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Framework for Resolving Problems Resulting from Lean Integration from the Early Design Phases of Production 3D Printing Machine

We focus on improving the performance of production machines (time-saving, flexibility, cost-effectiveness, safety) from the early design phase.
Lean integration during the design phases might be a more appropriate solution, but this could be a source of some contradictions related to the machine performance and the usage requirements.
In this paper, we propose an approach, based on Lean and Inventive Design Methodology (IDM-TRIZ), to identify and resolve these contradictions due to the Lean integration and also to provide innovative technical solutions.
The approach is illustrated by the integration of the functionalities of the "Single Minute of Exchange of Dies" (SMED) and the "5S" method from the early design phase. A case study about the "3D printer clogged nozzle" outlines the feasibility of the proposed approach.

Keywords: *Production machines design., Lean Thinking, Single Minute Exchange of Die (SMED), Inventive Design Methodology (IDM-TRIZ), Theory of Inventive Problem Solving (TRIZ).*

1. INTRODUCTION

Due to the current innovative situation, to face industrial competitiveness, to satisfy the requirements of new technologies and the need of customers and users, smart machines must be designed in a way to give more autonomy to operators and machines. That will guarantee usability and safety of usage for the operator and increase productivity by enhancing machine performance and reducing wastes and sources of errors and breakdowns. As we know, production systems, with their components: Machines and equipment, humans (operators and technical), and computers and software, tend to increase productivity by adding new equipment and searching for new solutions. First, the cost of improvements to existing systems could be the subject of further research and discussion. Second, new technologies can help to develop new skills and open up new horizons in eliminating waste. Lean dedicates particular attention to improve the global performance of the production machines and to increase productivity by using some tools like SMED, 5S, etc. in the use phase. 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. Considering Lean in designed systems from their design phases might be a more appropriate solution that guarantees a more productive production machine by optimizing the time of operation from the design phase.

This leads to minor improvements via Lean in the use phase. It is important to emphasize that machine design plays a significant role in the evolution of production systems.

It should point out that few studies propose systematic approaches to consider Lean functionalities from the early design phases of production machines.

We aim to propose for the designers a holistic approach to carry out their design work to improve the performance of their systems to be designed from the early design phase by taking into account the requirements of Industry 4.0 and considering Lean functionalities from the design phases.

This integration of Lean functionalities could be a source of some contradictions. So we use Inventive Design Methodology (IDM-TRIZ) derived from the Theory of Inventive Problem Solving (TRIZ) to identify and solve these contradictions due to this integration to provide innovative technical solutions. So, our scientific contribution resides in the identification, the modulization, and the resolving of contradiction resulting from integrating Lean methods and functionalities from the design process.

The global framework providing all the details which concern the study's methodology is the topic of another research paper.

In this research paper, we integrate the functionalities of the "Single Minute of Exchange of Dies" (SMED) and the "5S" method from the early design phases to improve the performance of production machines (time-saving, flexibility, cost-effectiveness, and safety).

These considerations led us to choose the ideal technical solutions to reduce the expected downtime that could happen for the production machine (changeover time, preventive maintenance, stops, and clea-

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ning time.), and to provide the best working conditions for the user.

After the introduction, in section 2, we present a literature review of the combination of Lean and TRIZ on the production systems and machine design. In the first part, we position our work according to Lean Design and Design for X. In section 3, we present our approach with three main parts: 3.1 shows the general framework of Lean integration from the design phase of production systems and machines. 3.2 concerns the integration of SMED and 5S from the early stages of machine design. 3.3 shows how IDM-TRIZ could be used to identify and resolve contradictions due to the conversion of internal operation to external operation. Thus, to show the feasibility of our framework, we present in section 4 a case study concerning the clogged nozzle of a "3D" printer to discusses the usefulness of IDM-TRIZ to solve this problem. In section 5, we present the conclusion of this study and future research directions.

2. LITERATURE REVIEW

4.1 Positioning

Undoubtedly, a poor design leads to changes, rework, budget overruns, delays making it a major cause of waste [1].

Many studies mentioned in the literature attempt to integrate disciplines, concepts, and criteria during the design phase of the production machine to meet the needs of customers and users and to reduce modifications by adding additional procedures to the production process to increase the efficiency. Thus, we could mention the work relating to Design for X: where X can be a safety and ergonomics [2-4], cost [5], reliability [6, 7], and user experience [8].

Various studies have shown that Lean may play a significant role in adding some performance criteria to the system, such as reconfigurability [9], time-saving and cost-effective [10], human factors and ergonomics [11], and sustainability [12], etc.

It should be pointed out that many recent studies affirm that the implementation of new technologies in Industry 4.0 is compatible with Lean practices [13-15].

