Lean System Design Framework Based on Lean Functionalities and Criteria Integration in Production Machines Design Phase

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Manufacturing needs more and more requirements (sustainability, agility, Industry 4.0 technologies, etc.) to meet customer demands. Nowadays, companies apply Lean tools to improve machines and systems performance in their use phase. Lean tools application on existing machines ensures some functionalities like (Reduce changeover time, eliminate wastes, Involve Human Skills, etc.).
The purpose of this paper is to offer designers a design support method and tool to design a performant system (production system, machines, etc.) by integrating Lean functionalities from the early design phases, with a minimum of needs to improve the system in the use phase via Lean.
For this purpose, we analyze the Lean principles and tools to identify functionalities provided by Lean. These functionalities are analyzed and classified to integrate them into the design of manufacturing systems in the context of Industry 4.0. A "Lean-System-Design" approach defines a systematic and detailed guide for the integration of Lean from the early design phase. We provide the software tool specifications, which represent the first steps of its implementation. We have illustrated our proposal with a case study on the design of a waste treatment machine.

Keywords: *Production machines design., Production systems design Machines design, Lean thinking, Lean Design, Industry 4.0,Performance criteria.*

1. INTRODUCTION

Today many companies apply Lean principles and tools to their manufacturing systems to fulfill some performance criteria. They do that because the designed systems are not always optimal and need sometimes some improvement to increase their performance.

However, the application of Lean tools requires a particular organization, and it is limited by the designed system or the machine itself. Most of these Lean tools require time and budget to be invested for the implementation of a continuous improvement project either by the company's teams themselves or by calling on Lean experts. Besides, according to Lean expert Hohmann [1], Lean worksites focus on local problems or a given area, regardless of the links, interactions, and impacts in other areas, which makes that the improvements are not optimal and does not cover the whole manufacturing system.

Lean functionalities integration during the design phases could be a more and more appropriate solution to enhance the global performance of the system, machines, final products, and to optimize the interdependencies between their components. The operator can perform his tasks without losing time in optimal workplace conditions, enhancing safety, teamwork, and usability.

The machines can be designed to perform tasks in an optimal, cost-effective, and ecological way.

The integration of Lean functionalities during the design phases could be a more and more appropriate solution to enhance the global performance of the system, machines, final products, and to optimize the interdependencies between their components. The operator can perform his tasks without losing time in optimal workplace conditions, enhancing safety, teamwork, and usability. The machines can be designed to perform tasks in an optimal, cost-effective, and ecological way.

Furthermore, considering Lean requirements from the early stages of production system design could facilitate the development of Industry 4.0. It should be noted that many recent studies affirm that the implementation of new technologies in Industry 4.0 is compatible with Lean principles [2] [3].

This paper aims to propose for the designer a holistic approach to consider Lean functionalities to design a future system that did not need to apply Lean tools in its phase use.

We should specify that our system could be a machine, an apparatus, a device, or a manufacturing system. This work does not involve the application of Lean tools to improve the design process.

In section 2, we present a literature review on the integration of Lean from the design phases. In section 3, we present our contribution to Lean integration

Received: April 2021, Accepted: June 2021
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doi:10.5937/fme2103575S

from the design phases of manufacturing systems. In section 4, we provide the software tool specifications based on our method. In section 5, we apply the proposed method to a case study of a Waste Treatment Machine 4.0. Then, we conclude.

2. LITERATURE REVIEW

We present in this section the state of the art of integration of Lean functionalities from the design phases of the system/machine.

In the first part, we present some of the most com–monly used industrial performance criteria. Then, we highlight how most methods of design could be helpful to consider different performance criteria. In the third part, we provide a review of the literature on Lean integration from the design phases. Finally, we discuss our analysis.

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2.1 Performance criteria

The fundamental activities of engineering design are to find the optimal technical solution, which guarantees a set of requirements and constraints related to human, material, technological, economic, and environmental [4]. Normally, designers follow the imposed criteria to take into account the requested requirements. According to koren et al. [5], the manufacturing system needs to have several characteristics and criteria, such as automation, mobility, modularity, extensibility, convertibility, and diagnostic ability to be reconfigurable. Drohomeretski et al. [6] consider the criteria of quality, reliability, flexibility, speed, cost and innovation as competitive priorities that lead to the best performance of manufacturing companies. Ramos et al. [7] use the automation, processing, flexibility, usability, support assistance, and cost of user training such as evaluation criteria. Design for sustainability is crucial to enhance the social conditions, reduce the waste of energy and water, and improve the environmental conditions [8].

The list below in Table 1 presents an extract of the most widely used and known characteristics and criteria removed from literature according to the evolution of paradigms of manufacturing systems [9-16].

