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## Development of Assembly Systems in Lean Learning Factory at the University of Split

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### Abstract

The analysis of mechanical engineering curriculums and industrial practice in Republic of Croatia has showed that assembly and assembly processes are taken for granted, without proper educational and practical learning. In order to bridge the gap between usual practice and real needs of industry, two assembly lines have been installed in Lean Learning Factory at the University of Split. First assembly line represents assembly process of a gearbox for Fiat-Zastava cars. It is a conventional, manual assembly line with implemented Lean elements and tools (5S, Heijunka, Supermarket, Value Stream Mapping, Kaizen, etc.). The second one represents assembly of 'karet' (traditional children vehicle in Split, Croatia). It is equipped with four intelligent assembly stations (RFID system and sensors, tablets, etc.). Additionally, a collaborative robot is planned to be implemented in this line. These assembly lines are used for education of students at the University of Split, and for Lifelong Learning of personnel from industrial practice. This paper presents a case study of two balanced assembly lines development in Lean Learning Factory at the University of Split, presenting achievements and giving directions for further research.

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## 1. Introduction

Croatian Science Foundation (CSF) is financing the project Innovative Smart Enterprise (INSENT) according to the priority to strengthen cooperation between research institutions and entrepreneurship. The main objective of this project is to develop a Croatian model of Innovative Smart Enterprise (HR-ISE model). The aim is to develop a model for regional fit, i.e. to harmonize the Innovative Smart Enterprise model with the specific regional way of thinking, manufacturing and organizational tradition along with specific education. Its results should help Croatian enterprises to bridge the gap between their competencies and EU enterprises' competencies and capabilities [1].

One of the objectives is to establish a special learning environment in one laboratory. It will be a learning factory, i.e. simulation of a real factory through specialized equipment. The laboratory will be organized to simulate a factory based on HR-ISE model. Hence, the laboratory will be a learning environment; not just for students but also for engineers from manufacturing enterprises. It will be a place in which transfer of the developed HR-ISE model to the economy subjects will be achieved. All necessary supporting material and equipment for learning of selected methods and tools will be provided.

The Lean Learning Factory at FESB is based on a didactical concept emphasizing experimental and problem-based learning, using tools and methods from lean management [2]. The continuous improvement philosophy is facilitated by interactive involvement of the participants (students or industrial employees). Furthermore, the Lean Learning Factory at FESB is a part of the "Network of Innovative Learning Factories - NIL" (DAAD project) [3].

The vision of the Lean Learning Factory at FESB is to create a place where the university, industry and government meet each other, share needs and expectations, and work on collaborative projects.

The mission of the Lean 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 lifelong learning, and also to help the government to identify needs for industrial enterprises.

In the Lean Learning Factory at FESB following diversity of activities are done or in process (Fig. 1):

- Education of FESB students,
- Workshops for foreign student groups and professors
- Implementation of the lean and green concept in economy through seminars,
- Scientific research activities,
- Innovative products developments.

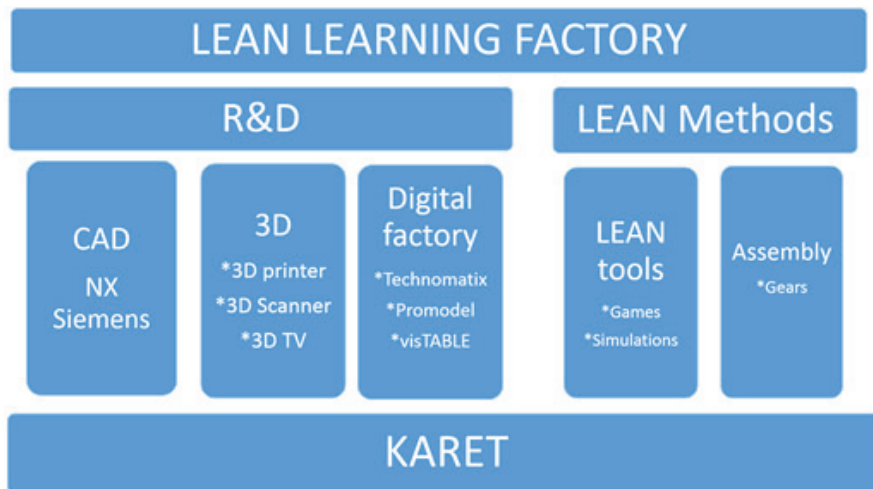


Fig.1 Lean Learning Factory sections [2]