Normally, to improve an existing machine, the main purpose of Lean Thinking is the elimination of waste. Lean thinking is based on five principles:

1) Specify Value: Identify what customers want.
2) Identify the Value Stream: Identify activities that contribute to these values.
3) Flow: Create continuous work processes without interruptions.
4) Pull: Produce only in response to customer demand.
5) Perfection: Generate, test, and implement process refinements of continuous process improvement [16]

As we know, to implement Lean thinking, several tools and methods have been developed. Lean is applied to existing machines to improve their efficiency by eliminating waste in a continuous improvement process. And also, Lean can be implemented during the design work either to enhance the work of the designer or to improve the system to be designed.

Lean integration from the design phases could be an increasingly appropriate solution to improve the overall performance of the production systems by optimizing the interactions between their components (human, machine, product, etc.). 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 operations in an optimal, cost-effective, and ecological way.

As we have shown previously, many design methods have been developed in order to help designers to satisfy the constraints and requirements by designing a performant system.

Lean can be applied from the early design phase in the form of Lean keys performance indicators [17] or Lean design rules [18].

We share the same goal of Lean Design and Design for X. In this paper, we have not attempted to show these limitations in detail. Rather, we want to emphasize that the integration of Lean in design can be a source of some contradictions related to various reasons such as system performances and user considerations. For example, we have identified that Design for X and Lean Design require the designer to add additional constraints and functionality in addition to the functions identified by the designer to meet the customer's requirements. Adding these constraints minimizes the solution area and can render it null.

We focus in this study to solve this problem by proposing an approach that uses IDM-TRIZ to identify, model, and resolve the contradictions resulting from the integration of SMED and 5S in production machine design.

4.2 Lean and TRIZ

Sometimes all these design methods (Design for X, Lean Design, etc.) can increase the number of functions and constraints that the designer has to find a solution that fulfills and respects all of them. In this case, the designer cannot propose a performant solution because the set of solutions becomes very small and perhaps equal to zero. So, he has to use inventive design methods like Axiomatic design, or the "Theory of inventive problem solving" (TRIZ).

These methods are useful to solve design problems when classical design methods do not meet all performance criteria. Because of that, our laboratory is the leader in France in research on TRIZ. We adopt this method for the case where finding a solution requires inventive design.

TRIZ provides a set of technical methods and tools to search the optimal solutions like contradictions matrix, separation principles, standard solutions, etc.

Fig.1 illustrates the different steps of TRIZ. As this figure shows, the designers should first formulate the generic problem. For this purpose, they could apply one of several tools like function analysis, problem graph, and nine screens, etc. In the next step, it is essential to use one of some tools such as "Contradiction Matrix", "76 inventive Standards", Ariz, etc. to transform the generic problems into generic solutions. At the end of the process, it is possible to create specific solutions related to the initial problem [19].

For example, to resolve the design problems, Hmina et al. (2020) proposed an approach to analyze and structure the design problem to exploit the TRIZ contradiction matrix through the Decision-maker-preferences (DMP) integration [21].

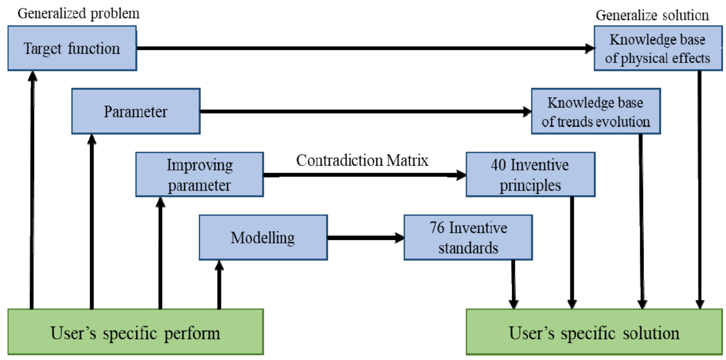

Figure 1. Contributions of TRIZ (Revised from [20])

So, the integration of Lean functionalities from the early design phase could be a source of some contradictions related to various reasons such as system performances and user considerations. Using TRIZ can help designers to resolve major contradictions that can arise and find appropriate solutions. For example, to remove an internal operation to an external operation when taking SMED functionalities in the design phase, we ask the user to make a setting-up operation during a machine operating. So the operator may not be safe. The contradictions here are between productivity and user safety. These contradictions could be solved using TRIZ.

Many studies mentioned in the literature highlight the use of TRIZ on the integration of Lean thinking into the design phases to enhance the global performance of production systems.

According to these authors, using TRIZ to integrate some requirements and criteria could be useful for the designer to choose the most optimal solutions.

Harrington [22] proposed an inventive method to improve or modify the design by combining Lean and TRIZ. His approach is the derivation of the TRIZ 39 × 39 contradiction matrix. He uses a "41 × 3 " matrix in that the three parameters are: quality, cost, and productivity).