Table 1. The proposed principles in contradiction matrix

Criteria	Description
Accessibility	Is the ability of system to be access easily.
Agility	Is the ability to react quickly and flexible to unexpected changes in a dynamic environment.
Automation	Is the ability of the system to change the degree of automation of operations, depending on certain factors such as the production rate.
Autonomous	Is the ability of the use of robots for automating activities in a way that systems work autonomously and consciously aware of the surroundings that make them work collaboratively with the human.
Communication	Is the ability of system to exchange the information with interoperability through the networked machines at the shop floor and human (Machine-Machine (M2M) and Human to Machine (H2M)).
Complexity	Is the degree of complexity of system.
Cost	Is the total cost of the system design.
Customization	Is the ability to make a personalized flexibility that cover the DMS and FMS.
Extensibility	Is the ability of system to modify easily the capacity of production by adding or removing resources (e.g. machines) or by replacing system components.
Flexibility	Is the ability to adapt operations whenever necessary and respond quickly, whether it is due to changes in demand or needs of the production process;
Human skills 4.0	Is the capacity of users to have the skills to work in the context of Industry 4.0.
Innovation	Is the ability to design new products that are more diverse development times than competitors.
Multi-skill work	Is the ability of user to perform several tasks.
Maintainability	Is the ability of equipment to be easy to repair and maintain.
Safety and ergonomics	Is the ability to adapt works, tools, and the workplace to the user to ensure the human-machine interaction, and to respect safety laws and standards.
Standardization	Is the following of the global standards like the International Organization for Standardization (ISO).
Self-Cleanliness	Is the ability of the system to stay clean, tidy, and standard.
Smart technology 4.0	Is the ability to integrate new technologies of Industry 4.0.
Sustainability	Is the ability to cover economic sustainability, environmental, and social sustainability (waste reduction, emissions mitigation, lowering energy consumption, and resource utilization).
Supplier and customer integration	Is the ability of the system to provide a platform to exchange in real-time all information related to productivity and delivery.
Usability	Is the ability of the system to be used easily.
User satisfaction	Is the percentage of customer and user satisfaction based on actual cases and previous experiences.
Longevity	Is the ability to increase the life of product along with easy reparability, upgradability, and recyclability.

In the following paragraph, we present some of the most commonly used design methods to meet these industrial criteria performance.

2.2 Methods of Design integrating Lean performance criteria

A lot of efficient methods and processes of design are carried out to help the designer to consider some performance criteria, such as Design for X, Reliability Design, Axiomatic Design, TRIZ, etc.

The "X" of "Design for X" generally represents the design criteria that the system (manufacturing, machines, apparatus, etc.) must satisfy first. "X" can be "Cost" in "Design for Cost", production in "Design for Production", safety in "Design for Safety", and so on.

The Design for Production provides a compre–hensive view of the entire production system, aiming to stay up to date in product development [17]. Design for manufacturability is a method to evaluate product design through a performance ration according to some characteristics and criteria [18]. Design for Assembly principle aims to reduce the number of parts for minimizing the assembly time, fasteners, parts inventory, and the cost of the products. Design for Maintainability aims to eliminate the waste of repairing time, thus, decreasing the cost of remanufacturing by taking into account the criteria of repair and maintenance [19]. Weisheng Lu et al. [19] presented a design guideline from the review of the literature of "Design for Manufacture and Assembly" to help designers to optimize the design of the production system by linking the principles of Lean construction with the principles of "Design for Manufacture and assembly". Design for Additive Manufacturing highlights how to design components that take full advantage of these Additive manufacturing technologies [21]. The Design for Environment aims to consider the environmental impact from the early design phase [22]. Design for Maintenance is a method to optimize maintenance activities from the design process [23].

To keep pace with contemporary design, to establish a vital link with a technical problem, Stevanović et al. [24] use Biological bionics, which bases on the knowledge of botany, zoology, medicine collected by observing the functioning of living organisms, to extract the principles helping to find solutions. In the same way, to improve its ergonomic properties, Elena et al. [25] inspired by the skeletal structure of the seahorse and its ability to bear loads while maintaining its flexibility for the design of school backpacks with an integrated mechanical system based on the biological skeletal structure of the seahorse, allowing a maximum comfort and healthy posture. Gavrilović et al. [26] tested several wingtip shapes by adapting them to a clean wing on providing quantitative and qualitative analysis, and the following advantages and disadvantages.

To resolve the design problem, the theory of inventive problem solving "TRIZ" uses some technical methods such as contradictions matrix to find the inventive optimal solutions [27]. To find the optimal solution, Chibane et al. [28] combine inventive methods with optimization using Design of Experiments (DoE) which aims to model and understand the process with a minimum number of experiments and overcoming this optimum by using TRIZ.

There are other methods, which aim to enhance the performance of a production system or industrial machinery. For example, Design for Six Sigma describes the use of the steps of the method of Six Sigma in the Engineering design process [29]. The Value Driving Design aims to focus the design solution according to the customer value. Therefore, it provides methods and tools that take the value as a basis of measurement for selecting and evaluating the optimal configuration for the operations and the tasks of the design work [30].

We share the same goal of these methods in improving the performance of the system. However, these methods propose to integrate one or two criteria included in Lean principles. The scientific question still how the maximum or all of Lean criteria could be integrated from manufacturing system design.

In the next paragraph, we outline the Lean integration from the design phases.

2.3 Lean from design

Lean are applied from the early design phase in the form of keys performance indicators, or Lean design rules. "Lean rules are a set of explicit rules based on the lean theory, principles, and practices [31]. Black et al. [32] provide some Lean design rules to explain how Toyota changed the final assembly lines into a mixed-mode, and the linear subassembly lines into U-shaped.

The combination of Lean thinking with the strategy of Design for Six Sigma, is significant for giving a global and complete method to satisfy all requirements [33]. Lean Product development (LPD), as the name indicates, is some Lean principles, methods, and tools implemented to minimize waste and improve the process of product development [34]. Using Axiomatic Design (AD) matrix, Rauch et al. combine the Lean principles and Industry 4.0 with Lean Product Deve–lopment (LPD) to introduce a new notion of Smart Pro–duct Development [35]. In the same way, Lean production development aims to integrate Lean thinking from the early design phase to design an effective production system based on Lean principles [36].

