Methodology for improving production flows on an assembly line

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Abstract. Globalization of production and strong competition in the economic environment requires manufacturers from automotive industry to offer their customers a wide range of products, of the best quality and at lower prices. In order to achieve a competitive advantage, the automotive industry must adapt their production systems to mass customisation, so that they can provide the variety demanded by the customers while limiting their costs and maintaining their profitability. In this context, research to increase the performance of assembly lines is increasingly numerous and use different techniques, as: layout design, mathematic modeling, dynamic simulation, Lean manufacturing etc. This paper presents a methodology for improving production flows on an assembly line, which was developed to provide the designer and manager of assembly lines in the automotive industry with a set of logically related steps and steps that would allow to achieve a high-performance assembly line. The stages and steps of this methodology consist in the use of methods from different fields, such as: layout design, modelling-simulation of production flows, labour study, lean manufacturing, and for their application different techniques and tools are used.

1. Introduction
Automotive industry faces many challenges in the era of globalization and therefore tries to continuously improve its production system in order to satisfy its clients demands with lower and lower costs.

The assembly is an important part of the production system, and therefore, to increase the performance of the assembly lines were used, along the years, different techniques, as: layout design, mathematic modeling, dynamic simulation, meta-heuristic approach, cost based approach, integrated approaches, Lean manufacturing etc. [1]. Some of the most relevant researches in the field are presented in the followings.

The first research direction concerning the organization of an assembly lines is the layout design because a good layout would contribute to the overall efficiency of operations. This layout must to facilitate the manufacturing process, and additional objectives include [2]: minimizing material handling, maintaining flexibility of arrangement and operation as needs change, promoting high turnover of work-in-process – keeping it moving, holding down investment in equipment, making economical use of floor space, remoting effective utilization of labor, providing for employees’ safety, comfort and convenience.

Another important direction of research is to optimize the performance parameters of the assembly line. Hakami and al. [3] showed several mathematical models of different performance parameters of an assembly line. Chramcov and al. [4] proposed a mathematical model to reduce the assembly
duration on an automated assembly line. Authors included, also, heuristics algorithms in their simulation model to determine the control of the assembly line. Lee and al. [5] studied the effect of monotony on the performance of operators to improve the productivity of the assembly line. Dao and al. [6] proposed a genetic algorithm to find an optimal solution for the performance of a line. Kia and al. [7] used genetic programing and discrete events simulation to study the influence of production programing rules on the performance of an assembly line.

In order to achieve a competitive advantage, the automotive industry must to adapt their production systems to mass customisation, so that they can provide the variety demanded by the customers while limiting their costs and maintaining their profitability [8]. In this context, research on the implementation of Lean manufacturing concepts in the organization of assembly lines is increasingly numerous. The core idea of Lean manufacturing is to work permanently on eliminating waste from the manufacturing process [9]. Lean facility layout means to arrange the physical equipment within a workshop to help the facility work in a productive way [10]. Using the same equipment and production line for the different models of a product, and standardized work are two of the Lean principles [9]. An empirical review of the Lean Manufacturing strategy is carried out by Chahal et al [11]. The result of the research done in this article show that Lean Manufacturing is the most profitable methodology of continuous improvement in the industrial area and in the research area.

Based on the literature overview and on discussions with experts in the field, this paper presents a methodology for improving production flows on an assembly line, which was developed to provide the designer and manager of assembly lines in the automotive industry with a set of logically related stages and steps that would allow to achieve a high-performance assembly line. The stages and steps of this methodology consist in the use of methods from different fields, such as: industrial systems design, modelling-simulation of production flows, labour study, lean manufacturing, and for their application different techniques and tools are used.

2. Methodology description

The methodology presented in this paper is part of a research project in which the authors are involved and is the result of several studies and research conducted in recent years [12-21].

The development of this methodology was based on a conceptual starting model [12], which was appreciated as having a level of technological training 2 - TRL2 [22]. This proposed model has 3 main interrelated investigations areas: layout design, modelling and simulation flows and Lean manufacturing, and includes both static activities and dynamic activities.

2.1. Methodology stages

The methodology was developed as an iterative process of design, implementation and exploitation, integrating the three main areas of the conceptual model of improving production flows. The application of the modern production requirements, expressed through the concept of Lean manufacturing, is found in the most activities within the methodology, especially in the design and exploitation of the assembly line. The stages and activities specific to the methodology for improving production flows on an assembly line are shown in figure 1 and there are briefly explained in the following subchapters.

