Digital Factory, Lean Management and Industry 4.0 into the Learning Factory – Case Study at University of Split

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Abstract

The Learning Factory's mission is to integrate those needed knowledge into the engineering curriculum. Therefore, Learning Factory at FESB (University of Split) is in continuous development and improvement process to support practice-based engineering curriculum with possibility of learning necessary tools and methods, using real life and didactical equipment. In this research a concept of Triple helix model connected via Learning Factory concept is presented. Learning Factory could be place where University, Industry and Government meet each other, share needs and expectations, and work on collaborative projects. It could be a solution of a missing link in Triple helix model. Learning Factory at FESB, based on a didactical concept emphasizing experimental and problem-based learning using tools and methods from Lean management, Digital Factory and Industry 4.0.

Keywords: Industry 4.0, Smart enterprise, Learning Factory

1. Introduction

The process of globalization, liberalization of international trade and the global economic crisis in 2007 showed that the classical vision of the enterprise and its business activities cannot survive in today's turbulent economy. Globalization has created new enormous challenges for today's enterprises: fierce competition, frequent product introductions, and rapid changes in product demand. Many manufacturing enterprises have moved away from a mass production orientation to more agile production approaches. The challenge is to succeed in a turbulent business environment where all competitors have similar opportunities, and where customer wants personalized product (Koren, 2010).

Furthermore, the first three industrial revolutions came about as a result of mechanization, electricity and IT. Now, the introduction of the Internet of Things and Services into the manufacturing environment is ushering in a fourth industrial revolution: Industry 4.0 (Kagermann, Wahlster & Helbig, 2013), as presented on Figure 1.

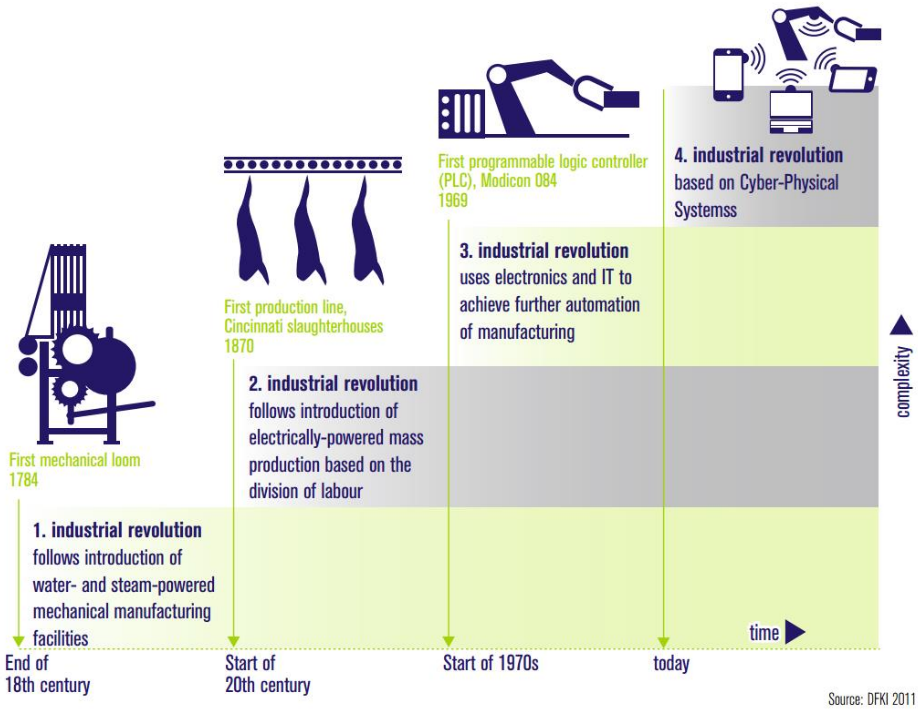


Fig. 1: The four stages of the Industrial Revolution (Kagermann, Wahlster & Helbig 2013)

This new type of industry is based on Smart Factory model. The embedded manufacturing systems are vertically networked with business processes within enterprises and horizontally connected to the dispersed value networks that can be managed in real time. Smart Factories allow individual customer requirements to be met and mean that even one-off items can be manufactured profitably. In Industry 4.0, dynamic business and engineering processes enable last-minute changes to production and deliver the ability to respond flexibly to disruptions and failures on behalf of suppliers, for example.