2.4 Discussion

Most of these methods mentioned in the literature are: either theoretical, based on Lean thinking, but they are not detailed enough to cover all performance criteria and appropriate functionalities, or they focus on one phase of a system's life cycle more than another. For example Lean Product development and Lean Production Development are aimed more at improving the product design process and improving the product over its entire life cycle, including the design phases.

However, we do not focus on the design process to highlight that Lean can eliminate waste in its phases.

In this literature review, we have not attempted to show these limitations in detail. Rather, we want to emphasize that the integration of Lean from design is an important and widely known topic in the Lean field to make the system performant and clean from the early design phase.

We share the same goal of Lean Design and Design for X. But we seek to avoid their limitations. Design for X works on a specific stage of system or specific criteria [37].

Table 2. Our proposition in comparison with existing methods

Design for X	Our proposition	Lean Design
Systematic approach	Systematic approach	Theoretical approach
X refers to a specific criteria	X cover most of criteria	Based on Lean thinking
Specific stage of product life cycle	All stage of product lifecycle	All stage of product lifecycle
Complex optimisation	Optimization of Value add functions	Preventing Non Value add functions
Give a suitable solution for a specific decision according to criteria dependent on X	Able to give a suitable solution to improve system global performance	Not able to give a suitable solution for any kind of decision

For example, Design for Cost is intended to help designers to propose a low-cost solution. But, to improve their efficiency in the use phase, this solution needs to apply some Lean tools such a 5S, SMED, ANDON, etc., which could increase the cost of system exploitation. So somewhere, the integration of several criteria could cause some contradictions. Slim et al. [38] propose to use TRIZ to solve these contradictions when designers confront this situation.

In this paper, we propose a method that could take as early as possible in the design process all (or the maximum of) Lean performance criteria by avoiding ulterior contradictions.

Also, Lean Design focuses on value-adding activities from the perspective of the end customer, resulting in the elimination of all non-value-adding activities. Accordingly, Lean Design has been considered as a theoretical approach to reduce waste and focus on customer value [39]. Lean Design suggests to designers to follow some general rules according to Lean thinking. But detailed information is not provided, especially in the final stages of design to help designers to make their decisions [37].

To precise the position of our contribution, we have analyzed the advantage and limitations of both methods "Design for X" and "Lean Design" as presented in table 2.

3. CONTRIBUTIONS OF LEAN INTEGRATION FROM THE EARLY SYSTEM DESIGN PHASES

In section 3.1, we specify our example system which is a production system.

In section 3.2, we defined the Lean functionalities to be integrated from the design phase of the system.

Then in section 3.3 we present the steps of our methodology Lean-System-Design.

3.1 Lean designed system

Our proposed “Lean designed system” depends on several actors that react with each other.

The Octopus diagram, as shown in Fig.1, highlights the relationships between the different elements and factors of the system. Functions are classified into two categories that each one can contain Lean functionalities:

Primary Functions (PS) and Constrained Functions (CF)

FP1 Allow Human to use machine.

FP2 Allow humans to have the necessary information.

FP3 Allow machines to have the necessary information.

FP4 Allow humans to know transfer functions.

FP5 Allow machines to know the transfer functions.

FC1 Take into account the ecological aspect.

FC2 Respect buildings and structure.

The purpose is that Lean should cover all the functions of the Octopus diagram.

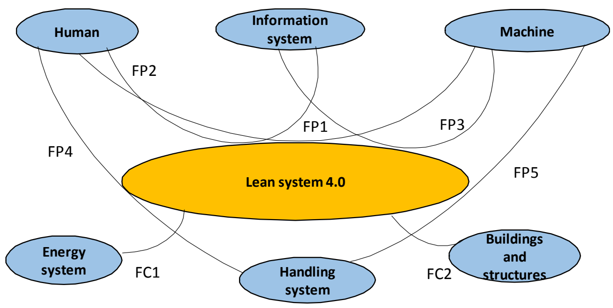

Figure 1. Octopus diagram of our system

3.2 Lean functionalities

To improve our system from the design phases, from literature analyzing, we collected an extract of the most important Lean methods and practices mentioned in the literature, related to Lean tools and Lean functionalities.

In table 3, we define for each Lean principle the concerned criteria and the appropriate Lean tools, and the identified functionalities that these tools fulfill to improve system performance.

Table 3. Lean functionalities from different Lean paradigms

Lean Paradigm	Lean principles	Related functions	Lean functionalities	Criterion	References
Lean And Six Sigma	Process Mapping Seven Quality Standardized Mistake Proofing	ALL	- Eliminate the cause of defects. - Eliminate Waste. - Eliminate Non Value Add activities. - Reduce Cycle time.	Cost Quality Reliability	[6]