Navas et al. [23] showed that using both TRIZ and Lean methodologies enables enterprises to manage their products through their lifecycles more efficiently, which provides better management of product end-of-life and recycling. Accordingly, Costa et al. [24] proved that using some tools of TRIZ to implement Lean in the Textile and Clothing Industry to eliminate waste provides the agility of the system and attends to customer's demand. To consider the Human factors and ergonomics in the design phases, Sun et al. [25] focused on the resolution of contradictions that can appear by taking into account not only functional requirements during the engineering design phase but also the user requirements. Further, Wang et al. [26] highlighted the usefulness of using the Lean Six Sigma approach with TRIZ to reduce waste and cost in a savings bank company. To improve process performance, they used four steps: 1) Develop solutions using TRIZ. 2) Implement an improvement plan. 3) Identify the new process capability. 4) discover system failure.

Toivonen et al. [27] improved the Toyota Kata Continuous Improvement Method, which defines objectives, problem-solving, coaching, and management, by adding TRIZ techniques to the method. There are many other examples like this that one can give, could be established the relation between the Lean Thinking principles and TRIZ methodology in terms of increasing system performance and eliminating waste of existing systems.

Muruganantham et al. [28] studied the synergy between the two concepts Lean and TRIZ to find solutions without wastes. To go for new sustainable solutions, Anabela et al. [29] use Lean and TRIZ to involve eco-efficient products and cleaner production. Many of these solutions have been developed through educational case studies.

From the literature, we found that few studies discuss the use of Lean and TRIZ in detail. Hence, the importance of such a study.

3. LEAN REQUIREMENTS FROM DESIGN PHASES

3.1 Global framework to integrate Lean at early design stage of production machines

We propose to the designer a systematic framework to integrate Lean functionalities into the different phases of the design process.

Thus, designers must follow the methodology presented in Fig. 2 and composed of the steps below:

1) In step 1, as the classical design method, the designer 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, which allow fulfilling the chosen criteria in step 3 to the functionalities required by customers (technical functionalities).
5) In step 5, the designer does his work 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.