The initial data are related to the product, the production process and the industrial system, as well as to the preset performance indicators.

The specific initial data of the product to be assembled are related to:
- the product to be assembled: shape, mass, overall dimensions, quality characteristics, specific requirements (brittleness, positioning during transport etc.), the product components and the joint mode of them to the product;
- the product components: shape, mass, overall dimensions, material and quality characteristics, specific requirements (brittleness, positioning during transport etc.), mode of realization (purchase from the supplier, execution in the company).

The specific initial data of the production process are related to:
- the general production flow, highlighting the position of the assembly process under it (connections with suppliers and customers) and takt time;

- the assembly process, highlighting: the technological assembly process (operations and specific phases), the available means of production (assembly equipment and tools, control, marking, labeling, inter-operational transfer, supply of workstations etc.).
- the organizational elements of the process: production capacity and accepted limits for variation, possibilities for launching production.

The specific initial data of the industrial system are related to:
- the general plan of the industrial system, highlighting the positioning of the area intended for the assembly line under it and its characteristics (shape, dimensions, inputs-outputs etc.);
- the energy sources availabilities (compressed air, electricity etc.);
- the production environment characteristics (temperature, humidity, lighting etc.);
- the average dimensions of operators.

The performance indicators of the assembly line can relate to: the operation (cycle time, takt-line), the production achieved (production capacity, interoperation stocks size), the occupied areas (size, occupancy degree, production capacity/ surface), the NVA activities of the operators (displacements, handlings), the operation flexibility (possibility of variation to production capacity, possibility of attendance for several workstations by the operators), the cost (implantation, operation).

In order to ensure some preset objectives, the management of the company can impose for these indicators (or only for some of them) certain values, minimum or maximum, which the assembly line must to ensure in its operation, so that its performance is defined.

2.2. First stage: assembly line design

The objective of this stage is to develop the spatial organization plan of the production system associated with the assembly line (consisting of the assembly line and the related logistics system) and its operation mode, so that to ensure the achievement of preset performance indicators for the assembly line.

The first step of this stage consists in “Design of the spatial organization of the assembly line” [12, 13]. The purpose of that is to develop a several variants of spatial organization plans, which can realize, mainly, as a result of:
- the different design of the work space for the operators (area independent of the part supply method to the workstations);
- the use of different methods to supplying the workstations with parts;
- the use of different means to achieving the inter-operational transfer;
- the spatial organization of the logistics area;
- the spatial arrangement of the assembly line.

In this extensive step, on which can return for five times (through the 5 loops), it integrates specific Lean manufacturing concepts, such as:
- ensuring a high flexibility for workstations, so that a greater diversity of products of the same type can be realized;
- the realization of modular - unitary structures of the workstations, so as to decrease the costs of their realization and the operating times;
- the possibility of adapting the process to the client's request: the “one-piece flow” production in order to increase the reactivity to the client's request, which requires the achievement of “setup zero” times for the workstations;
- to minimise the activities without added value (especially displacements and handlings) so as to be meet the “NVA = 0” objective.

After developing of the variants for the spatial organization plans of the production system, in the second step of this stage - “Indicators analysis”, the performance indicators for each variant are calculated and compared with the preset ones, being possible two situations:
- the values of some indicators are not appropriate: the design of the spatial organization (loop 1) is being re-examined, so that to ensure the obtaining of the desired values for the preset indicators, for at least one variant.
- the values of all indicators are appropriate for the analyzed organization variant: the following step may be taken.
The third step, "Lean Manufacturing Analysis", aims to analyze the application of Lean principles to the design of spatial organization variants with appropriate performance indicators, two situations being possible:
- the Lean principles were not applied for a variant of the analyzed spatial organization of the production system: the design of the spatial organization of that variant is being re-examined (loop 2).
- the Lean principles were applied for the analyzed spatial organization variant: the fourth step may be taken.

"Modeling - simulation of assembly line operation" [14, 15] is the fourth step and consists in simulating the operation of the assembly line for each variant of spatial organization with appropriate performance indicators and meeting the requirements of Lean manufacturing. The operation of the assembly line is simulated for different production scenarios.