Lean and Agile	Customer requirements Competitive intensity Continuous improvement Automation Rapid prototype technologies Decentralized decision making Short development cycle times Culture of learning	FP3 FP5	- Enhance the variety of production. - Enhance the effectiveness response to the customer change needs. - Reduce Lead time. - Apply skills from different company functions from experts.	Flexibility Speed Agility Automation Complexity Smart tools 4.0	[40] [41] [42] [41]
Lean and Sustainability	TPM VSM 5S SMED Kanban cellular manufacturing Poka-Yoke	FP1 FP2 FP3 FP4 FP5	- Improve Supply chain. - Improve Social Human Skills. - Reduce Environmental impact. - Improve the efficiency of system and equipment. - Improve the product durability. - Improve Human performance tasks. - Optimize the choice of material. - Minimize waste. - Optimize End-of-life and life cycle. - Reduce the emissions.	Sustainability Innovation Longevity Reusability Remanufacturability Disassembility Safety Cost Quality Sustainability TRIZ	[43] [44] [45] [44] [46] [47]
Lean and Industry 4.0	Robots Internet of things Simulation Cyber security System integration Cloud computing 3D Big Data Augmented Reality	FP1, FP2, FP3, FP4, FP5	- Enhance the human skills to use the new technologies of I4.0. - Enhance the performance of system by adding the new technologies of I4.0. - Allow Human to work with robots in collaborative way. - Simulate and follow in 3D products and production process. - Provide the communications between agents. - Make decisions autonomous and in real time.	Smart tools 4.0 Human skills 4.0 Reconfigurability Agility Diagnosis Safety Supplier and customer integration Automation Autonomous	[48] [49] [49] [50]

3.3 Steps of Lean-System-Design

The purpose is that Lean should cover all the functions of the Octopus diagram. Thus, we propose to the designer the following approach presented in Fig. 2, and composed of the 7 following steps.

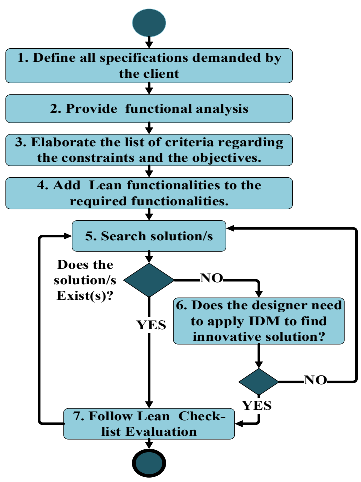

Figure 2. Steps of Lean-System-Design

1) In step 1, as a classical design method, the de–signer defines all specifications demanded by the client.

2) In step 2, the designer provides a functional analysis to define technical functions, service functions, and constraints.

3) In step 3, the designer elaborates on a list of criteria regarding the objectives and the constraints.

4) In step 4, the designer adds Lean functionalities, that allow fulfilling the chosen criteria in step 3, to the functionalities required by customers (technical functionalities).

5) In step 5, the designer applies design procedure to develop a solution to fulfill all required functionalities (technical functionalities and lean functionalities). However, we did not impose here how a designer should do. This step could be different in the function of his field and artifact subject of the design process. Depending upon the situation and condition, the designer can use adequate available methods and tools in his possession (FAST, SADT, etc.) or his expertise.

6) In step 6, if the designer did not find any solution after considering all functionalities and

constraint that he wants, which means the solution zone becomes zero. So, to solve the problem and to find an innovative solution, we propose to use the Innovative Design Method. If in spite of IDM use, the designer cannot find a solution, he has to relax some constraints by taking off some lean functionalities or other constraints (cost, etc.).

7) In step 7, designer follow the Lean Evaluation Check-list before prototyping in order to avoid any missing (not developed in this paper).

After the detailed design, a check-list evaluation of the integration of Lean functionalities could be provided. And depending on the results, the designer could rethink other solutions more Lean and thus guarantees more performance to the final optimal solutions envisaged. And therefore, a new attempt to resolve contradictions and to find innovative solutions can be implemented.

To apply this proposed approach, we propose the framework presented in Fig.3. In this framework, we adopted the production system design method developed by Pahl et al. [3], which has four phases: Initialization phase, Conceptual Design, Embodiment phase and Detailed phase.