Two parallel assembly lines will be installed: one according to conventional organization layout found in most of assembly working places within Croatian manufacturers, and a second which is improved by using lean tools and methods, together with intelligent components. Those two lines will be used to demonstrate major differences in effectiveness of assembly systems to the learner, from organizational, technical and ergonomics point of interest. By deeper analysis of both assembly lines, hybrid assembly lines could be designed, to balance the assembly tact time according to customer demand on one side, and total cost of installation and running on the other side. Both assembly lines are presented more thoroughly in the following.

## 2. Development of gearbox assembly lines

Simulation of assembly processes using didactic games and real products takes large part of hands-on education in the Lean Learning Factory.

Assembly process of toy trucks and toy formula cars is carried out on four assembly workplaces from BeeWaTec AG [4]. The participants have to schematically draw (in form of map using symbols according to VDI 2860 standard) the assembly process on each workplace. Manipulation and fixation of parts are done manually, by hands, and the only tool used is a toy screwdriver. After mapping, the map of the assembly process can be analyzed and improved to reduce duration of assembly process on one hand, and to design the assembly process in that way to become more appropriate for automation.

Modified “Lego flowcar®” simulation game is used to teach students and industry employees methods related to efficient warehousing and logistic systems. Balancing a workload on assembly stations for different game scenarios is also included. By hands-on simulation, through assembly products from Lego bricks, participants are convinced that they could reduce total batch assembly time with about 80%, which is average time saving in more than last 30 simulation runs carried out in the Lean Learning Factory with different groups of participants.

The major problem related to listed didactic games is its lack of seriousness, from participant’s perspective. The products meant to be assembled are toys. Additional effort has to be made to convince participants that implementation of the same methods to real products and real assembly lines will results with similar improvements.

Therefore, in effort to make hands-on learning process more familiar to mechanical and industrial engineers and industry employers, an assembly line for gearbox assembly process has been developed. Workplaces are designed and produced by BeeWaTec AG. Complete used car gearboxes, from models Zastava 101 and Yugo 45, produced in factory “Zastava Automobiles”, are used. There are two versions of gearbox cases, which, together with the combination of different parts that can be fitted, could make more than 20 different final products.

Students were involved in the layout planning of assembly line. Their work was evaluated and their solutions were implemented, if they were chosen as the best ones. The student’s work was a part of their master theses, and the groups of students were using this assembly line development process for the course “Study of time and work”.

The initial phase of developing a balanced assembly line was to draw a precedence graph. The gearbox consists of 118 parts. Some parts are preassembled due to its difficulty to be assembled in the developed assembly line, as those parts require special tools and manipulation with heavy assemblies. Second phase was to gather data about assembly process time for every working element. Standardization of the assembly procedure was also implemented to reduce ratio of standard deviation and mean value of process times. The balancing of the assembly line was done according to the available number of assembly stations, not according to customer tact time. Therefore, main goal was to achieve close to equal workload on every assembly station by taking the developed precedence graph into consideration. After balancing the assembly line, initial warm-up runs (to achieve stabilized assembly time) were performed. After the warm-up period, 15 runs were performed and assembly process times (in seconds) were collected (Fig. 2.). Balanced results can be seen for workstation 1, 2, and 4. For workstations 3 and 5, the workload is smaller due to the precedence graph procedure and the fact that some assemblies have to be installed in gearboxes in one assembly step. To balance workloads even more, two or more different assemblies have to be transported from one workstation to another, for one final product, which increases transportation efforts and needs clamping devices. Therefore, this solution was assumed as the final solution. Future work on this assembly line will include reducing assembly times at stations 1, 2, and 4 by using clamping devices, faster screwing tools and low cost automation.