The results obtained by simulation for each scenario related to the performance indicators are analyzed in the fifth step, "Results analysis", two situations being possible:
- the results are not appropriate: the design of the spatial organization is being re-examined (loop 3).
- the results are appropriate: the following step may be taken (six).

The sixth step of the first stage, "Selection of the optimal variant of spatial organization", consists in selecting that variant of organization that leads to obtaining the "best" performance indicators of the assembly line. Depending on the tactical objectives of the management, one or more selection indicators can be chosen, in addition to those preset by the initial data. The results of this stage are represented by the location plan (implantation) of the assembly line, the operation mode of the assembly line and its set of performance indicators.

The location plan (implantation) of the assembly line is a complex document, which includes:
- the plan for the positioning of the production and logistical means,
- flow chart,
- the pedestrian traffic plan and the utilities connections plan etc.

The operating mode of the assembly line is a document that presents:
- the organizing of the logistic flow, respectively, supplying the line workstations with parts or other materials / equipment specific to the assembly process;
- the parts flow management, respectively: definition of the launch order, the launch point in execution and production declaration, presentation of the manufacturing change principle.
- the organizing of the production maintenance means;
- the mode to recover of the packaging and waste.

2.3. Second stage: implementation

The objective of this stage consists in the physical realization on the allocated location of the assembly line and the related logistics system also the production and work organization (work standardization and training of operators), so that the assembly line to ensure a stable process with the preset performance indicators.

In the first step of this stage, "Equipment construction", the components of the assembly line (workstations and logistic equipments) designed in "Spatial design" step are sent for execution. Thus, these equipments can be made within the company and/ or can be purchased from suppliers. The fabricants of these equipments analyze the possibilities of respecting the execution projects and, in case the execution requirements can be respected, they continue with the next step. If the execution requirements cannot be met, it returns to the step " Spatial design " in the first stage (loop 4), in order to redesign the equipment with problems and rebuild the layout.

The second step of this stage, "Implementation", consists in the physical location on the allocated site for all components of the assembly line (workstations and logistics area), according to the optimal spatial organization plan (established in stage I). It is recommended to carry out an installation project, in which the following main phases of the installation are highlighted: preparation (has the role to ensure the basic conditions for installing machinery and equipment on the allocated sites and refers to all participants from this process), moving (moving machinery, equipment and industrial furniture to
the installation points), the actual installation (positioning and effective installation of machinery, equipment and industrial furniture on the allocated sites), start-testing (checking the correct operation of the equipment), general cleaning (general checks of the implantation and cleaning of the area).

The third step of the methodology includes two directions of action carried out in parallel, respectively “Work and process standardization” and “Operators training”. The work standardization aims to establish the working standards (working instructions) for each workstation of the line and the area of logistical preparation, in which are detailed: gestural rules for operations performing, self-maintenance activities, workplace health and safety rules, operation duration etc. The process standardization aims to establish the rules regarding to the development of all the processes necessary for the operation of the assembly line and their concatenation, respectively: the operations durations and supply processes with components (same as those of work standards), interoperation stock sizes, management of parts flow, maintenance of production means, recovery of packaging and wastes. To meet these standards, a series of techniques and tools of visual management are used, of different levels, such as: level 1 - communication of information to a large group of employees (production area information panels, announcements, process maps, skills / flexibility matrices etc.); level 2 - standards documentation (instructions for standard work on the workstation, checklist before work, overflow markings of containers etc.); level 3 - warning of the failures occurrence / abnormal conditions (panels and patterns with failures, cables and Andon plates, etc.); level 4 - preventing the failures occurrence - (motion sensors, Poka Yoke systems etc.).

The purpose of the operators training is to develop their skills, so that they reach the desired rate as quickly as possible. In this regard, specific techniques are used, such as: DOJO workshops, workstations rotation (versatility), communication skills training workshops (changing roles between the workshop leaders and operators), one off lesson etc.

In the fourth step, “Functional testing”, the verification of the mode in which the assembly line works is carried out, through the implementation by the trained operators of the previously developed work and process standards.