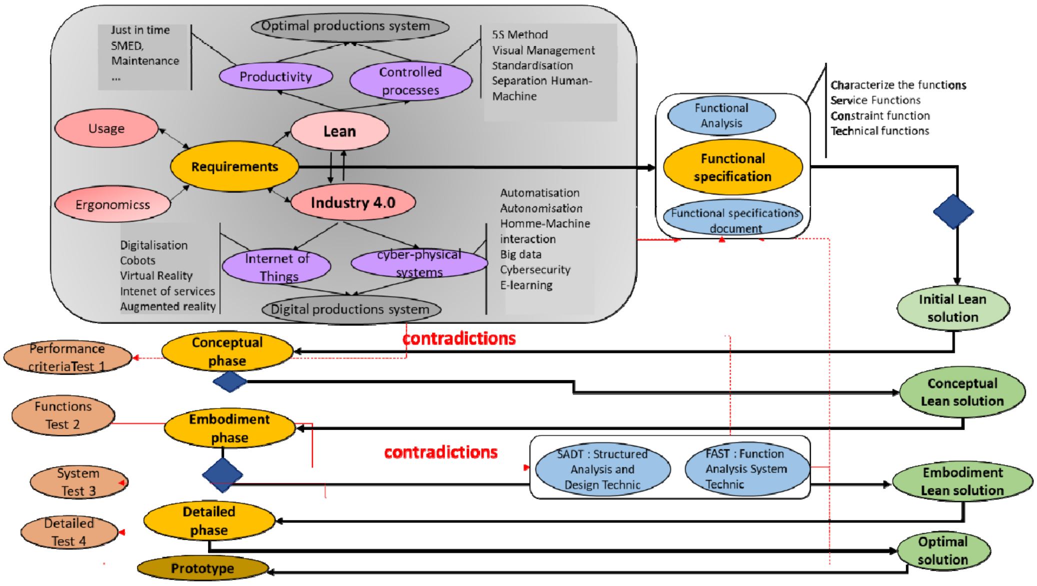

Figure 2. Framework of the proposed approach

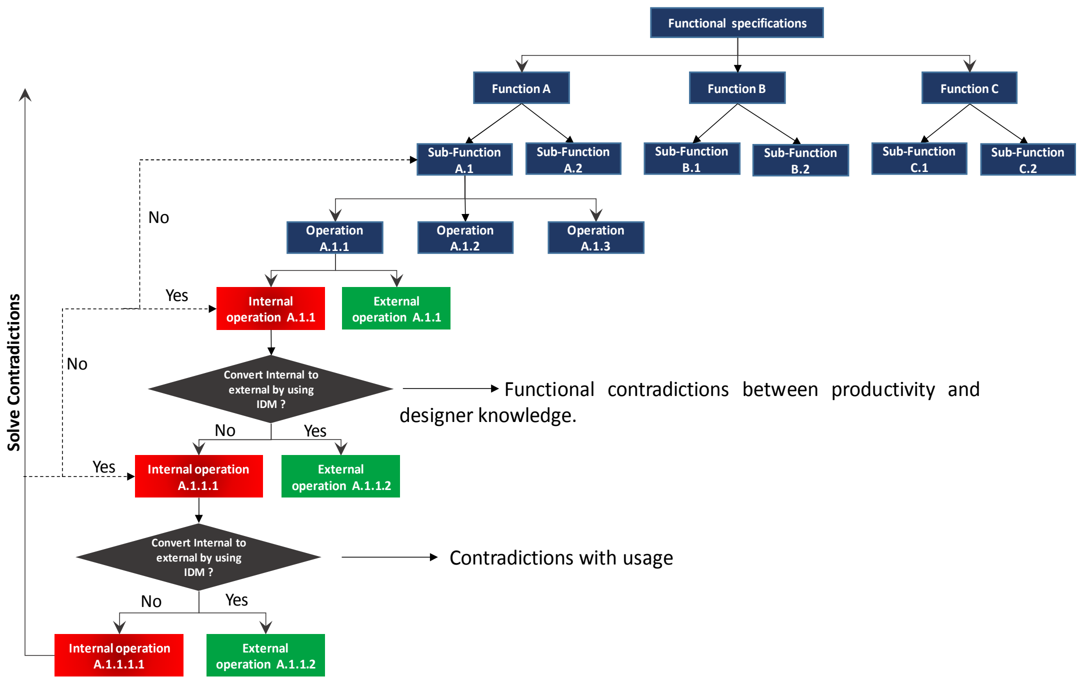

Figure 3. Resolving contradictions due to the conversion of internal operation in external one

6)In step 6, if the designer did not find any solution after integrating all functionalities and constraints that he wants, that means: the solution zone becomes zero. So, to solve the problem and to find innovative solutions, we propose to use the Inventive Design Method, which is an extension of TRIZ for the generation of solution concepts by solving contradictions. If in spite of IDM-TRIZ 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, the designer follows the Lean Evaluation Check-list before prototyping to avoid any missing.

We adopted the four phases of the design method: Initialization phase, Conceptual Design, Embodiment phase, and Detailed phase [30].

A check-list evaluation of the integration of Lean functionalities could be used. And depending on the results, the designer could rethink other Lean solutions 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 by using IDM-TRIZ.

3.2 Identification and resolve contradictions due to the conversion of internal operation in external operation

A function is a conceptual model of a system that can break down into sub-functions of lower complexity.

The overall function is a combination of individual subfunctions to identify sub-functions that facilitate the future search for solutions and combine these sub-functions into a simple function structure.

For example, a Single-minute Exchange of Die (SMED) offers a fast and efficient way to convert a manufacturing process into a product change [31]. SMED uses a methodology, some techniques, and tools that have a positive impact on the flexibility of existing systems and machines [32]. The function of SMED is to optimize the changeover time. Some other Lean tool as 5S is related to the workstation, users, and machines, which improves quality management, maintains the workplace, the safety of users, optimum productivity, and minimum wastes and keeps standardized of the system [33].

The main functions of 5S are [34]:

- Seiri (Sort): Keep things which are necessary, remove unnecessary things, time-saving, eliminate obstacles, and increase safety.
- Seiton (Set in Order): Arrange items in close proximity, make the system easy to use, and time-saving to access tools or items.
- Seiso (Shining): A clean and safe workplace.
- Seiketsu (Standardise): Standardized, clean-up, and involve users.
- Shitsuke (Sustain): Sustain the disciplines.

During the design phases, we can differentiate four types of operations:

Technical operations: Operations that can perform by the machines without the intervention of the user. And Socio-technical operations: Operations that can perform with the interaction between the user and the machine [35].

Internal operations: Operations that can only perform when the machine is at the stop. And, External operations: Operations that can perform while the machine is running [36].

We share the same goal of SMED and 5S on the conversion of the possible internal operations to external operation and the ensuring of the optimal conditions in terms of safety and wastes reduction during the Human-Machine interaction.

But we ask the questions early in the design process:

- What do they force the designer to choose internal operations?
- How could they do to convert technical solutions requiring internal operations to another one requiring an external one?
- How could improve the safety of the user without decreasing the productivity of the machine?
- Are there solutions to keep the machine more productive?
- Are there solutions to keep the machine and workplace clean?
- Are TRIZ could be useful to find innovative solutions?

To answer the questions, a function tree model that represents the result of function specifications aims to analyze the function and find some contradictions (see Fig. 3). This inventive method is performed in an iterative manner based on the decomposition of tasks as follows:

1) Analyze and elaborate system functions, and define for each the required operations to fulfil them.
2) Classify the operations of the function into internal and external.
3) Convert the internal operations into external operations by using IDM-TRIZ.
4) Convert internal operations to external operations by using IDM-TRIZ.