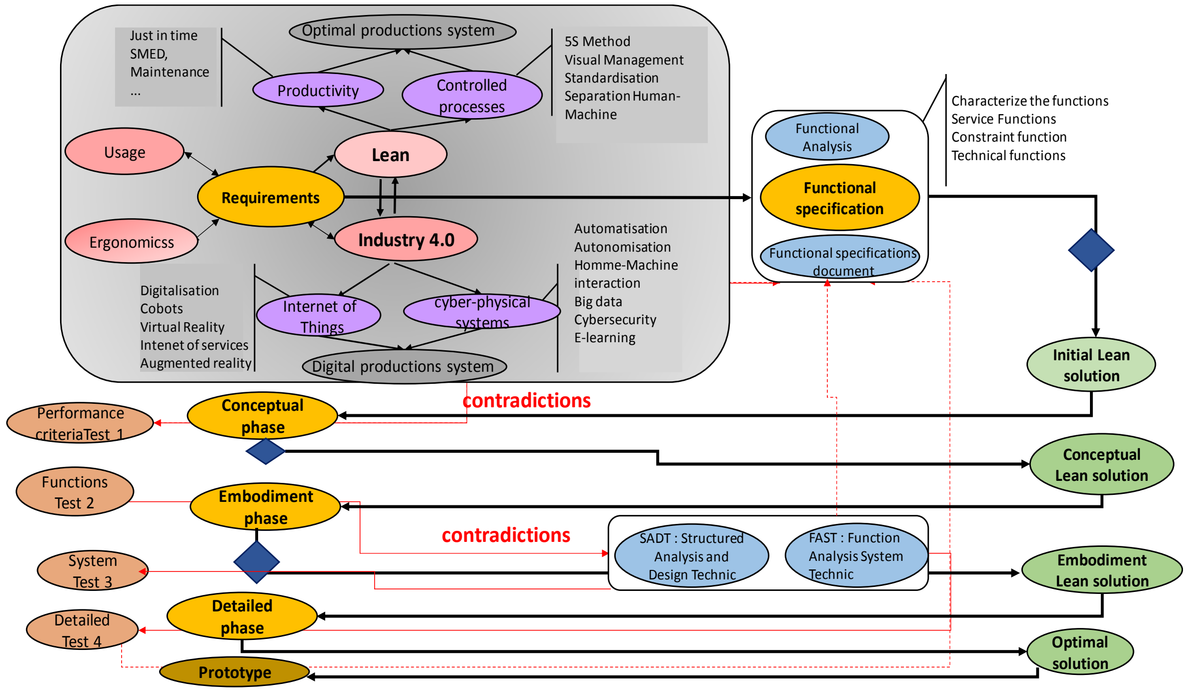

Figure 3. Lean-System-Design framework

1) Initialization phase: In this phase, the design problem is defined; data from Lean and Indus–try 4.0 can be provided.

The functional specifications document (FSD) will be constantly improved and refined according to Lean criteria, requirements and functionalities.

The functional specifications contain all specifi–cations and information that the system must perform to satisfy all requirements.

2) Conceptual Design: This data conceives the initial functional specifications. From the specifications, the concept of the main solution is chosen to be developed.
3) Embodiment phase: When the requirements are obtained, the function hierarchy can be developed, using Functional Analysis (AF), with the constraints of the configuration of functions and the linkage between the sub-functions.
4) Detailed phase: Finally, in the detailed design, the design is based on a complete technical description of the complex system.

To apply our proposition and make it easier to use by designers, we think it very important to elaborate a software tool to guide designer in his work.

4. LEAN-SYSTEM-DESIGN SOFTWARE SPECIFICATIONS

In this section, we propose the software specifications based on proposed criteria, functionalities and approach. We present successively the module specifications, the module architecture, then the UML analysis diagrams: object, class, and activity.

4.1 Specifications

We decide to implement the Lean-System-Design approach to integrate it as a module into CAD software. We called it "Lean-System-Design (LSD).

Our Lean-System-Design software consists to integ–rate the Lean functionalities to carry out the function specifications to help the designers to take into account the maximum of the performance criteria to satisfy all the functional, use, and performance requirements. For that, the data of the list of criteria, the appropriate Lean functionalities, and Lean parameters should be provided to the designer, additionally to the design methods (FAST, IDM, Task Decomposition, etc.) to carry out the initial, conceptual, and detailed functional specifi–cations.

4.2 Architecture

The architecture of the modeling targeted in our methodology consists of four parts (Fig. 4):

1. In the requirements list, the designer collects all the specifications of the system.
2. The design center covers functions and tasks.
3. In the Lean Centre, the designer uses the list of criteria suitable for the requirements, accompanied by the appropriate Lean functionalities and parameters. Thanks to this Lean center, the designer can optimize all solutions, from the technical and socio-technical tasks, the internal and external tasks.
4. In the IDM center, the designer can use the IDM to find solutions more suitable for the chosen cri–teria and Lean if the solution set is null.

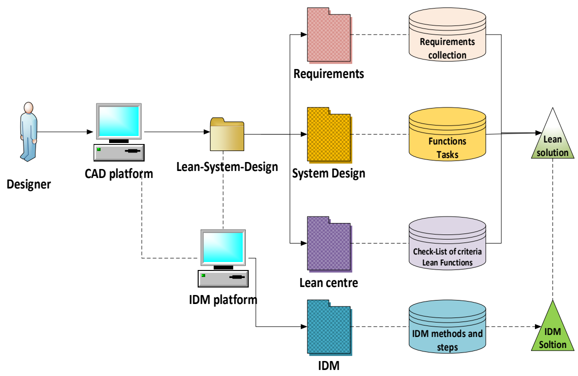

Figure 4. Architecture of Lean-System-Design

To better understand the system modeling, we use the ‘‘Unified Modeling Language’’ (UML) to precise the objects of the Lean-System-Design module.

Our system modeling depends on the user (Design team, engineers) that reacts with the CAD platform to design a complex system. For that, it is crucial to precise the classes of our system into:

External classes: Designer, Engineer team, CAD platform, IDM platform and all documents that the designer enters into the LSD module (Requirements collection, etc.)

Internal classes: List of criteria, List of Lean functionalities and All methods of Design, which can be used by designers to follow each step of the Lean System-Design approach (Functional specification, FAST, SADT, IDM, etc.).

For example, if the customer requests an environ-mentally and friendly system, this is an external output. The criterion of "Sustainability", the appropriate Lean functionalities, and the data of examples of Lean and IDM solutions are corresponding to the internal output. This class diagram specifies classes, their attributes, operations, and relationships between objects in the LSD module. It provides architectural modeling for the implementation of the system.

Fig. 6 shows the activity diagram of our LSD mo-dule, representing the dynamic aspects of our module. The diagram illustrates the description of the LSD module when used. It explains the different scenarios that the designer will face when designing a system.

The designer can use the LSD module while drawing on the CAD platform.

After this presentation of our proposed method and the LSD software model, in the following section, we present the application of our method on study case.

