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Lebanon Learning Factory at the University of Pitesti

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Abstract: Today, the globalization of production and strong competition in the automotive industry requires manufacturers to offer their customers a wide range of products of the best quality and at lower prices. In order to accomplish this objective, the production systems must be as flexible and responsive to customer requests as possible and the production flow should be uniform. The usage of the most modern methods, techniques and tools, such as modelling and simulating production flows and Lean manufacturing, in the layout planning, work organization and production management is imperative to such production systems. In this context, at the University of Pitesti, a Learning Factory has been in development, that facilitates the research in laboratory conditions of modern manufacturing methods and their transfer to factories from automotive industry. The laboratory was developed within a research project and includes integrated research and teaching platforms, specific to layout design, modelling and simulation flows and Lean manufacturing, while also comprising elements of digitalization (Industry 4.0). The Lean Learning Factory at the University of Pitesti is in a continuous developing process which will allow students to enrich their practical skills and competencies concerning modern methods, techniques and tools, by using factory-like equipment. Moreover, this laboratory can also be accessed by automotive companies’ employees from Arges County to improve their abilities in Lean manufacturing.

1. Introduction

The globalization of production and strong competition in the automotive industry requires manufacturers to offer their customers a wide range of products of the best quality and at lower prices. In order to accomplish this objective, the production systems must be as flexible and responsive to customer requests as possible and the production flow should be uniform. In consequence, more and more automotive factories have shifted their production type from mass to lean manufacturing.

Koren [1] has proposed a new concept for these modern manufacturing systems: Reconfigurable Manufacturing System – RMS (figure 1). In addition, the fourth industrial revolution - Industry 4.0, requires introducing the Internet of Things and Services into the manufacturing environment. Thus, the Smart Factory concept has emerged as a new approach to production: smart products are unique, identifiable, can be located at any time and know their own history, current state and alternative ways of achieving their target. To implement these features, an enterprise must be Enterprise Smart [2]: “it must incorporate its machinery, warehousing systems and production facilities in the shape of Cyber-Physical System (smart machines, storage systems and production facilities capable of autonomously exchanging information, etc)”.

A Learning Factory is described [3] “as a platform to transfer fundamental knowledge, e.g. about methods for process improvement, to students or seminar participants from industry within a real
manufacturing environment”. The label comprising the words learning and factory implies that systems need to address both terms alike: “it should include elements of learning or teaching as well as a production environment” [4]. Learning Factories could ensure the development of the Reconfigurable Manufacturing System and/or the Smart Factory. They allow the analysis, simulation and optimization of various aspects of production systems in order to implement them industrially.

![Figure 1. Historical cycle of manufacturing paradigms [1].](image)

Learning factories must be adapted to the experiment-based learning process, where experimental or real products can be executed. They partially imitate the industrial factories, but without being a carbon copy of these [5]. The choosing and design of the experimental products are made in accordance with the educational objectives, manufacturing field and physical constraints of the laboratory [6]. The Learning Factories concept can be implemented in different ways, significantly depending on the available funding and the operation and maintenance cost [4]. Therefore, learning factories are classified by:
- purpose: training, research and applications, or any combination of these;
- implementation: physical, virtual, internships, and joint projects;
- size: full-scale, scaled modules, bench-top, Lego and other learning games;
- functionality: static and operational;
- location: in the Lab, remote connection with plant or in industry.

In the area of manufacturing process amelioration, Lean Learning Factory offers a well-suited hands-on approach for competencies development [7, 8]. The fundamental concepts in the field of Lean manufacturing are mainly based on the ideas in connection with the introduction of the Toyota Production System [9]. The methods of Lean manufacturing can be grouped in three categories [10]:
- problem solution: 5-Ws question asking technique and the Ishikawa-Diagram, both serving the systematic analysis of causes for a defined problem;
- process orientation: Autonomation (Jidoka), Heijunka principle, Just-in-Time principle, Kanban principle, One-Piece-Flow, Single Minute Exchange of Die and Value Stream Design, methods which serve to design the production processes;
- process and solution control: 5S, the Continuous Improvement Process (CIP), Poka Yoke, Standardization, and Visual Management.