The results obtained after testing the operation of the assembly line are analyzed in the fifth step, “Indicators analysis/ Six Sigma”. The method used to analyze assembly line performance indicators is Six Sigma which uses quantitative data based on which statistical analyzes can be performed (Pareto, Analysis Hypothesis / Inference Tests, Correlation / Regression Analysis). These data are specific to the manufactured product (dimensions, deviations, tolerances, physical and / or mechanical properties, etc. obtained in different operations on the assembly line) and the assembly process (activities durations, stocks sizes, productivity, delivery times, etc.).

If the performance indicators are not appropriate, it is possible to intervene on:

- the implantation of the assembly line, through the appropriate modification of its spatial organization (loop 5). For example: the work standardization shows that the workstation from the assembly line is not well organized, in which case a new spatial organization of the workstation is proposed.

- the spatial design (loop 6). This situation can occur when there are large deviations of some indicators from those preset, which may have as a cause the non-compliance (during the implementation stage) of the spatial organization plan developed (for example, by using other machinery or equipment than those initially planned) or as a result of the constructive or technological modification of the product. This loop is one with a major impact on the whole process and longer duration.

- the training of operators and / or work and process standardization (loop 7). For example: it is found that there are major differences between the durations of identical operations performed by the same operator, in which case it is proposed to resuming the work standardization process.

If the values of the indicators resulting from this stage are in accordance with those preset through the initial data, it is considered that the assembly line is working apropriate and proceed to the exploitation stage of the assembly line.
2.4. Third stage: exploitation

The objective of this stage is to operate / use the assembly line and apply Lean Manufacturing techniques and tools, so as to ensure its operation at a high level of performance.

The implementation of the Lean Manufacturing concept at the company level, so as to ensure its successful and sustainable development, is significantly influenced by the good start of this process. In this regard, the company must ensure the realization of all the basic / fundamental elements of Lean Manufacturing, such as:

- the highest-level management demonstrates leadership and commitment to the LM project by developing a Lean policy to support the strategic direction of the organization and by setting Lean objectives. LM's objectives must be consistent with the company's overall policy.
- the company's management is responsible for setting up the "Lean team", which does not have to include many people, but must be a multifunctional team.
- the Lean team is trained. This training should be conducted by a consultant / expert Lean, providing a first impetus for the introduction of Lean culture within the team.
- the company's management must establish and maintain communication and feedback channels with the Lean team.

Within the proposed methodology, it is considered that all these basic elements have been achieved within the company. Thus, the first task of the Lean team is to delimit the perimeter of action, which can be done using the product / process matrix or a Pareto analysis. Proper selection of the initial scope of action is important for concentrating resources and maximizing gains. After selecting the initial perimeter, the team must develop a Lean implementation plan (master plan), which must include a timely planning of actions to be taken and a budget. Then, it can proceed to the first step in implementing the Lean Manufacturing methodology.

In the first step of this stage, "Lean Manufacturing indicators setting", the Lean performance indicators specific to the assembly line are defined, derived from the Lean objectives established at the company level. The initial values of these indicators are also determined to define the current state of assembly line performance. Lean performance indicators of the assembly line (whose value is to be achieved / increased by implementing the Lean Manufacturing methodology) can be related to:

- Productivity - the number of products assembled in an hour;
- Quality - the number of products without defects;
- Cost - unit cost with assembling the product on the assembly line;
- Delivery time - the period of time elapsed from the moment the customer requests the product and the moment when it is available for it.
- Safety and environment - possible risk situations regarding the working environment, together with the measures to prevent them, the actions of their correction and constant monitoring (in order to overcome the possible danger situations and to guarantee the conditions of safety).
- Morality - teamwork or optimal use of available human resources knowledge. The aim is to increase the skills of team members (to work in a team, lead a team, think clearly and logically, solve problems) and strengthen the self-confidence of team members.

"Lean Manufacturing application" is the second step and consists in analyzing and improving the performance of the assembly line by implementing methods specific to the concept of Lean Manufacturing. In this large-scale step, a set of specific methods and techniques are used, such as: Kaizen, 5S, Kanban/ Conwip, Jidoka/ Poka-Yoke, Hoshin etc. For their efficient use, the authors aimed to develop and integrate a specific methodology for their application.