Hence, the main features of Smart Enterprise can be summarized into the following:

- Smart personalized product – Requires flexibility and high level of ICT integration into manufacturing system to produce a product which fits the customer's exact needs and which is uniquely identifiable, may be located at all times and knows its own history, current status and alternative routes to achieving customer. It can be realized through Reconfigurable Manufacturing System (Koren & Shpitalni, 2010) or Industry 4.0 Smart Factory (Kagermann, Wahlster & Helbig, 2013).
- Product and service provider – Ability to offer extended products: product and service integrated into single product for delivering value in use to the customer during the whole life cycle of a product; or to offer manufacturing as a service and become manufacturing service provider (Meier, Roy & Seliger, 2010). It can be realized through specialized Internet portals and Cloud computing (Kiritsis, 2011).
- High level of collaboration – Also requires high level of ICT integration to support collaborative product development, collaborative manufacturing and all other value adding processes (Mourtzis, 2010). It can be realized through vertical integration called

Production Networks (Schuh & al, 2008), or through horizontal integration called Manufacturing Networks (IMAGINE, 2014).

Therefore, Smart Enterprise or Smart Factory integrates some elements (Figure 2) that, sometimes, are developing for itself and, sometimes, they are competitive. Actually, they can be all connected and there is no Industry 4.0 without setting up basics of Lean management (process identification and process measuring).

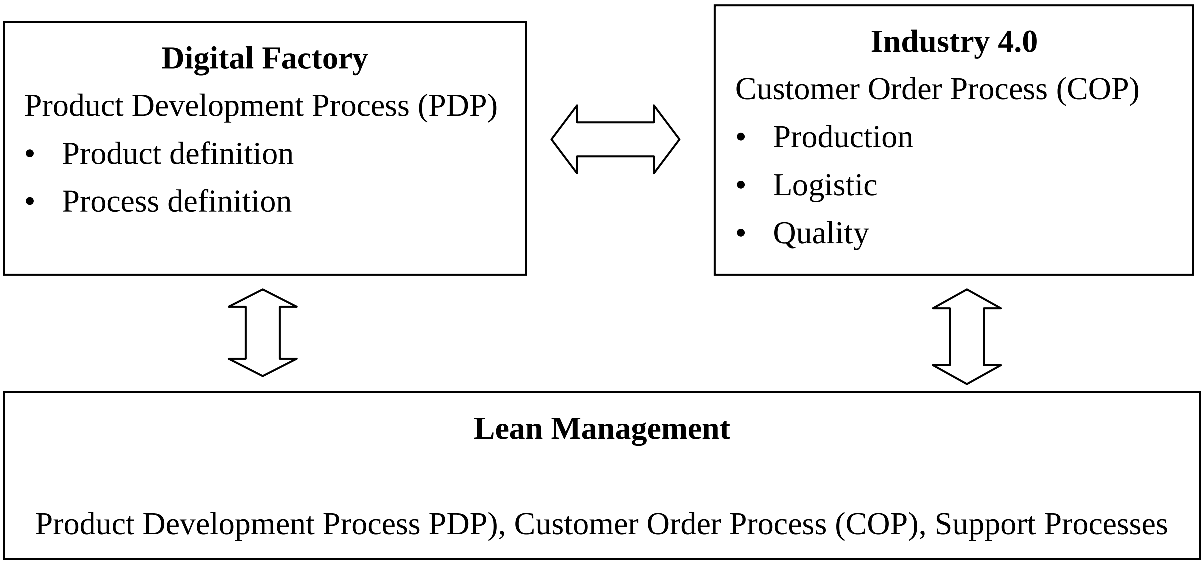


Fig. 2: Optimization approaches and their underlying technical processes (Huber, 2016)

2. Objectives of project INSENT

Last year's developments are a turning point for the whole European industry, characterized by a dramatic drop in customer demand leading to reduced working hours, layoffs and idle factories. As a consequence, in the future the overriding objectives in Croatian enterprise will be flexibility, agility and scalability, in order to survive turbulences caused by erratic customer behavior on the one hand, and market turbulences on a large scale on the other hand.