3.3 IDM to resolve contradictions

The Inventive Design Methodology (IDM) is a systematic approach proposed by Cavallucci [37] to eliminate the limitation of classical TRIZ and to supplement its body of knowledge with other theories like graph theory. This methodology contains four phases. In the following, we briefly explain these phases:

(1) Phase 1: Initial Situation Analysis: In the first phase of IDM, the designer collects all the knowledge by reviewing the available data on the subject and translates them into a graphical model. This graphical model, which is called a problem graph, is a network of connected problems and partial solutions. In the following, to formulate the contradictions, the action parameters should be extracted from the problems and evaluation parameters from partial solutions [38].

(2) Phase 2: Contradiction formulation: In this step, the designer could apply the poly-contradiction template to organize the extracted parameters in the last step to formulate the contradictions. The contradictions are the barriers to the development of the system. These contradictions are essential to apply TRIZ techniques and methods in the next steps [39].

(3) Phase 3: Solutions Concepts Synthesis: After formulating the contradictions, the designer applies the tools and techniques, which have been proposed by TRIZ to resolve the contradictions. The contradictions Matrix is one of these tools, which ordered 39 improving parameters and 39 worsening parameters on a vertical and horizontal axis to interact with one another. This matrix, in the interaction of the parameters, proposes the concepts, which could help to resolve the contradictions [40].

(4) Phase 4: Solution Concept Selection: At the end of the process, the external experts should evaluate the impact of each concept on the graphical model in the first step of IDM. The applied tool for doing this evaluation is called Pugh's [41].

To find the contradictions, it is necessary to capture the expertise of the domain by questioning the experts or by extracting in canonical form the knowledge of the domain, on the use of algorithms that can be automatically or semi-automatically populate the ontology and then alleviate the work of the experts [42].

4. CASE STUDY: 3D PRINTER CLOGGED NOZZLE

To show the usefulness of IDM-TRIZ, we applied our approach to a pedagogical case use.

Our Fablab laboratory contains six 3D printers that are used for different missions to design and prototype products. These 3D printers are in line with other machines (laser cutting machine, Strato design machine, etc.). In this platform, we manufacture products composed of several components, made from several raw materials, then they will be assembled and finalized.

In this environment, we have a recurring problem, which is the clogging of the nozzle of the 3D printer. We show in Fig. 4 the structure and the main elements of the nozzle of the 3D printer example. The material continues to enter but could not go out, which causes other problems, such as the blocking of the material during the routing thereof.

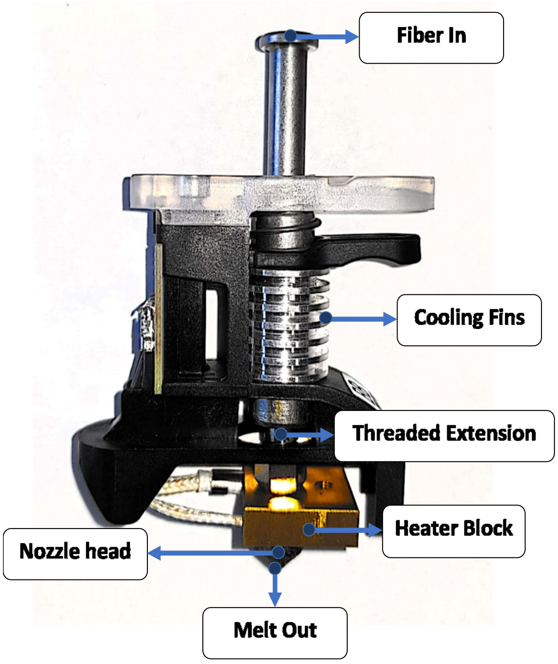

Figure 4. Structure of the nozzle

This 3D printing does not detect when the nozzle is clogged. Other machines detect this phoneme. But in both cases, this maintenance problem requires periodic cleaning and too frequent loading of the nozzle.
Cleaning operation must be performed when the 3D printer is stopped. So it is, from a Lean point of view, an internal operation as shown in Fig. 5.

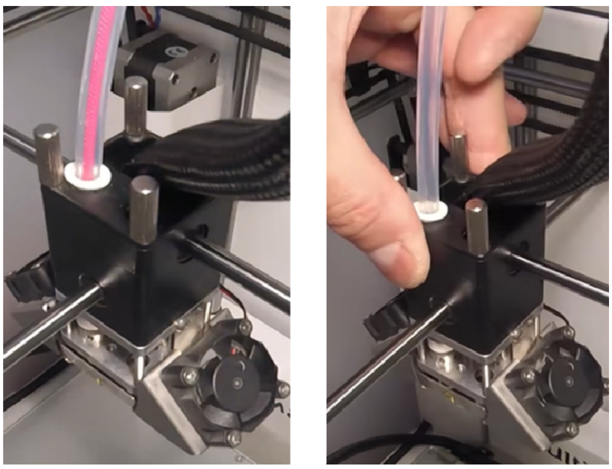

Figure 5. Changing of the clogged nozzle

The question that can be posed is:
How to clean the nozzle without stopping the machine?
To answer this question, we are looking to apply the steps of our approach to redesign the wire feed systems of the 3D printer to make cleaning operations external.
To improve machine performance, we can use:
(1) The SMED method to reduce the changeover time of cleaning of the nozzle.
(2) The 5S method to facilitate the cleaning or the replacement of the clogged nozzle.

