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Transfer of Model of Innovative Smart Factory to Croatian Economy using Lean Learning Factory

Nikola Gjeldum[a]*, Marko Mladineo[a], Ivica Veza[a]

[a]*University of Split, Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, R. Boskovica 32 - 21000 Split, Croatia*

* Corresponding author. Tel.: +385-21-305-934; fax: +385-21-305-776. E-mail address: ngjeldum@fesb.hr

Abstract

Croatiaés manufacturing industry faces many problems and obstacles that have a large impact on its competitiveness. Insufficiently educated and unskilled personnel, particularly in the production and management fields, are decreasing competitiveness that is necessary for survival in the global market. Objective of project Innovative Smart Enterprise is to establish a special learning environment in one Laboratory as Lean Learning Factory, i.e. simulation of a real factory through specialized equipment. The Lean Learning Factoryés mission is to integrate needed knowledge into the engineering curriculum. Therefore, Lean Learning Factory at University of Split is in continuous developing process to support practice-based engineering curriculum with possibility of learning necessary tools and methods, using didactic games or real life products and equipment. Solution proposal for best balance between toys and real products consider design and production line development for product Karet. It is a traditional and original product from Croatia, so it will raise enthusiasm in learning process in both students and industry employees. Two assembly lines will be developed, one traditionally equipped and one intelligent, networked, flexible, and fully improved by Lean tools. By deeper analysis of both assembly lines, hybrid assembly lines could be designed, to balance on one side assembly tact time according to customer demand and total cost of installation and running on the other side. Methods and tools adapted and implemented, in both design and analysis process for optimization of this hybrid assembly line would be scaled and adjusted for industry use as part as knowledge transfer from university to enterprises.

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Keywords: Lifelong Learning; Product Lifecycle Management; Assembly line balancing; Didactic simulation games; Product development

1. Introduction

Manufacturing is today, as it always has been, a cornerstone of the economy of developed nations. Having a strong base of manufacturing is important to any advanced country because it impels and stimulates all the other sectors of the economy. It provides a wide variety of jobs, both blue- and white-collar jobs, which bring higher standards of living to many sectors in society, and builds a strong middle class.

Croatiaés manufacturing industry faces many problems and obstacles that have a large impact on its competitiveness. The initial plan during the last fifteen years was to restructure the economic subjects efficiently and to become competitive enough in order to compete efficiently in the domestic as well as in the export markets. Unlike projections, the Croatian manufacturing industry has not been completely and efficiently restructured. On the other hand a recent dramatic drop in customer demand leading to reduced working hours, layoffs and idle factories.

Croatian economy is still burdened by previous economic system inherited anomalies and some transitional problems. Low productivity is additionally burdened by a great number of employees and obsolete technology. Insufficiently educated and unskilled personnel, particularly in the production and management fields, decreasing competitiveness necessary for survival in the global market. There is a predominant lack of products and services which are demanded by developed markets. The government meddling with development of strong economy. Grey economy is growing encouraged by infirm justice and unstable tax administering during recent years. However, public property and enterprises privatization, which is a sine qua non prerequisite for sound market basis establishment and prospective growth, has not been successfully implemented. Most public enterprises completely disappeared in the privatization process, and those that managed to survive, have undergone numerous recovery programs or have gone into liquidation. In these conditions, small and medium-sized enterprises development could not have support by big industrial systems. Therefore, economic development has been mostly turned to the service sector, especially tourism.

There is the lack of a unique and commonly agreed economic strategy at the national level. One of the primary strategic goals is to develop a competitive, diversified, technologically advanced and environmentally sustainable economy that will be oriented to enhance the living standard of the local population. Consequently, such clearly defined goals require a radical change of the existing settings, in which an inadequately competitive economy still prevails.

The main question is how to detect competitive advantages of the manufacturing industry and therefore achieve a higher level of export competitiveness in the regional and the international markets, like the market of the European Union. Croatiaὂs manufacturing industry participates in a large proportion in the gross domestic product, employing a large proportion of the entire workforce, is one of the greatest generators of tax revenues in the country, and is one of the most propulsive export industrial branches of the economy of the Republic of Croatia [1]. Generally speaking, during the transition process there was no industrial development whatsoever, particularly there were no new technologies or new products introduced. Cooperation between economy and science was rather weak, and the accompanying infrastructure required to support technological development and innovations was developing rather sluggishly. Taking all this into consideration, a basic prerequisite for making a turnaround to a successful economic development in Croatia is to restructure its economy.