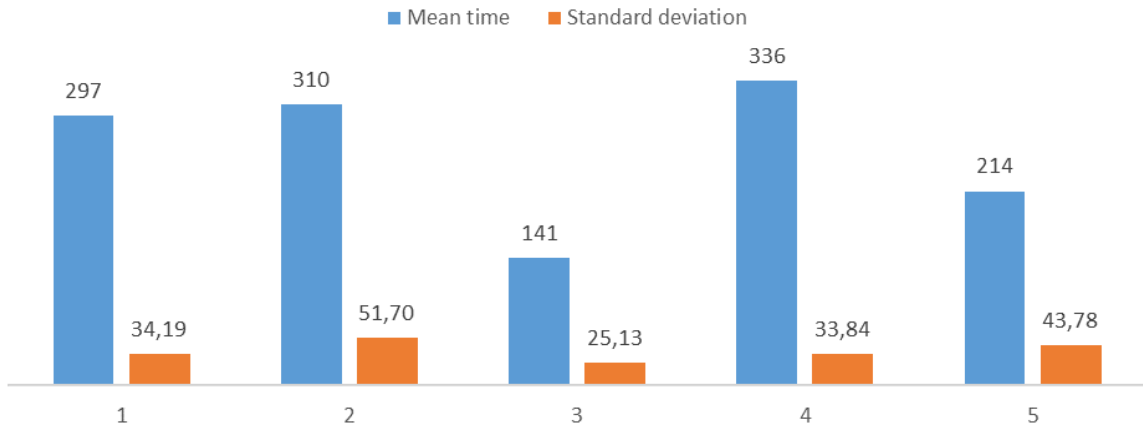


Fig. 2 Workloads and each gearbox assembly station

The precedence graph after line balancing is shown on Fig. 3. Squares are representing assembly from more than one part. Circles represent parts to be installed, while numbers in brackets shows how identical parts are installed, e.g. screws. It can be seen that the assembly process starts in first assembly workstation with assembly S5, on which assembly SM and five additional parts (from part 1 to 1.4) are installed. In the same workstation, SM is assembled from nine parts (from part 2 to 2.7). Part 2.2, a sealing, was expelled from the assembly, as it became damaged after few assembly and disassembly processes. The same thing is done with other sealings, as those gearboxes will never be filled with lubricating oil in Lean Learning Factory.

As gearbox is a real product made to transfer torque and power from an engine to shafts that drives wheels, it has to have robust design. Therefore, its mass as a final product is around 32,7 kg, which is heavy for learning factory purposes. Moving an assembled gearbox by lifting it from one workstation to another cannot be done according to safety at work rules.

To resolve this problem, a simple conveyer line is developed and produced inside the Lean Learning Factory, which was also a student's task. Gearboxes are leaned against wooden plates which travel throughout conveyer line. After the arrangement of working places around the conveyer, the layout of assembly line is shown on Fig. 4.

These developed, real assembly stations and tools for complex product assembly, together with the real products for assembly, provide the opportunity to learners for further improvement of the balanced assembly line and the conveyor system. Development of assembly documentation and procedures, clamping tools, measurement procedures and quality assurance tests could also be included in future work.