The main objective of project INSENT is to develop Croatian model of Innovative Smart Enterprise (HR-ISE model). The aim is to perform model’s regional fit, i.e. to harmonize Innovative Smart Enterprise model with specific regional way of thinking, manufacturing and organizational tradition, specific education, and especially to help Croatian enterprises to bridge the gap between their competencies and EU enterprises’ competencies and capabilities. Following objectives are crucial to achieve main objective of this project:

- *Objective 1:* It is important to perform profound research to describe current state of Croatian manufacturing enterprise. It will be done by questionnaires and interviews with CEOs and/or technical directors of manufacturing enterprises in Croatia. The aim is to gather the data from as much as possible enterprises. After that, analysis will be done to describe current state of Croatian manufacturing enterprise. It will be the answer on the question: “Where are we?”

- *Objective 2:* A synthesis of analysis of Croatian manufacturing enterprises will be done through development of Croatian model of Innovative Smart Enterprise (HR-ISE model). HR-ISE model will be based not just on State-of-the-art theoretical models but also on State-of-the-art practical models like Lean Management philosophy from Toyota Production System. Special efforts will be made to bridge the cultural and mentality gaps between State-of-the-art models and current Croatian model. It will be the answer on the question: “Where we want to be?”
- *Objective 3:* A special learning environment will be established in one Laboratory. It will be a Learning Factory, i.e. simulation of a real factory through specialized equipment. Laboratory will be organized to simulate factory based on HR-ISE model. Hence, Laboratory will be learning environment not just for students but for engineers from manufacturing enterprises. It will be a place in which transfer of developed HR-ISE model to the economy subjects will be achieved. All supporting material and equipment for education will be provided. It will be the answer on the question: “How can we get there?”

This Learning Factory concept (Objective 3) is presented in the rest of the paper.

3. The Learning Factory

The Learning Factory’s mission is to integrate design, manufacturing and business realities into the engineering curriculum. This is accomplished by providing balance between engineering science and engineering practice (Rentzos & al, 2014, Wagner & al, 2014).

However, sometimes there is a missing link in Triple helix model – an institution or organization that would really establish a relationship between Government -Industry-Universities. In this paper, a Learning Factory is seen as a missing link in Triple helix model (Figure 3). Through Learning Factory, using practice-based engineering curriculum and real life projects, a link between University and Industry can be established.

The relation between the academic environment and the political decision making is similar to the separation between politics and science (Slaus, 2003). It is indeed difficult to create a framework in which synergy between University and Government can be generated through the actions and interactions of governmental officers, having a limited mandate and functioning within more or less bureaucratic institutional structures, representatives of the economic environment, with their fundamental interest of profit maximization and members of the academic community, concerned more with ideas, innovation and latest methodologies and then being acquainted with the regulations of public institutions and the specific constraints of the business world. However, using Learning Factory dissemination activities, i.e. projects outputs (deliverables, analysis, etc), a link between University and Government can be established in order to identify needs of industrial enterprises and define industrial strategy, and in that way, at the same time, a link between Government and Industry is established.