Generally, organizing a Learning Factory supposes 3 directions of development: experiences lab, research lab and education lab. The first direction, experiences lab, is a research-based learning environment focused on practice-oriented application of methods and tools, usually on a small scaled modular production system. In the experiences lab the learners are free to modify and rearrange process and production equipment and to apply organisational measures to experience the dynamic response from the production system with all systemic interdependencies. The second direction, the research lab, is focused on disseminating research project results by implementing developed platforms in factory
environments. The third direction, education lab, focuses on the transfer of knowledge on predefined learning paths that consist less in a research-based learning experience, and more in an application-oriented one [11].

2. Development of the Lean Learning Factory

2.1. Context of development of the Lean Learning Factory
The Lean Learning Factory has begun its development at the University of Pitesti in relation to the project research “Smart manufacturing technologies for advanced production of parts from automotive and aeronautics industries”, starting in 2018. This project research has as aim to develop new methodologies of improvement for the production flows of automotive industry, by integrating modern methods, techniques and tools of production management in an experimental laboratory.

In order to keep or enhance their performance in a competitive environment, the automotive industry companies must change and continuously develop new and more complex strategies. The layout design and Lean manufacturing can be a way to reduce costs and to increase profits. Integrating the system analysis with the help of modelling and dynamic simulation can also be an important step in increasing the efficiency and agility of an organization as part of a complex production system. The simulation brings very important insight into the impact of changes, identifying the vulnerabilities and the opportunities. In a more ambitious perspective, adding the three aspects: Layout Design, Lean Manufacturing and the Dynamic Simulation, as proposed in this project, can bring flexibility and competitiveness to companies.

Figure 2. Conceptual model for improving production flows.

The starting conceptual model of our Lean Learning Factory is appreciated as having Technology Readiness Level 2 - TRL2 [12] and is presented in figure 2. The proposed model has 3 interrelated investigation areas:
- layout design: the subject of analysis is the facilities (F), and the result is the plant layout (LP);
- modelling and simulation of the flows: the subject of analysis is the production (P), and the result is the system’s operating mode (OM);
- Lean manufacturing: the subject of analysis is the production system (SP), and the results are the improved layout plan (LP) and the system’s operating mode (OM).
The starting element in this general methodology is the layout design of the production system, which can be made in a static (S) or dynamic (D) way. The resulting layout plant can be improved, first by modelling and simulating the production flows, and after – in a continuous manner (C) – by using the methods and techniques specific to Lean Manufacturing.

In order to experiment these methods of manufacturing flows improvements, in relation to the project, an experimental laboratory of Lean Learning Factory type (TRL4 level) was designed and developed. This laboratory contains integrated learning-research platforms, specific for each previously mentioned study direction.

2.2. The structure of the laboratory

For the learning-research platforms’ development, finding a range of products that imply manufacturing flows specific to automotive industry: products manufactured in a high variety and in mass production, was needed. At the same time, the manufacturing flows must be complex enough to allow the usage of modern methods of manufacturing management: flows with manual activities, complex and diversified BOM. Thus, it was chosen as experimental product a steering wheel, figure 3, and its assembly process.

This experimental product allows to obtain a wide range of products (8 types, using components of different colours: components 4, 5 and 7 in figure 3 (c), and using components with different functionalities: components 6 in figure 3 (c)), and its assembly process needs manual activities.

In order to experiment and research different models used in layout design, a production line for the assembly process of the experimental product - steering wheel - was developed. This assembly line must integrate the Lean manufacturing principles:
- high flexibility for the workstations, so a higher variety of products can be made with minimum of changeover;
- modular structures - built into modular workstations, in order to decrease the costs of design and manufacture of the industrial system, and also to decrease the impact of reconfiguration of layout and process flexibility;
- the possibility to adapt the process to the client’s demand – manufacture on an „one-piece flow” to increase the reactivity to client demand, this needing “zero setup” for workstation;
- minimizing the activities with non-added value (mainly, movements and handlings), in order to achieve the target of “NonVA = 0”.

The 3D models of the modular and flexible workstations, and the modular and flexible supply and transport systems are presented in figure 4, and respectively, in figure 5.