In this study, we integrate the SMED and 5S functionalities to reduce the 3D printer downtime needed to clean the nozzle or make it possible while the 3D printer is running.
In the following, we present step by step the application of our approach on this 3D printer:

-In step 1: Regarding the feedback collected from user experience, we have defined all specifications demanded by the client (we listed all the technical functions of the 3D printer).

-In step 2, we provided functional analysis.

-In step 3, we selected the required performance criteria:

Reliability
Safety of operator
Productivity
Cost

- In step 4, Also, we believe that the integration of Lean from the design phase could concern criteria intrinsically to the system and that the designer is supposed to have acquired.
We have seen that considering SMED and 5S functionalities could be helpful to take into account these criteria.

-In step 5, we listed all the solutions that we found:

The solution, which is currently on the machine (cleaning at the stop), can guarantee the safety of the user. However, to clean the nozzle, the 3D Printer should be stopped, which harms productivity. In this case, the safety of the user is ensured but not productivity.

An automated solution exists on other machines, which is "Do the cleaning automatically" by heating the nozzle or blow air into it to clean it. In this case, productivity will increase (automatic cleaning time). However, it is performed in masked time while the machine is running. Safety is ensured because the user does not interfere with the 3D Printer. Perhaps, these types of solutions need to add some systems to the machine, such as a heating system or blowing air system, which can be expensive and can change the range of the machine. And they are not fully effective, which does not give the expected results because, on most nozzles, automatic cleaning by temperature requires disassembly of the nozzle.

Therefore, these solutions do not meet the criteria of "Reliability" and "Cost", and there is no solution area. As a result, there are contradictions between the chosen criteria: "Safety", "Productivity", and "Cost".

-Thus, in step 6, we use IDM-TRIZ to find innovative solutions.

We aim to convert the problem of clogging of the nozzle into an external operation, which can be performed when the machine is running.

The 5S functionalities enable us to determine how this external operation can be performed by the user.

To solve this problem, we have formulated all data about our problem.

In Fig. 6, we have used the problem graph for the problem formulation to identify the problems and partial solutions.

We started with forming our initial problem of the clogging of the nozzle. Then, we look for the effects of this initial problem in terms of partial solutions, and thus the other problems that can be generated by the partial solution.

In TRIZ, there are there types of contradictions:

(1) Administrative contradiction: this contradiction describes a desire to improve a system without showing the direction.

(2) Technical contradiction: this kind of contradiction shows itself when the improvement of one parameter of a system leads to the deterioration of another parameter in that system.

(3) Physical contradiction: this contradiction occurs when one part of a system must have two opposite values at the same time.

Table 1 shows the list of all identified contradictions related to the nozzle according to the TRIZ classification.

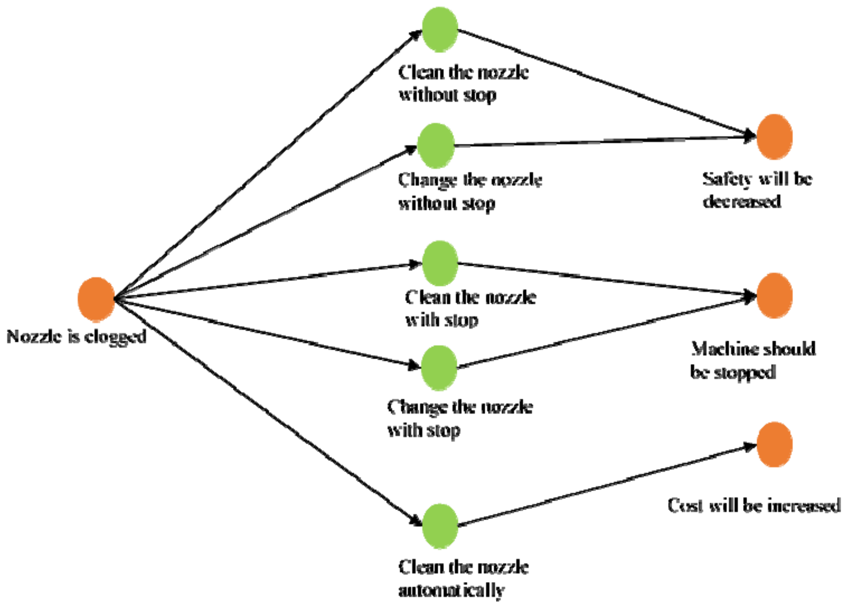

Figure 6. Problem graph of the clogging of the nozzle

Table 1. The list of all possible contradictions related to the nozzle according to the TRIZ classification