LSD allows the designer to apply our approach by providing him all information and methods that needs to design his system. To understand our system, the class diagram in Fig. 5 contains all information that covers the three initial, conceptual, and detailed functional specifications according to the list of criteria and Lean functionalities: Function components, function, and sub-functions, definition, and their decomposition etc.

The model is presented as the connection of the different classes corresponding to the different aspects of the LSD module.

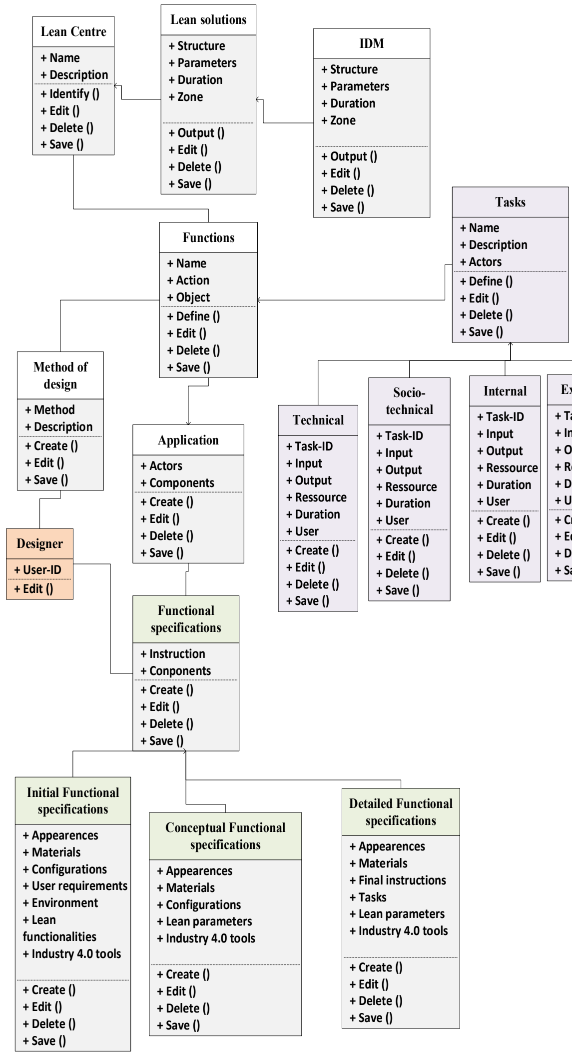

Figure 5. Class diagram of LSD module

5. CASE STUDY: SMART WASTE TREATMENT MACHINE

In spite of that our method is developed for manufacturing and production systems and also for machine design. In this section we present the application of our proposed method on a smart waste treatment machine.

Within a context of sustainable development and the implementation of Industry 4.0 technologies, the issue of waste recycling is increasingly addressed. As raised by several waste sorting centers, the transfer of recyclable waste to the treatment center generates both high transport costs and considerable energy losses. For this reason, reducing the volume of waste before transport could reduce the costs and losses associated with transporting it to the treatment center. During the design work, we have followed the steps of our Lean-System-Design method to illustrate and verify its feasibility.

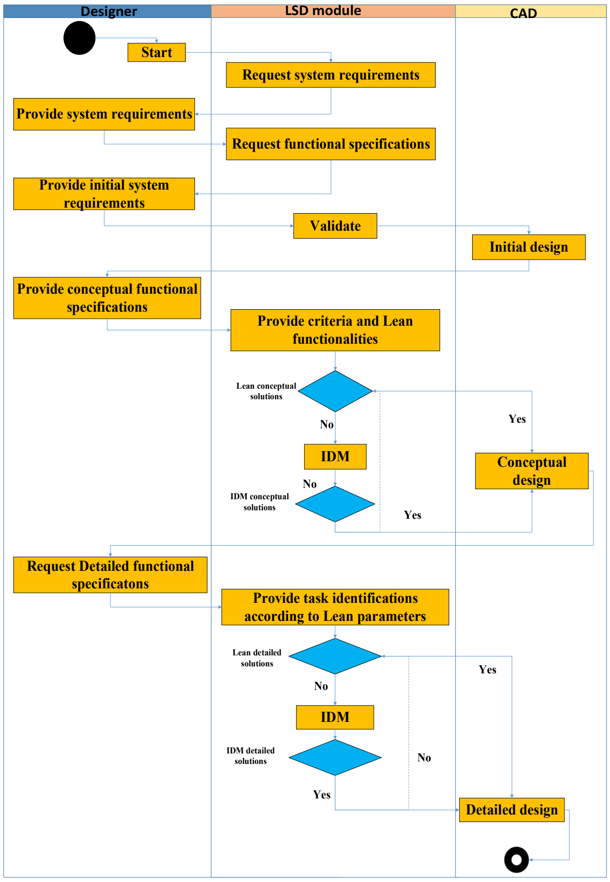

Figure 6. Class diagram of LSD module

Figure 7. Range of products

The purpose of this case is to design a system that would be placed next to a drink distributor so that the user could throw the container of his drink into the device, which has to recycle bottles and cans from 33 to 50cl (most common sizes) (Fig. 7).

This study is carried out as part of a machine design project by students from the Mechanical Engineering department of INSA Strasbourg, under the supervision of H. Chibane and S. Poli.