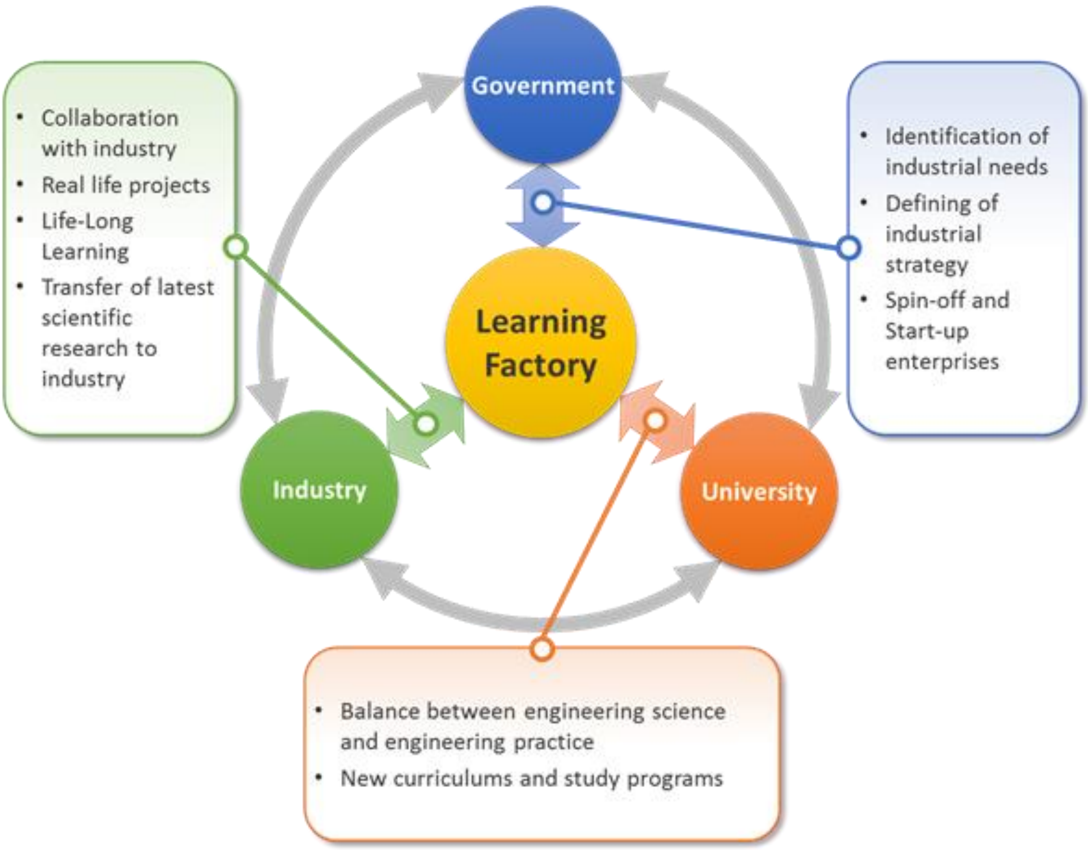


Fig. 3: Learning Factory as a missing link in Triple helix model

3.1 Vision, Mission and Aims

Since 2009, Learning Factory has been establishing at Laboratory for Industrial Engineering at Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture (FESB), University of Split, Croatia. Learning Factory at FESB is based on a didactical concept emphasizing experimental and problem-based learning using tools and methods from Lean management. The continuous improvement philosophy is facilitated by interactive involvement of the participants (students or industrial employees). Furthermore, Learning Factory at FESB has been a part of “Network of Innovative Learning Factories – NIL” (DAAD project) and it is a member of Initiative on European Learning Factories.

Vision of Learning Factory at FESB is to be a place where University, Industry and Government meet each other share needs and expectations, and work on collaborative projects.

Mission of Learning Factory at FESB is to help bring the real-world into the classroom by providing practical experience for engineering students, to help transfer latest scientific research to industry through collaborative projects and LLL, and to help government identify needs of industrial enterprises.

Main aim of Learning Factory at FESB is establishment of “living lab” for research, development, demonstration and transfer to economy Croatian model of Innovative Smart Enterprise (HR-ISE model) till October 2018. “Living lab” is based on Learning Factory concept.
In Learning Factory at FESB there are following activities: education of FESB students, workshops for foreign student groups and professors, implementation of Lean and Green concept in economy through seminars, scientific research activities, and innovative products developments.
Concept of the Learning Factory is setup according to concept presented on Figure 2, so its activities are grouped into following groups (Figure 4):

- Digital Factory
- Industry 4.0
- Lean Management

These parts of Learning Factory will be analyzed in the rest of the paper.