List of the possible contradictions related the nozzle		
Contradictions		Type of the contradiction
Parameter 1	Parameter 2	
Productivity (The machine operating time)	Objected-generated harmful factors (User Safety)	Technical contradiction
Productivity (The machine operating time)	Reliability (Clogging problem)	Technical contradiction
Productivity (The machine operating time)	Extent of automation(Cost of the production)	Technical contradiction
Change the nozzle	Not to change the nozzle	Physical contradiction
Stop the machine	Not to stop machine	Physical contradiction
Clean the nozzle	Not to clean the nozzle	Physical contradiction

Table 2. Table of technical Contradictions

Evaluation parameters	Action parameters	
	Clean the nozzle without stop	
	Yes	No
Productivity (The machine operating time)	☺	☹
Objected-generated harmful factors (User Safety)	☹	☺
	Change the nozzle without stop	
	Yes	No
Productivity (The machine operating time)	☺	☹
Objected-generated harmful factors (User Safety)	☹	☺
	Change the nozzle without stop	
	Yes	No
Productivity (The machine operating time)	☺	☹
Reliability (Clogging problem)	☹	☺
	Clean the nozzle with stop	
	Yes	No

Productivity (The machine operating time)	☺	☹
Reliability (Clogging problem)	☹	☺
	Clean the nozzle automatically	
	Yes	No
Productivity (The machine operating time)	☺	☹
Extent of automation (The cost of the production machine will be increased)	☹	☺
Definition of the TRIZ parameters		
• Productivity: The number of functions or operations performed by a system per unit time. • Objected-generated harmful factors: The harmful effects that are generated by the object or system. • Reliability: System's ability to perform its intended functions. • Extent of automation: The extent to which a system or object performs its functions without human interface.		

We choose to formulate the technical contradictions for all the problems illustrated by the problem graph. For this purpose, we used the poly-contradiction template to show the relationship between evaluation parameters (the parameter that allows us to evaluate a criterion) and action parameters (the parameter that machine or user has to do to improve evaluation parameters) (Table 2).

To elaborate this table 2, we made correspondence between TRIZ evaluation parameters and our chosen criteria.

We used "Productivity" for the "Machine operating or stopping time" problem because if "the Machine stopped" the time of producing, the output of the system will increase, so its productivity will decrease. Furthermore, we allocated "Reliability" to the "Nozzle is clogged" problem due to the reduction of the ability of the system to perform its intended functions in predictable ways.

In the same way, we applied the evaluation parameter "Objected-generated harmful factors", which means that the system has a harmful effect to describe the safety of the user.

Besides, "Extent of automation" means that the machine needs a supplementary automatic system to perform a function without human intervention, which increases the cost.

It is a choice taken from an analysis of the TRIZ evaluation parameters.

In our case, for each action parameter, we have attributed one contradiction.

For example, the action parameter "Clean the nozzle without stop" causes one contradiction between "Productivity" and "Objected-generated harmful factors".

After formulating the contradictions, it was necessary to evaluate these contradictions to choose the most important one that eliminates the problem situations.

This task, performed by the designer, is depending on his experience and knowledge, and the order of priority of the criteria.

In this way, we selected the contradiction between "Reliability" and "Productivity" when the action parameter requires the stopping of the machine.

To solve the selected contradiction, we propose to apply the contradictions matrix.

The inventive principles will help us to obtain the final solution.

The following table 3 is part of the contradictions matrix, which suggests the following principles:

1. Segmentation.
35. Parameter change.
29. Pneumatics and hydraulics.
38. Strong Oxidants.

Table 3. The proposed principles in contradiction matrix

	Worsening feature / Improving feature	Weight of moving object	…	Productivity
		1	…	39
1	Weight of moving object			35,3 24,37
…	…		…	…
27	Reliability	3,8 10,40		$\boxed{1,35\ 29,38}$

Then, we should analyze the proposed principles to understand which of them could help us more to solve the problem.

Table 4. Comparing of the proposed TRIZ solutions

Principles in contradiction matrix	Cost of solution for the user	Capacity of our laboratory to develop the solution	Total
Principle 1 :Feeding system in sort to allow the two nozzles to be mounted and independent of each other	2	3	5
Principle 35: Changing the type of material, which is used in the machine or Increasing the temperature of the nozzle	2	1	3
Principle 29 use liquid or gas parts instead of solid parts of the object	1	3	4
Principle 38 : Strong Oxidants use chemical reaction to prevent drying material in nozzle	1	1	2
Point 0 Minimum Point 3 Maximum			

As can be seen in table 4, the first principle is number 1 or Segmentation, which means "Divide somet-

hing into smaller pieces to receive a new valuable piece of innovation.".
This principle is divided into the following sub-group:

- Divide an object into an independent part.
- Simplify the assembly and disassembly of an object.
- Enhance the degree of segmentation in an object.