![Figure 4. The 3D model of a modular-flexible workstation.](image1)

![Figure 5. The 3D model of a modular-flexible transport system.](image2)

To integrate in the lab the concepts of Industry 4.0, a digital structure, figure 6, that can be extended in the future to all the assembly line, was developed for one of the workstations. This actual digital structure contains:
- Scanner system which allows to identify the product type to be assembled;
- “Pick to light” and “Put to light” systems placed to identify the assembly sequence and, respectively, the supply sequence. Each box with the components of the steering wheel assembly has lighting indicators and confirmation buttons;

![Figure 6. The digitalization of a workstation: (a) architecture; (b) photo.](image3)
- Control camera system with the role of checking the conformity of the used parts. This digital system can be used like a "poka-yoke" system, using the checking video system connected to the controller and the computer;
- Controller that allows the configuration of the “pick to light” and “put to light” sequence by manual input from the controller interface;
- HMI interface which allows the operator to visualize sequences in work and to highlight any errors in the process.

In order to analyse, improve or optimize different layouts of the workstations or production system and production flows, more specific software is used: IMPACT, TECNOMATIX (FactoryCad, FactoryFlow, Jack, Plant Simulation) and ARENA SIMULATION.

IMPACT software allows, starting from technical data on the production (articles, nomenclatures, load stations, ranges), to study possible layouts, to propose uploads or an implementation minimizing the distances between machines [13].

TECNOMATIX software offers integrated solutions to planning, simulation and production [14], such as:
- FactoryCAD – a software that has all the needed tools to create detailed and intelligent models of a factory. The “intelligent” objects that represent all the resources of a factory: floor, transport conveyers, cranes, storage equipment and operators, can be described and have their parameters changed according to the study conditions.
- FactoryFLOW – a software to design and to optimize the general layout of a factory, considering the material flow distances, frequencies and costs. This is done by analysing and evaluating the information about the routes of products, the needs for storage, handling equipment specifications and information about the products assembly in the general layout of the factory.
- Jack – used to simulate, test, improve and fine tune the designed models and the industrial tasks, using the most complex set of human simulation tools available on the market.
- Plant Simulation – allows to model, simulate, explore and optimize logistics systems and their processes. These models enable analysis of material flow, resource utilization and logistics for all levels of manufacturing planning from global production facilities to local plants and specific lines, well in advance of production execution.

ARENA SIMULATION software allows to model and analyse process flow, packaging systems, job routing, inventory control, warehousing, distribution and staffing requirements [15]. Thus, it is possible to increase throughput, identify process bottlenecks, improve logistics and evaluate potential process changes.

To learn and experiment with "lean manufacturing" techniques, two platforms have been developed in the experimental lab: a platform for the 5S method and another for the Value Stream Map method. The platforms were made into Lean cubes from modular aluminium tubes. The Lean cubes for the two platforms are display systems that mix a white board with Lean display concept, providing a compact teaching solution, information display and visual management. These cubes have the following characteristics: can be written on with any type of marker; can be erased; magnetic surface; the base is on wheels.

The 5S platform, figure 7, allows to correctly apply this method in a manufacturing system and is organized as following:
- the first face of the cube is dedicated to the first S and contains: the definition of 1S, the red, the green and the yellow list and also the register of red labels;
- the second face of the cube contains information about the second S: definition, 5S colour codes, surface marking rules and labelling rules;
- the third face of the cube is dedicated to the third and fourth S and contains: definitions of 3S and 4S, the methodology of cleaning and the methodology of standardisation;
- the fourth face of the cube allows to apply the fifth S: definition of 5S, the audit list for 5S, the list of improvement opportunities and the list of 5S achievements.
The Value Stream Map - VSM platform, figure 8, is also formed of 4 sides, each side is dedicated to a step of the method’s application:
- the first side of the cube is organized so that it helps identify the product or the range of products that will be analysed with the help of Value Stream Map;
- the second and the third side of the cube allow to build the Value Stream Map in the current state and contain symbols and methodologies used to build the VSM, to represent the material and information flow, and the lead timeline as sum of activities with added value and non-added value;
- the fourth side of the cube is dedicated to the analysis of the Value Stream Map and the identification of improvement means. This contains cycle time and takt time analysis, OEE analysis, methodologies
to analyse the manufacturing programming mode, the manufacturing batch size etc., to make the future VSM and to develop the improved plan of production flow.

A writing board with magnetic rubber sheets is used, figure 9, to analyse different solutions of layout design and also to visualize the manufacturing flows. Using these tools: lean manufacturing platforms, writing board and magnetic rubber sheets, it can be easier to design and analyse in teamwork, which represents a gain compared to the software solutions, where there is a more individual approach.