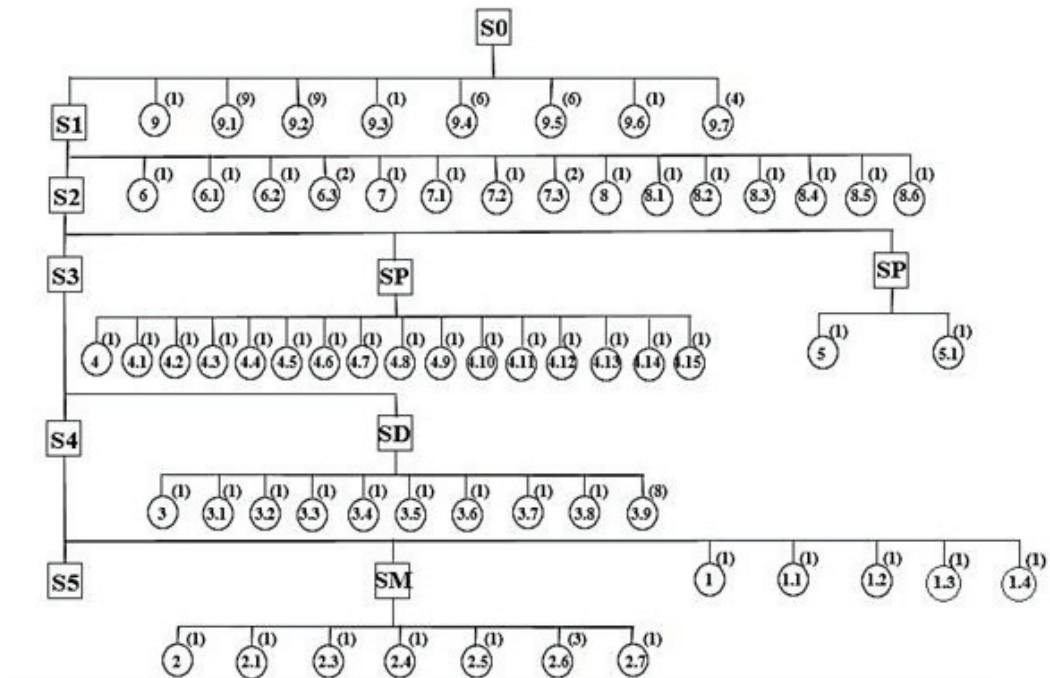


Fig. 3 Precedence graph for gearbox assembly



Fig. 4 Finished assembly line

### 3. Development of assembly line with elements of Industry 4.0

Integration of information and communication technology (ICT) into manufacturing systems is generally considered as the next step of the industrial evolution (Industry 4.0). This new industrial platform will be introduced in the Lean 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. The idea was to implement a system of RFID

sensors, in order to create a 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, the following Industry 4.0 elements have been installed: RFID readers for product tracking through assembly line [5], interconnected tablet computers at every working unit, connected altogether on online server with central ERP [6] and MES database. Combination of these elements creates one simple MES, which enables production monitoring in real-time (Table 2). The complete MES is connected with the ERP; i.e. the production is initiated by working order created in the ERP.

Table 2. Manufacturing execution system elements implemented in assembly line 'karet'

I4.0 element	Element installed in LF@FESB	Cost range (in general)
RFID antenna	TURCK BL R/W Antenna 13.56 MHz (2 – 4 antennas)	1.000 – 5.000 EUR
RFID I/O module	Lucas-Nuelle Evaluation unit (TURCK BL I/O modular system) with up to 4 antennas	1.000 – 5.000 EUR
CPU	Siemens PLC 314	5.000 – 10.000 EUR
User interface	Tablet Lenovo MIIX 300	100 – 500 EUR
Total		7.100 – 20.500 EUR

In Fig. 5 the way ERP and MES systems are interconnected in this assembly line is shown. It enables a cyber-physical representation of this assembly line. RFID antennas at the beginning and at the end of the process provide the information when the assembly process of a certain product started and ended. This information enables a lead time calculation and monitoring. By adding more antennas to the system (two additional antennas possible), elapsed assembly process time data could be provided for each of the assembly stations separately. This enables process optimization by using methods for production line balancing or by using some other, similar lean management tool.

The complete assembly line operates as following: the responsible person (technologist) is opening a working order in the ERP which is automatically sent by an e-mail to the operators in the assembly line. At their working units, the 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, the operators get overviews and descriptions for assembly steps, which decrease the error probability rate. When the final product is leaving the assembly process, it is read by an RFID antenna, after which the MES sends the information signal to the technologist 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 the working order remains manual in the ERP system. In fact, opening of the working order itself is a financial decision that can cause significant costs in the production process and consumed material, so it is logical not to give over such decisions to computer systems in the near future, or to anyone else inside the organisation, beside certain authorised personnel.

Further development of this assembly line includes improvement of the MES, particularly its connection to the ERP to become more automated. Due to the reasons aforesaid, opening of the working order 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 (shown in Table 3), could represent a significant financial investment. Thus, a low-cost RFID system development is initiated as well as its implementation in the gearbox assembly line. This system is presented more thoroughly in the following paragraph.