The results obtained from the implementation of the Lean manufacturing concept are analyzed in step three, "LM indicators analysis/ Six sigma". As the name of this step suggests, the method used to analyze assembly line performance is SixSigma. If the results obtained are not adequate, it is possible to intervene on:

- implantation of the assembly line, by corresponding modification of its spatial organization (loop 8). For example: if the application of the Kaizen method shows that a workstation within the assembly line is not properly organized, a new spatial organization of the workstation is proposed.
- training of operators and/or standardization of work and process (loop 9). For example: if a 5S audit reveals that labor standards are not being met, it is proposed to resume the operator training process.
- Lean Manufacturing continuous improvement process (loop 10): if the required LM indicators are not achieved, the specific Lean manufacturing methods will be applied again, so as to identify the solutions for achieving the desired indicators.

When the results obtained from the analysis of performance indicators are in line with the objectives set out in the first step of this stage, the assembly line is considered to operate at the desired level of performance.

3. Methodology application

The developed methodology was experimented and validated in the laboratory using an experimental demonstrator (TRL4 level) developed in a Lean Learning Factory laboratory, figure 2.

This laboratory [16, 17] includes integrated platform for research and learning, such as:
- for the layout design direction: modular and flexible equipments for configuring and supply workstations; equipments for interoperable transfer; digitized system for a workstation (PLC system, HMI, identification camera, scanner, pick to light, wireless communications); support elements for the analysis of the location of the means of production (support write board and video projector);
- for the modeling - simulation direction of production flows: guide for learning the use of modeling and simulation in the analysis of production systems;
- for the work study direction: platforms for learning and applying specific methods and techniques (DOJO, Standardization etc.);
- for the Lean manufacturing direction: platforms for learning and applying specific methods and techniques (VSM, Lean corner, 5S, Poka-Yoke, Kaizen, Visual management).

Along with the physical supports (research equipment and platforms), the laboratory also includes computer supports, being equipped with a server and computers interconnected in the network on which software specific to the research directions are installed: layout design (IMPACT, Tecnomatix-FactoryFlow), production planning (ABAS), modeling and simulation with discrete events of production flows (Rockwell Arena and Tecnomatix-PlantSimulation).
Thus, along with experimenting with the developed methodology, this laboratory also allowed research on layout design for an assembly line [12, 13], workspace and ergonomics analysis [18, 19], modeling and simulation of the production flow [14, 15], Six Sigma application [20] and a RFID based Kanban system implementation [21].

4. Conclusions

The methodology presented in this paper had as a starting point a level of technological training 2 - TRL2 with 3 main interrelated investigations areas: layout design, modelling and simulation flows and Lean manufacturing, and includes both static activities and dynamic activities. During the research project, this model was developed until TRL 4 and the developed methodology was experimented and validated in the laboratory, within an experimental demonstrator.

The methodology for improving production flows on an assembly line developed in this context consists of an iterative process in three stages (design, implementation and operation of the assembly line), with several steps each and return loops.

The data necessary for the application of this methodology are numerous and complex, coming from many fields of industrial activity: product design, technology design, industrial systems design, ergonomics, production management, and the variables involved in the process are diverse (products - through their diversity), process (through assembly technology), supply of components (methods of supply of workstations), organization of workstations (working methods used), location of workstations and means of transfer (various models and variants), production management and control (by the methods used).

The methods used in the activities are, in turn, very diverse: standards and norms specific to industrial fields (technical drawing, ergonomics, logistics), rules and principles specific to the design of assembly processes, spatial organization, ergonomics and work organization, and production management. The concepts of modern production, expressed through the concept of Lean manufacturing, are found in most of the activities within the methodology. The techniques and tools used are largely in the field of computer aided engineering (computer aided design, technological design, balancing production lines, optimization, modelling-simulation), but also in the field of flow analysis (flow charts) or comparative analysis (decision-making techniques, Six Sigma).

The results obtained by applying the methodology are quantified by the performance indicators of assembly line operation and specific Lean manufacturing and are influenced by the accuracy of input data, as well as the use of different methods, techniques and tools in the application of the methodology. Therefore, in order to facilitate the proper understanding and application of the methodology, the authors aim to develop a "Guide to using the methodology to improve production flows on an assembly line", which should be available to the main beneficiaries: students and companies.

Also, another direction of further research aims at integrating in this laboratory the specific methods and techniques of Industry 4.0 and the development of a Lean Learning Factory with Industry 4.0 at the University of Pitesti.

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