3. Developed research

Until now, in the experimental laboratory several studies were conducted. These studies concern: analysing the layout design, improving workstations’ organization and its ergonomics, and simulating the production flow. In the following, the most important elements of these studies are summarized.

3.1. Layout design

A first direction of researches was the layout design for an assembly line. First, a layout design methodology for an assembly line was developed [16], and then this methodology was tested in the laboratory [17]. The assembling process considered was that of the steering-wheel and the assembly line design was integrated into the lean manufacturing concepts (modular and flexible workstations and transport system).

The workstations design and the assembly line layout design were made using CAD solutions. By applying the elaborated methodology, several layout variants were realized, figure 10. The construction of this layout variants of the assembly line has been experimented with in the laboratory. Thus, the methodology of the assembly line’s layout design was tested and improved.

![Figure 10](image).

**Figure 10.** Designing the assembly line: (a) 3D model of the workstations; (b) 3D model of the assembly line; (c) real assembly line layout.

Also, layout line variants were analysed using the IMPACT software, figure 11. This has allowed the analysis and flows’ improvement, as well as the indicators’ calculation of the line’s performance.
Moreover, the physical construction of the workstations and the assembly line with different configurations allows to apply the Lean manufacturing methods in order to learn their use, but also to improve the indicators of the assembly line’s performance.

3.2. Workspace and ergonomics analysis
A second direction of researches was the organization of the workstation and its ergonomics. These studies have been conducted in a context in which the modernization of manufacturing processes to increase production efficiency and increase operator safety and comfort is one of the key points of Industry 4.0 implementation. The analysed workstations were those in the steering wheel assembly line.

A first study [18] followed to ensure operator ergonomics on the one hand, so that the load for both operator’s arms is as evenly distributed as possible, and on the other hand to ensure that the supply of finished parts of different types (with different properties) is distributed as equally as possible. The study was conducted on the digitized workstation (described in subsection 2.2 of this paper) to which a computer with a server application and a client terminal was attached. The block scheme level and system components are shown in figure 12. The server application runs a Genetic Algorithm specialized in multi-objectives optimizations.

Figure 11. Analysis of the layout assembly line using IMPACT software: (a) 3D layout; (b) Chart flows.

Figure 12. Block diagram of the system.
This study combined two points: research - the use of an intelligent algorithm (Genetic Algorithm) for optimizing the workplace organization; and development - implementation in production: the proposed solution is tested in laboratory conditions (on an assembly line).
To optimize the workplace organization, it was considered the operator's effort (done by the motion trajectories in the ergonomic work area), the production flow (constraints on the sequence of the assembled components or their location) and the application of the principles of motion economy. The objective function of the genetic algorithm was represented by the weighted sum of the operator's load difference on the hands for the 100 processes and the sum of the dispersions per type of parts of the final lot.

For the second point, the developed project uses typical IT technologies from production environment - web server application where the intelligent algorithm runs, and graphical reporting engines for clients. The operator receives visual indications of the sequence to be followed (on HMI) and “pick to light” visual indications (to pick the part). Figure 13 shows a workstation photo and a detail of the control panel. In the left photo there can be seen “pick to light” indications for the boxes with components. “Pick to light” sequence is manually loaded from optimal flow generated by GA using controller panel.

Figure 13. Workstation (left) and detail with controller panel (right).

A second study [19] focused on the combined application of Artificial Neural Networks and the Rapid Upper Limb Assessment (RULA) analysis in the process of redesigning ergonomic workstations. The Neural Network was simulated with MATLAB and RULA analysis was made using CATIA V5 software.

The parameters considered in this study are to be taken into account when designing or redesigning the workstations. These parameters characterize the physical load of the human operator and physical environment. A feed forward neural network having three layers of neurons was used:
- the input layer - used to train the network: the relative humidity, the noise, the lighting and the RULA score. Each of these parameters corresponds to an input neuron;
- the hidden layer;
- the output layer: the workspace ranking, divided in three levels: P - poor, M - medium, G - good, representing the possibilities of output neurons.

The most difficult positions identified in this ergonomic study are those where the operator works with their hands up, figure 14 (a). In this case the microclimate’s conditions were: 20°C, 30% Relative Humidity, 44 dB and 500 lux, and the RULA score was 5. The workspace ranking, calculated by the trained network for the initial workstation, was P-poor.