In order to set things in motion, the following priorities have been defined:

- to strengthen cooperation between research institutions and entrepreneurship that will enable new technologies implementation and technologically innovative products production,
- to restructure organization in traditional manufacturing sectors, agriculture, fishing industry and tourism, in order to achieve bigger competitiveness,
- to support export-oriented, specialized production of products and services with higher VAT,
- to encourage regional and inter-regional integration processes (including transnational ones) and to support cluster organizations in order to strengthen overall synergetic impact in the sectors and between them,
- to ensure business, entrepreneurial and managing training,
- to increase employment opportunities.

In the future the overriding objectives in Croatian enterprise will be flexibility, agility and scalability, in order to survive turbulences caused by erratic customer behaviour and market turbulences on a large scale.

2. Innovative Smart Enterprise project objectives

Croatian Science Foundation (CSF) is financing the project Innovative Smart Enterprise (INSENT) according to the priority to strengthen cooperation between research institutions and entrepreneurship.

Manufacturing enterprises are in the main focus of this project. Vision of Innovative Smart Enterprise for with long term sustainability can be summarized into following features:

- Lean,
- Flexible,
- Agile,
- Efficient,
- Responsive,
- Information enabled,
- Predictive,
- Safe.

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

- Objective 1 (completed): It was important to perform the analysis of the current state of Croatian manufacturing industry with regard to Industry 4.0 concept. It shown that Croatia is far away from Industry 4.0. An average industrial maturity level of Croatia calculated in [2] was estimated to 2.15 which represents second industrial generation, i.e. middle of 20th century. It means that in Croatian manufacturing practice technology and organizational concepts are still similar to those 50-60 years ago. This research reveals current state of Croatian manufacturing enterprise and answers on the question: ñWhere are we?ò
- Objective 2 (to do): 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. A 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: ñWhere we want to be?ò
- Objective 3 (to do): 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 necessary supporting material and equipment for learning of selected methods and tools will be provided. It will be the answer on the question: ñHow can we get there?ò

Results of this project will be of the high value for competitiveness of Croatian industry. The development of Croatian model of Innovative Smart Enterprise (HR-ISE model) and its transfer to economy can have strong impact on recovery of Croatian industry. HR-ISE model can help improve competencies and capabilities of Croatian enterprises to make them more competitive on EU market.

3. Lean Learning Factory

Lean Learning Factory at University of Split, Faculty of electrical engineering, mechanical engineering and naval architecture (FESB) is located on 114 square meters large Laboratory of Industrial Engineering. Main aim of Lean Learning Factory at FESB is establishment of ñliving labò for research, development, demonstration and knowledge transfer to economy. Tools and methods, included in Croatian model of Innovative Smart Enterprise (HR-ISE model), adapted to regional fit and modified for laboratory use purposes, will be implemented and presented by demonstration materials, didactic games, working stations with real and didactic products, hardware and software system for Product Lifecycle Management (PLM), etc. ñLiving labò will be based on Learning Factory concept, and aims will be achieved through support of projects Network Innovation Learning Factories (NIL) financed by Deutscher Akademischer Austauschdienst - German Academic Exchange Service (DAAD) and INSENT project (CSF project).

Lean Learning Factory at FESB profile has been defined by a typology (Fig. 1) similar to one used in survey conducted within European Initiative on Learning Factories [3]. Grey marked fields in Fig. 1. presents current features related to FESB Lean Learning Factory.

Characteristic	Features					
Operating organization	industry	consulting	**university**	technical college	professional school	
Type of use	**education / training**	**research**	further industrial use			
Industrial target groups	**operational staff**	**engineer**	manager			
Academic target groups	**students**	research stuff / post graduated				
Other target groups	**lean experts / lean specialist**	other consultants				
Selected industries	machine building	**automotive industry**	chemical industry	electrical industry	**insurance, banks, etc.**	
Product	**real products**	**imaginary (didactic) product**				
Production process	machining	**assembly**	**logistic**	IT	indirect	production
Module content	**process improvement**	diagnosis	**system design**	**quality control**		
	quality	**material flow**	**technology optimization**	**lean transfer**		
Integrated departments	production	**distribution**	purchasing	ideas mgmt.	**design / develop.**	**prod. plan. and control**
Integrated teaching methods	**presentation**	**demonstration**	tutorial	web-based training	**simulation game**	
	discussion	case study	**role play**	**experimental game**	...	
Learning factory size	**< 300 sqm**	300 – 2000 sqm	2000 – 10000 sqm	> 10000 sqm		
Number of course participants	**< 5**	**5 – 10**	**10 – 20**	20 – 30	> 30	
Duration of module	**< 2 h**	**2 – 5 h**	5 – 10 h	10 – 20 h	> 20 h	

Fig. 1. Definition of Lean Learning Factory at FESB profile from a typology [3].