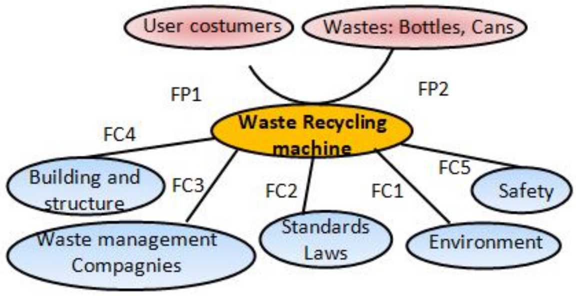

Figure 8. Octopus diagram of waste recycling machine

<u>Step 1. Define all specifications demanded by the client</u>

This system had to sort the cans and the bottles that people would throw away. Also, it would transform and reduce the volume of those wastes by grinding the plastic bottles and crushing the metal cans. Finally, the system must be easy to use by a large number of users.

<u>Step 2. Provide functional analysis</u>

Classical functional analysis was carried out to identify all technical functions and constraints

<u>Step 3. Elaborate the list of criteria regarding the constraints and the objectives</u>

The most required performance indexes will be the criteria that guarantee:

- Ecology (Sustainability): Since it allows a recycling efficiency that is close to 100%, thanks to the separation system for aluminum, plastic (PET, LDPE, etc).
- Economy (Cost): Placing the machines in front of the beverage dispensers will reduce transport and logistics costs. Besides, the separation of raw materials will also reduce costs, e.g. separated PET and HDPE plastics cost ten times more than a mixed material.
- Usability allows the simplicity of the machine, and recyclability allows a low rate of treatment which is significant for longevity.
- Smart technology (Industry 4.0): These machines will be connected to a central network that manages the periods of waste collection in the form of raw material available to be recycled. The latter includes the optimization of raw material collection and inventory management.
- User implication: The consumer of the drink participates directly in the protection of the ecosystem.
- Human-machine communication: Due to its electronic interface and its location in front of the beverage dispenser, these machines must offer easy-to-use human-machine communication.

<u>Step 4. Add Lean functionalities to the technical functionalities</u>

We have added in this step the Lean functionalities to guarantee the taking into account of the required technical functionalities, and to add more functionalities that make the system leaner by reducing time and non-add value operations. Table 4 shows a part of the functional specifications document (FSD). It contains some examples of Lean functionalities. The detailed technical part is not shown, the reason for confidentiality.

Table 4. Add Lean Functionalities

FUNCTIONALITIES	PARAMETERS AND TOOLS
Machine easy to use	User satisfaction
Machine easy to clean	5S
Reduce stop time	Setup Adjustment time
Reduce time boot time	Minor stoppages,
Eliminate waste Muda	Automation
	Sensor
	Waiting time
Reduce emission	Product life cycle
Minimize material waste	Cost
	Pollution rate
Optimize the choice of material.	
Improve information visibility	Standard
	Visualization
	Digital student cards QR code
Improve safety and workspace	Human skills

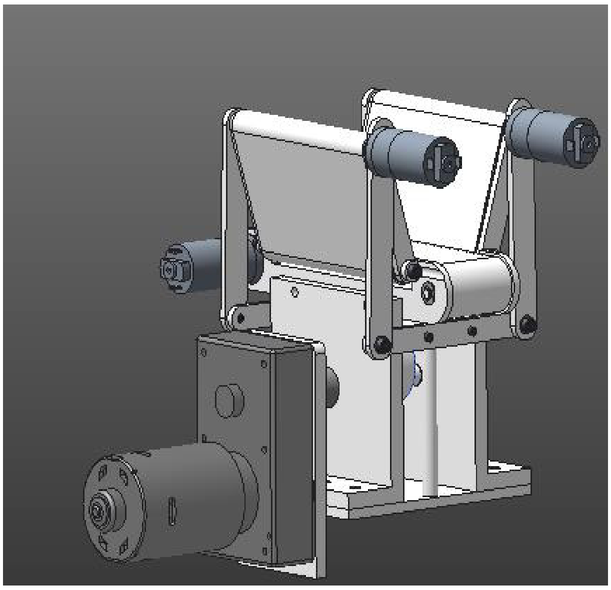

Figure 9. Sorting system

For the crushing system, which is located just after the sorting system:

Existing solutions for crushing cans such as pneu–matic or hydraulic cylinders are fast and efficient. But, they are not convenable to the list of performance criteria and Lean functionalities. Pneumatic cylinders cause noise that is detrimental to the user. The hydraulic cylinders are used at very high pressure without value add for our system. Besides, this would have created more sealing problems. For that, a suitable Lean solution is a grinding process using a trapezoidal screw. It is a system driven by an electric motor that transmits a rotational movement to this screw. In its turn, this screw will then rotate in a threaded hole to create a translational movement for a part that will crush the can. This process allows to crush and store cans.

When the sorting system detects a can, it will send it to the crushing system. The can will arrive in the inlet. Then, it will fall in the blue part (Figure 10). The blue part is pushed until a location to crash the can. Then, the blue part comes back to get another can, and when it returns to the crushing location, it pushes the former can in a pipe that leads to the storage box.