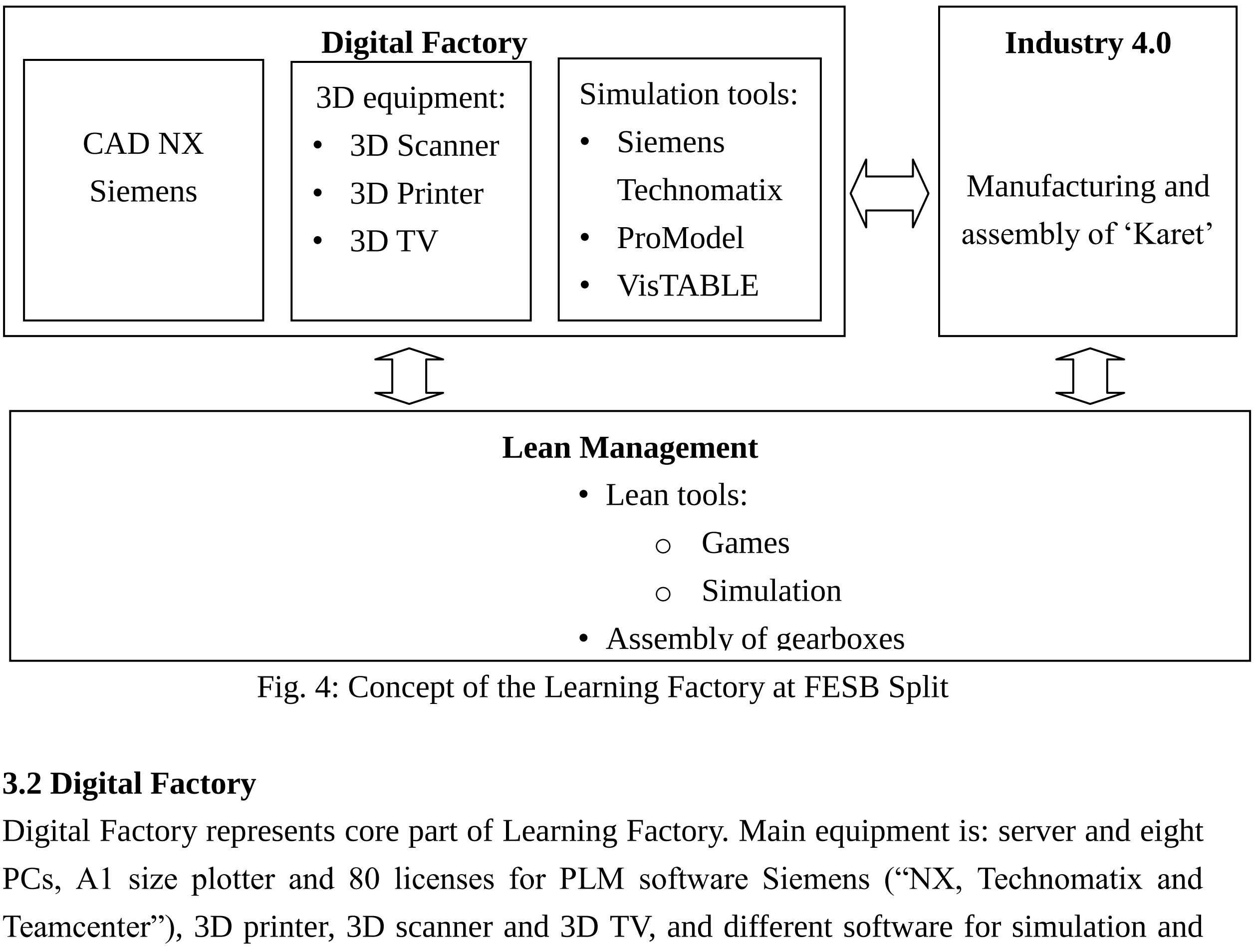


Fig. 4: Concept of the Learning Factory at FESB Split

3.2 Digital Factory

Digital Factory represents core part of Learning Factory. Main equipment is: server and eight PCs, A1 size plotter and 80 licenses for PLM software Siemens (“NX, Technomatix and Teamcenter”), 3D printer, 3D scanner and 3D TV, and different software for simulation and visualization (ProModel and VisTABLE) (Gecevska, & al, 2010).
Installed 3D scanner and printer drastically reduce product development process. Prototypes for demonstration with fair strength and surface quality are produced within few hours,

without need for manufacturing with machine tools (Peko, Bajic & Veza, 2015). Main aim is to “see” the product before it is produced or production system before it is made.