In Lean Learning Factory at FESB following diversity of activities is done or in process (Fig. 2.):

- education of FESB students,
- workshops for foreign student groups and professors
- implementation of Lean and Green concept in economy through seminars,
- scientific research activities,
- innovative products developments.

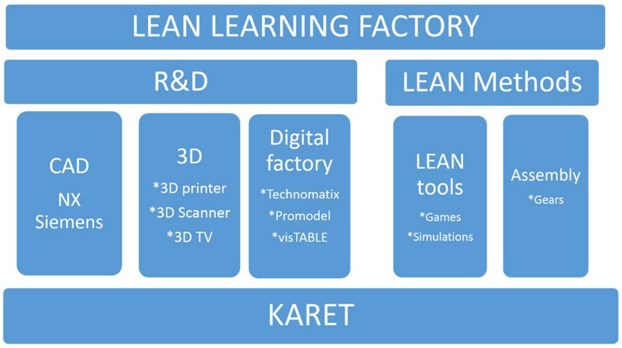


Fig.2. Lean Learning Factory sections

In product development phase PLM is used. PLM is an all-encompassing approach for innovation, new product development and introduction (NPDI) and product information management from ideation to end of life. PLM systems, as an enabling technology for PLM, integrate people, data, processes, and business systems and provide a product information backbone for enterprises and their extended enterprise [4]. PLM empowers a business to make unified, information-driven decisions at every stage in the product lifecycle. In todayôs highly competitive, fast-paced and global business environment, well-designed and implemented PLM practices, processes and technologies that support an organizationôs strategies for innovation and growth can afford enterprises a real competitive advantage. PLM solutions establish a cohesive platform to: optimize relationships along the lifecycle and across organizations, maximize the lifetime value of a business' product portfolio and set up a single system of record to support diverse data needs [5].

Project named Master studies programme and continuing education network in Product Lifecycle Management with Sustainable Production 144959-TEMPUS-2008-IT-JPCR financed server and eight personal computers, A1 size plotter and 80 licenses for PLM software Siemens (ñNX, Technomatix and Teamcenterò) [6].

Installed 3D printer drastically reduces product development process. Prototypes for demonstration with fair strength and surface quality are produced within few hours, without need for manufacturing with machine tools [7].

However, it is also important to establish Digital Factory as part of Lean Learning Factory. Main aim is to ñseeò 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 ñvisTABLE®touchò software as its platform. On the other side, software ñPromodel®ò enables extensive processes modeling and material flow mapping with simulation according to various scenarios.

Lean 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 ñvisTABLE®touchò,
- implementation of HR-ISE model in future-state layout,
- design of several future-state layouts and their evaluation,
- selection of optimal future-state layout.

Other section of Lean Learning Factory (Fig. 2) is already equipped with some didactic and real products for demonstration and learning of Lean tools and methods. Didactic game ñLego flowcar®ò 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. Enterprise ñBeeWaTecò equipped supermarkets for assembly stations. 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.

In order to promote domestic legacy and fit to diversity of different products specially developed for Learning Factory needs of NIL project partners, Lean Learning Laboratory is currently developing version of Karet, which is, generally, toy used for descend down the slope. As Split city terrain configuration is hilly, Karet were used for generations for play and for transportation down the slopes in some cases (Fig. 3.).

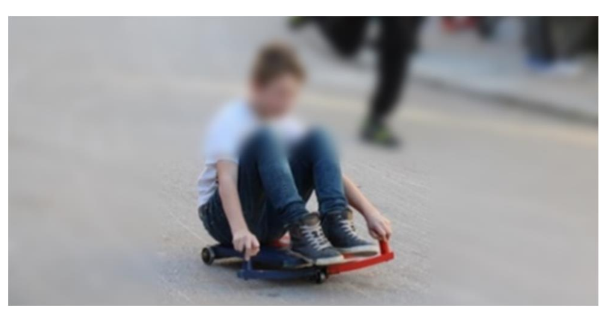


Fig. 3. Karet in use

This tradition was almost forgotten, and introduction of improved model developed and produced in batches in Laboratory, together with promotion outside University audience, will help return Karet in lives of youth, despite ascending pressure of virtual reality world.

Karet is designed in ñSiemens NXò 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 Fig. 4.