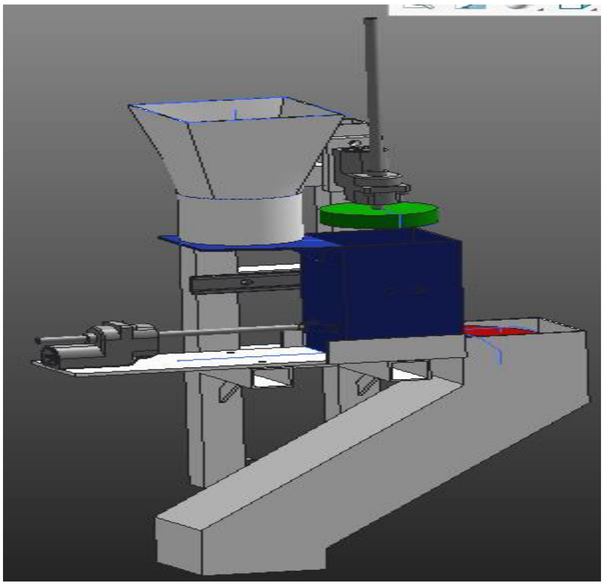

Figure 10. Crushing system

Step 5. Search solutions

By using the FAST (Function Analysis System Technique) diagram, several solutions were proposed for considering all listed functions notes above (technical and lean functions). The technical solutions we have chosen based on Lean functionalities are:

-For the sorting system:

To sort the different types of wastes and plastics, industries use an electrified conveyor belt system. Indeed, the different cans and bottles put on a moving electrified belt. The aluminum cans are attracted by a magnet situated over the belt. And, they will fall in the right box. The bottles will keep on going on the belt until a referral system, which will direct the bottles in different adapted boxes.

For that, according to Lean functionalities, we have chosen for the sorting system a conveyor which composed of a recognition system with a barcode with two secondary belts inclined. The utility of this system is to recognize the object that the user threw away in the system. If the barcode is not able to read or if the label is missing, then a material sensor will determine the type of material, which prevents a mix of materials in the storage at the end of our system (Fig. 9).

Step 6. Apply IDM to find innovative solutions

In this study case, we did not have a problem with contradictions between the criteria, and we did not need to use IDM.

Step 7. Follow Lean Check-list Evaluation

In this step, we have checked whether all the required Lean functionalities are taken into account during the design work.

Note: The CAD-Calculation part of this case study was carried out as part of a multi-disciplinary project for the design of industrial machines by engineering students from the mechanic's department. The details of CAD-Calculation are not shown.

6. CONCLUSION

In this paper, the review outlines Lean in engineering design. Our aim is to propose to the designer a method that helps him to design production systems that do not need to apply Lean tools to improve its performance. To do that we worked on the integration of the maximum number of criteria required to optimize the future production systems to enhance their performance from the early design phase. We specify that this work does not concern existing machines and systems. For that, we have specified our complex system to which our targeted methodology will react on. The designed system could be a production system, a machine, or an apparatus that classically enterprises used lean tools to improve its performance.

We analyze some existing design methods, which offer methodologies to increase the performance of a system. We concluded that Lean could be useful for integrating performance criteria required to enhance the efficiency of complex systems by optimizing its components and their interactions from the early design phase. Then we identified the functionalities of Lean by analyzing Lean principles, methods, and tools. Our method is based on integrating these functionalities in the functional analysis method. A representation of our Lean-System-Design method into a useful tool is provided to facilitate the work of the designer. We have shown the first step of implementing Lean-System-Design in CAD software to be ready for applying to a complex industrial case.

We work on the IT development part of the LSD module. To prove the feasibility of our approach, we have applied manually the Lean-System-Design in the waste treatment machine. We used many tables to capitalize on the data. It is quite long and not easy to apply.

There are some limitations of the proposed Lean-System-Design approach, which is the perspective works. We work on the evaluation of the sequences of a new workload on designer productivity and motivation. This workload could be engendered because the approach adds Lean functionalities to technical functionalities required by the client. So, it could increase the workload of the designer.

Also, the designer, according to his knowledge, does not know how to choose adequate Lean functionalities for his problem. Lean functionalities do not provide for the designer the most optimal solutions. The generation of the solution concept depends on the methods, tools, knowledge, and skills of the designer so we work on these limits

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ОКВИР ЗА ДИЗАЈНИРАЊЕ ОПТИМИЗОВАНОГ СИСТЕМА ПРОИЗВОДЊЕ БАЗИРАНОГ НА ОПТИМИЗОВАНОЈ ФУНКЦИОНАЛНОСТИ И ИНТЕГРАЦИЈИ КРИТЕРИЈУМА У ФАЗИ ДИЗАЈНИРАЊА ПРОИЗВОДНИХ МАШИНА

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Све је више захтева од стране купаца у погледу одрживости, флексибилности, технологија Индустрије 4.0. Фаза експлоатације подразумева унапређене машине и перформансе система коришћењем оптимизованог (lean) алата. Примена lean алата код постојећих машина осигурава функционалости као што су скраћење времена прилагођавања производне линије, уклањање отпада, укључивање вештина. Овај рад треба да понуди дизајнерима метод подршке и алат за дизајнирање перформанс система (система производње, машина) интегрисањем оптимизованих (lean) функционалности почев од раних фаза дизајнирања уз минималне потребе за унапређење система у фази коришћења путем leana. Циљ анализе оптимизованих (lean) принципа и алата је одређивање његове функционалности и интеграција у процес дизајнирања производних система у контексту Индустрије 4.0. Приступ „дизајнирање оптимизованог система“ представља смерницу за интегрисање lean система од најранијих фаза дизајнирања. Аутори су развили софтвер који чини први корак примене lean система. Предлог илуструје студија случаја.