Main feature of Digital Factory is software for the digital representation, test of products and processes prior to their prototyping and manufacturing. Digital Factory use “visTABLE®touch” software as its platform. Software visTABLE (visTABLE, 2016) is suitable for factory planning, optimization, evaluation, and visualization. This software has integrated planning functions for instant validation of layouts. So, its main purpose is factory layout planning. The second function is perfect user friendly virtual reality (VR) modeling system, without possibility for simulation of 3D objects. Therefore, it can also be used for another purpose, for example education. Also, visTABLE’s architecture provides distribution of business via internet, which is useful for group planning and modeling (Müller & Spanner-Ulmer, 2006). The areas of application proposed by visTABLE®touch company are (visTABLE, 2016): factory and layout planning, material flow analysis, implementation of results of a value stream mapping, optimization of logistics processes, assembly planning, scenario planning, running route organization, workshops, etc.

On the other side, software “Promodel®” enables extensive processes modeling and material flow mapping with simulation according to various scenarios.

Learning Factory would define procedure for improvement of production system layout as a part of HR-ISE model implementation by:

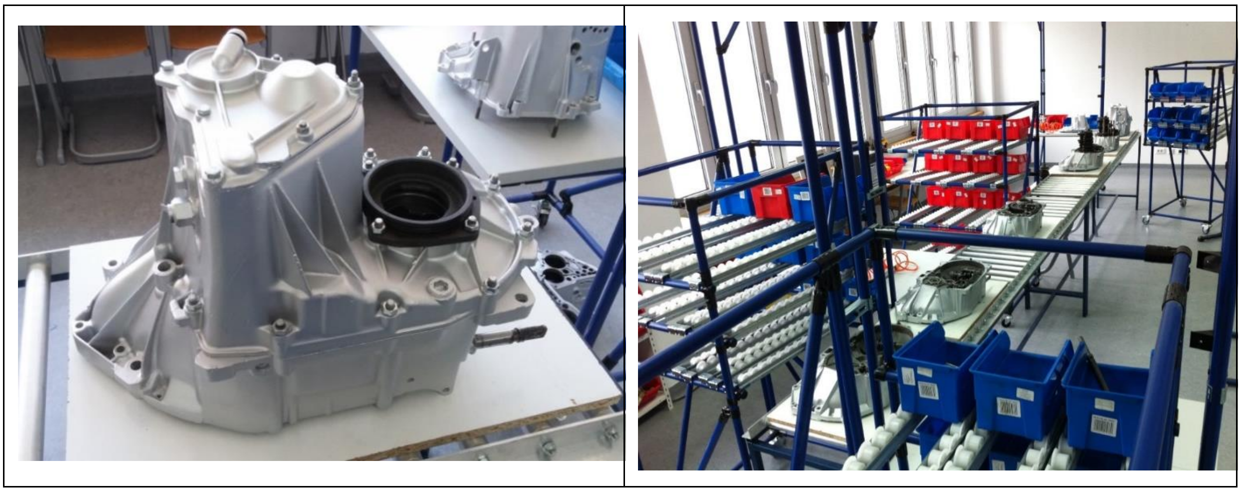
- analysis of some existing production system layout (Spaghetti diagram, process map),
- design of future-state layout using “visTABLE®touch” (Figure 5),
- implementation of HR-ISE model in future-state layout,
- design of several future-state layouts and their evaluation,
- selection of optimal future-state layout.

Fig. 5: 3D VR model of factory layout

3.3 Lean Management

Learning Factory is equipped with some didactic and real products for demonstration and learning of Lean tools and methods. Didactic game “Lego flowcar®” is modified to teach students and industry employees by hands-on simulation embedded in learning materials in form of presentations. It covers methods related to efficient warehousing and logistic systems, and balanced workload on assembly stations for different game scenarios. Methods for information flow are also included. Another game is developed using bunch of toy trucks and toy formula cars which can be easily assembled. Besides line balancing, assembly process can be analyzed, improved and schematically expressed by using this game. Beer game covers supply chain management tools, while KATA and scrum kanban board way of planning and reacting etc.