Fig. 4. One possible configuration of Karet

After initial batch production, assembly line will be designed and installed in area number 3 (Fig. 5). This area will have movable working places with flexible working tables and supermarket storage systems. Some of those will have intelligent components for data acquisition and therefore tracking of parts and product statuses. Aims and features of assembly line will be:

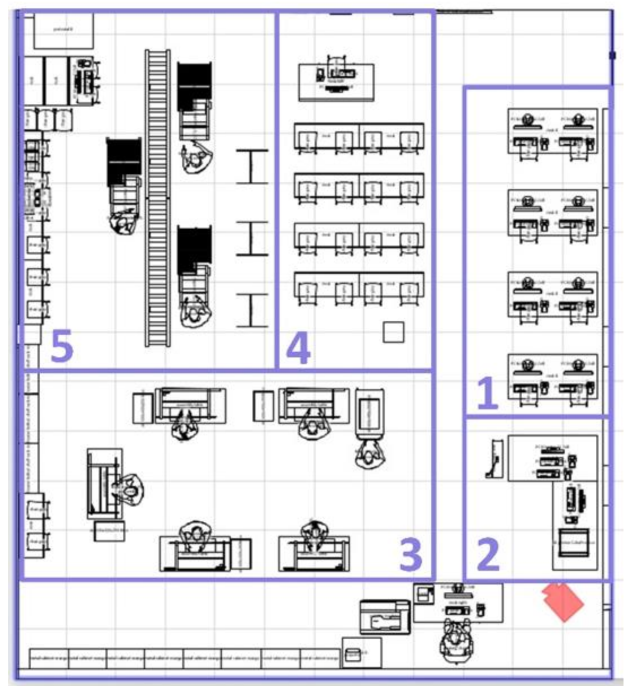
- flexible high product mix production,
- balanced line for batch production for each type of product,
- intelligent assembly station, with flexible clamping systems and adaptable data acquisition system,
- simple planning and control system,
- reduced set-up and changeover time, in comparison to universal assembly stations,
- reduced process and lead time due to optimized production steps, logistics and warehousing processes.

By introduction of intelligent components on assembly station, following functionality will be enabled:

- networking of assembly stations with workers and products,
- integration of planning and control department and assembly stations,
- reduced process steps and improved ergonomics.

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

Layout of Lean learning Factory with bordered areas for different activities and equipment is shown in Fig. 5.



Legend:
1. Server with 8 PCs and Siemens PLM
2. 3D scanner and 3D printer
3. Assembly line for Karet
4. Classroom with lean tools and simulation
5. Assembly line for Gearbox

Fig. 5. Layout of Lean Learning Factory

Photo of current state of Lean Learning Factory is shown on Fig. 6; and future layout of Lean Learning Factory is shown on Fig. 7. It was developed using software ñvisTABLE®touchò.

Lean Learning Factory at FESB has been integrated into the education of students and employees on all levels:

- undergraduate lectures: study of work and time, organization of production systems;
- bachelor thesis;

- graduate lectures: manufacturing technologies planning and optimization, plant layout;
- master thesis;
- postgraduate study lectures: Modeling and simulation, CIM, Logistics optimization
- doctoral thesis;
- professional study lectures: production planning and control;
- professional study thesis.

Fig. 6. Current state of Lean learning Factory at FESB

Fig. 7. Future state of Lean learning Factory layout developed with software ñvisTABLE®touchò

4. Conclusion

Lean Learning Factory at FESB, emphasizing experimental and problem-based learning using tools and methods from Lean management, has true potential to play important rule in regional development. It is equipped with hardware and software for Product Lifetime Management, empowered with rapid prototyping through additive manufacturing process and reverse engineering by using 3D scanner.

Didactic based equipment and games provides platform for implementation of Lean tools and methods by learner, student or industry employee. Anyhow, seriousness of learning process by embedded hands-on simulation games are compromised as those are conducted using toys.

Assembly line for real products shows better acceptance by learners, especially from industry employees. But, on the other side, complexity, effort and time necessary to conduct simulation runs, disable assembly line to operate in its full content. On some stations, parts are too heavy, or require special tools and impact force to be assembled. Therefore, only modules of assembly are conducted, and lack of excitement can be found when finished product cannot be seen as useful one.

Solution proposal for best balance between toys and real products consider design and production line development for Karet. It is final traditional product originally from Croatia, so it will raise enthusiasm in wider audience. In area allocated for Karet production, two assembly lines can be fitted, one traditionally equipped and one intelligent, networked, flexible, and fully improved by Lean tools. By deeper analysis of both assembly lines, hybrid assembly lines could be designed, to balance on one side assembly tact time according to customer demand and total cost of installation and running on the other side. Methods and tools adapted and implemented, in both design and analysis process for optimization of this hybrid assembly line would be scaled and adjusted for industry use as part as knowledge transfer from university to enterprises.

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