In order to ameliorate the workstation ergonomic, a simple solution was implemented: the conveyers from the top were rearranged and moved down by 30 cm, figure 14 (b). Therefore, the human operator’s posture was amended, the new score obtained with RULA method was 3, and the workspace ranking, calculated by the network, was M-medium.
Figure 14. Ergonomic study on a workstation: (a) initial workstation; (b) improved workstation.

3.3. Modelling and simulation of the production flow

The modelling and simulations of the production flow allow to imitate the operating mode of a real process or system in a specific period of time and implies the generation of the system’s artificial history and the observation of its effects to highlight the characteristics of a real system’s functioning [20]. Also, the modelling and simulations are used to estimate the performance, to compare alternatives and to optimize systems design.

In our Lean Learning Factory, the first step related to modelling and simulation of production flows was elaborating the learning methodology for using modelling and simulation [21]. The second step consisted in applying this methodology to the analysis of two layout models of the assembly line [22], models that were tested in the laboratory (subsection 3.1).

Figure 15. IDEF0 modelling of the workstation 3: (a) first layout; (b) second layout.

To model the functioning of the assembly line, the IDEF 0 method was used, figure 15. The examination and the validation of the functional model made with IDEF 0 method were done together with the layout’s designer and with the manufacturing system’s developer in the laboratory.

In order to establish the influence of the line’s layout on the line productivity and on the workstation’s efficiency, for each layout of the assembly line were considered three scenarios: without buffer, one pallet buffer, and two pallet buffers. The discrete-events simulation of the models was done using
SIMAN language used by the software Arena Rockwell, version 13.9, and the simulations’ results were optimized using the OptQuest module.

![Figure 16. Plan Simulation of the assembly line: (a) first layout; (b) second layout.](image)

The obtained results allowed to compare the two layouts for each scenario and compared this with the real situation. Also, for each layout, the buffers’ influence was established. To visualize the operation of the assembly line for the two layouts, the Plant Simulation software was used, figure 16.

4. Teaching and knowledge transfer
The University of Pitesti has begun to integrate Lean Learning Factory into students’ education, while also intending for it to be used by automotive companies’ employees.

For students, the main directions to use this laboratory are:
- undergraduate students: workspace design, study of work and movements, time measurement, analysis of logistics flows, bachelor thesis;
- graduate students: lean manufacturing techniques, plant layout, production planning, modelling and simulation of the flows, dissertation thesis;
- doctoral students: integration and development of industry 4.0 concepts into lean manufacturing techniques, optimizing the plant layout and the production planning, logistics optimization, doctoral thesis.

For employees, the main directions to use this laboratory are: plant layout design, modelling and simulation of the flows, lean manufacturing techniques and industry 4.0 concepts, in postgraduate studies.

Presentation lectures are supplemented with exercises in the experimental laboratory. Therefore, the students can experiment with different methods and tools and can highlight the influence of various parameters on the system production performance.

Moreover, this laboratory can be a place where these methods can be developed and experimented with, in the framework of certain research projects with industrial firms, where new solutions can be discovered, or some existing ones can be improved.

5. Conclusions
In this paper, a Lean Learning Factory, which has begun its development at the University of Pitesti, is presented. This laboratory was introduced in relation to a research project and addresses three interconnected directions: layout design, modelling and simulation of the flows and Lean manufacturing.

Until now, several research and learning platforms (layout design, modelling-simulation flows, 5S, VSM) have been developed and several scientific studies have been conducted. The learning platforms allow to use the concepts of learning factory in the training process of the students or employees. With these learning platforms they can learn how to develop a plant layout, how to use modelling and simulation in flow analysis and how to apply the lean manufacturing techniques in order to improve the manufacturing systems’ performance.

The Lean Learning Factory at the University of Pitesti is in a continuous developing process which will allow students to enrich their practical skills and competencies concerning modern methods, techniques and tools, by using factory-like equipment. Moreover, this laboratory can also be accessed
by automotive companies’ employees from Arges County to improve their abilities in Lean manufacturing.

Future work will focus on developing other Lean and Industry 4.0 platforms and integrating the developed methodologies into a unitary set-up. Also, collaborations with other universities with similar laboratories have been taken into consideration.

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