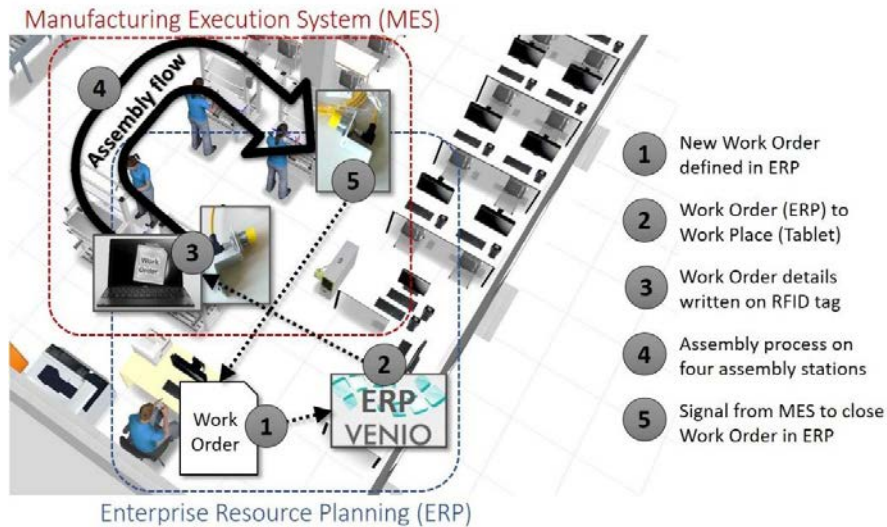


Fig. 5 Assembly line 'karet' with Industry 4.0 elements

#### 4. Using low-cost elements of Industry 4.0 for gearbox assembly line

Since the mission of the Lean Learning Factory within the project INSENT is to integrate the technology for enabling Industry 4.0 as much as possible, future work in this regard will be in developing of electronic inventory level control, trough sensors for counting boxes in supermarkets. Ultrasonic sensors are appropriate for this purpose. On the other hand, RFID sensors will be used for real time information (for instance: where is particular gearbox on the assembly line?). Both ultrasonic and RFID sensors will be connected, and communication with the computer, together with communication with ERP and MES, will be established. Current equipment available on the market for industry purposes is too expensive for the available budget. Therefore, development of new low cost system utilizing Arduino microcontrollers and low cost sensors is started. The gearbox assembly line with installed equipment is schematically shown on Fig. 6.

There are many systems available for developing sensors and communication with ERP and MES [4]. Probably the cheapest one is by using the Arduino microcontrollers with compatible shields and sensors. Total costs for system with gearbox assembly line are listed in Table 3.

Table 3. Elements to be installed on gearbox assembly line with their price on the market

I4.0 element	Element installed in LF@FESB	Market price
4 x RFID antenna	RFID RC522	2 – 8 EUR (x 4)
30 x Ultrasonic sensor	Ultrasonic HC-SR04	3 - 10 EUR (x 40)
5 x CPU	Arduino Mega microcontroller	8 – 40 EUR (x 5)
4 x User interface	Custom-made box with led display	10 – 30 EUR (x 4)
Total		178 – 652 EUR

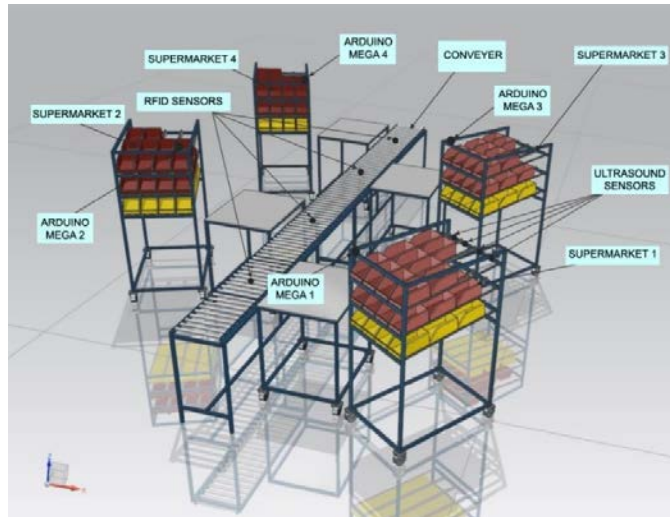


Fig. 6 Assembly line with sensors

## 5. Conclusion

In this paper, a development of two assembly lines according to the learning factory concept is shown; for educational, research and lifelong learning demands. Beside conventional, manual assembly gearbox line for Fiat-Zastava cars, the 'karet' assembly line with implemented Industry 4.0 elements, merging MES and ERP, is presented. Due to the considerable investment in RFID and other similar equipment, a low-cost RFID system development has begun. In future work, the implementation of this system will continue in the gearbox assembly line, based on the Arduino microcontrollers.

## 6. Acknowledgement

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