In effort to make hands-on learning process more familiar to mechanical and industrial engineers and industry employers, assembly stations and conveyer lines for gearbox assembly have been developed. Complete gearboxes, originally from FIAT 128 and its succeeding models, are used to show learners effect of numerous tools and methods for improvement and resolving assembly, warehousing and inbound logistics problems (Figure 6b). Enterprise “BeeWaTec” equipped supermarkets for assembly stations (Figure 6a). Real assembly stations and tools for complex product assembly, together with real products for assembly, gives opportunity to learners for further development of balanced assembly lines, assembly documentation and procedures, conveyor system or other transport system, clamping tools, measurement procedures and quality assurance tests. Despite continuous improvement of assembly line, simplification of gearbox parts for easier assembly, and elimination of many steps which have to be performed, complexity of assembly process is too high for whole gearbox, and therefore only selected modules are assembled during learning process.



a) One version of assembled gear box b) Finished assembly line

Fig. 6: Gearbox assembly

3.4 Development of the assembly line with elements of Industry 4.0

Since the integration of information and communication technology (ICT) into manufacturing systems, called Industry 4.0, it has been accepted as the next step of the industrial evolution. This new industrial platform will be presented in the Learning Factory at FESB. An assembly line for product called ‘Karet’ (traditional children vehicle in Split, Croatia) with elements of Industry 4.0 is under development (Figure 7. a).

‘Karet’ is designed in “Siemens NX” software with modular construction, which will enable selection of desired model through configurator software. Different modules which will be possible to installs are:

- wheels are ball bearings or wheels for in line skates or from transportation boxes on wheels (ball bearings was used in traditional construction),
- brake system or no brakes at all,
- extendable chassis for legs support or fixed chassis,
- backrest with electromotor for drive uphill or backrest without electromotor,
- parts of different materials for achieving different weight and ergonomics.

Currently developed wooden ‘Karet’ with one of possible configuration is shown on Figure 7b.

a) ‘Karet’ in use

b) One possible configuration of ‘Karet’

Fig. 7: Product ‘Karet’

The idea was to implement system of RFID sensors, in order to create Manufacturing Execution System (MES) and connect it with Enterprise Resource Planning (ERP). In the assembly line of ‘Karet’, that contains four working units with Lean assembly stations, following Industry 4.0 elements have been installed: RFID system readings for product transition through production line, interconnected tablet computers at every working unit, connected altogether on online server with central ERP and MES database. These elements combined from one simple Manufacturing Execution System (MES) that enables production monitoring in real-time. Complete MES is connected with ERP; i.e. the production is initiated by working order created in ERP. The way ERP and MES systems are interconnected in this assembly line, is shown on Figure 8.

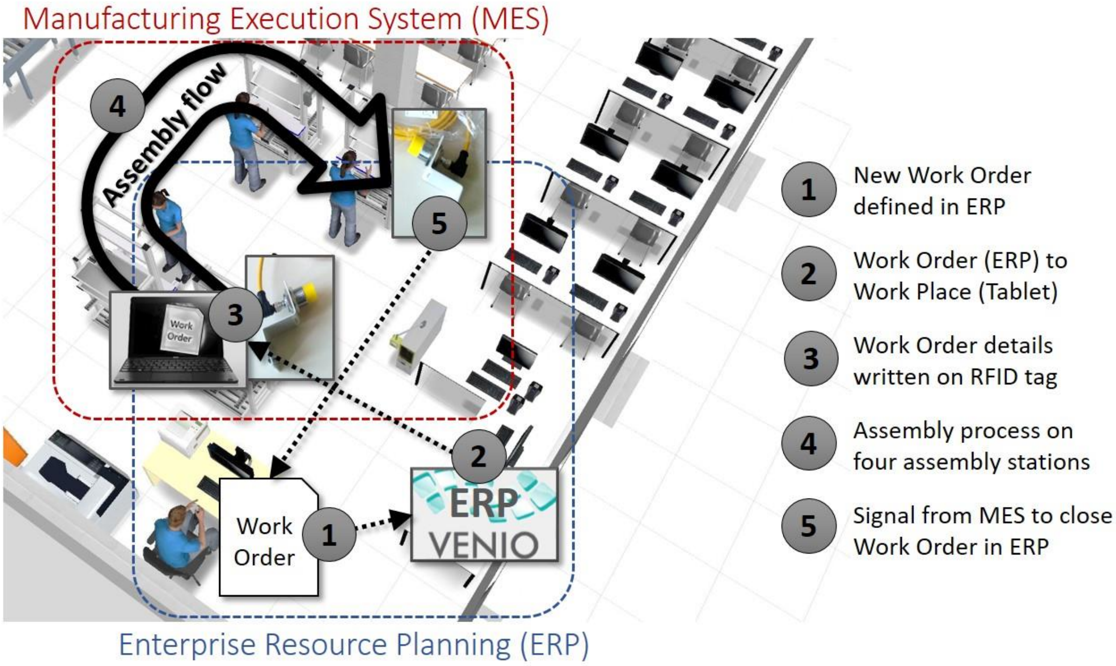


Fig. 8: Assembly line ‘Karet’ with Industry 4.0 elements

It enables a Cyber Physical representation of this assembly line, i.e. assembly process. RFID antennas at the beginning and at the end of the process provide the information when the assembly process of certain product started, therefore when it ended, which enables a time elapse monitoring for the entire assembly cycle. By adding more antennas to the system (this given system could be widen with two more additional antennas), assembly process time elapse data could be provided for each of the assembly stations separately. This enables the process optimization by using methods for production line balancing or by using some other, similar Lean management tools. The complete assembly line operates as following: the technologist is opening a working order in ERP which is automatically sent by an e-mail to the operators on assembly line. At their working units, operators get all the information related to the new working order on their tablet computers, which enables them to start the assembly process. At the precise moment when the first part of the product enters the process, its ID is encrypted on the RFID tag, along with serial number (lot), assembly process entering time, and other necessary information. On their tablet computers, operators get overviews and descriptions for assembly steps, which decrease the error possibility rate along with the need for assembly actions iteration. When the final product is leaving the assembly process, it is read by RFID antenna, after which the EMS sends the signal information to the technologists that the product has been assembled and transferred to the stock. By getting this information, the technologist closes the working order in ERP. Hereby, the entire assembly process (production process) from customers demand (which generates the working order) to the shipping point (closing of working order), is mostly automated. Only the opening of working order remains manual in ERP system and it is to stay that way for the majority of production processes. In fact, opening of the working order itself is a financial decision that can cause significant costs in production process and spent material, so it is logical not to give over such decisions to computer systems in the near future, or to anyone else inside the organization, beside certain authorized personnel.

Further development of this assembly line lies in the improvement of MES, particularly its connection to ERP that is to become more automated. Opening of the working order, due to the reasons aforesaid, is not expected to be automated. Nevertheless, closing of the working order could be automated. By reading the RFID tag of the product entering the stock (due to the closing of its production or assembly process), its working order could be automatically closed. Furthermore, RFID system components could represent a significant financial investment. Thus, a low-cost RFID system development began as well as its implementation in gearbox assembly line.

4. Conclusion

In this paper a concept of Triple helix model connected via Learning Factory concept is presented. Learning Factory could be place where University, Industry and Government meet each other share needs and expectations, and work on collaborative projects. Concept is presented as a solution of a missing link in Triple helix model.

Furthermore, Lean Learning Factory at FESB is presented. It uses tools and methods from Lean management (for rapid analysis, identification of problems, and ideas for improvement of production systems), digital factory (equipped with hardware and software for Product Lifetime Management, empowered with rapid prototyping through additive manufacturing process and reverse engineering by using 3D scanner) and Industry 4.0 (intelligent assembly line for ‘Karet’).

This concept is implemented in education, scientific research activities and in projects with industry.

5. Acknowledgments

This work has been fully supported by Croatian Science Foundation under the project Innovative Smart Enterprise – INSENT (1353).

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