Principle number 1 could help us to receive the solution "the feeding system in sort to design two nozzles to be mounted and independent of each other.". The user cleans one nozzle when the other is in use.

The cleaning operation follows the 5S steps to avoid the waste of time, and it can be performed in masked time. This solution was in the field of our laboratory competency.

The other proposed principle by the contradiction matrix is principle number 35 or Parameter change, which includes the following sub-group:

- Change the physical state of an object into gas, liquid, or solid.
- Modify the concentration or consistency of an object.
- Improve the degree of flexibility of an object.
- Modify the temperature.
- Change the pressure or other parameters.

By inspiring from this principle, we could propose a solution to change the type of material used by the machine by changing the characteristics of the material to prevent clogging of the nozzle. But, this solution was out of the capacity of our laboratory. Furthermore, it could also be inspired to solve the problem by increasing the temperature of the nozzle. However, this solution would increase the cost of used energy by the machine.

Another suggested principle is the number 29 or "Pneumatics and Hydraulics". This principle proposes to use liquid or gas parts, instead of the solid parts of the object. This principle could not help us to obtain a solution to our problem because a compressing system is also expensive.

The last suggested principle by the contradiction matrix is number 38 or "Strong Oxidants". In this principle, we could find the following sub-principles:

(1) Use oxygen-enriched air instead of common air
(2) Use pure oxygen instead of enriched air
(3) Expose Oxygen to ionizing radiation
(4) Use ozone instead of oxygen

The principle "Strong oxidant" also, like principle number 35, could give the concept of changing characteristics of the material by adding some other gas to make a chemical reaction to minimize clogging phenomena in the nozzle or to solve material in the nozzle. However, the proposed solution by this concept also could not be in the scope of our laboratory.

At the end of the process, we should select one of the proposed solutions to solve the problem. By looking at the analysis performed in the previous step, we choose the solutions inspired by the segmentation principle, which is:

"The feeding system in sort to allow the two nozzles to be mounted and independent of each other." (see Fig. 7).
We have inspired two solutions from this principle:

The first solution S1, as shown in Fig. 8, is to redesign the feeding system in such a way that when one nozzle is clogged, the system allows the other to be used. It is a nozzle blog with a nozzle that can be recessed.

One nozzle that is already working and then is clogged, the second nozzle takes over.

The fact that we add failure sensors when a nozzle is clogged, the machine can then move through a simple mechanical system to the other nozzle without stopping the 3D printer. This allows the two nozzles to work alternately and thus to be able to replace the work of the clogged one that either will be changed or cleaned in masked time following the 5S steps when the 3D printer is running or when the print is finished. The cleaning or changing of the clogged nozzle will be outside the printer.

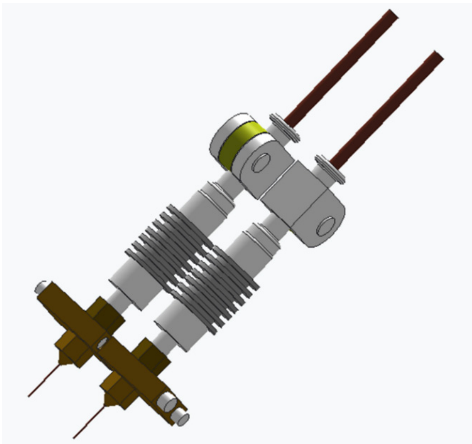

Figure 7. Structure of the proposed solution

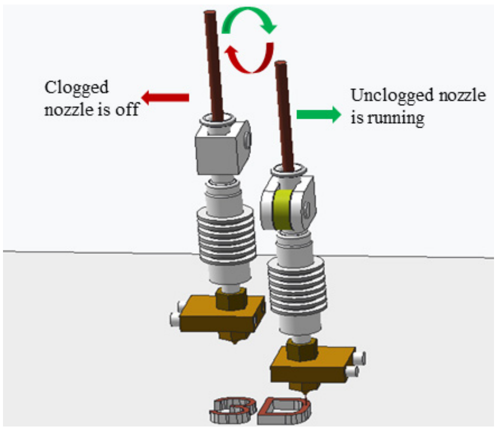

Figure 8. Structure of the proposed solution 1

The second solution S2, as shown in Fig. 9, is the same as the first solution, but it differs in the way and place of cleaning the nozzle.

This solution consists of adding to the 3D printer an integrated maintenance zone, and therefore the clogged nozzle would be transferred automatically to this zone in which the user can safely intervene with all the tools necessary for his maintenance work.

Finally, in Step 7, we follow the Lean Evaluation Check-list evaluation to choose the most appropriate solution for us before prototyping.
For the concept solution, we have chosen here three evaluation criteria:

"Cost" refers to the projected budget for the solution selection.
"Time" refers to the expected time to carry out the chosen solution.
"Usefulness" refers to the degree of usefulness of the chosen solution to meet the requirements.
The scale of grading is:
"1" and "-1" Normal with positive or negative impact.
"2" and "-2" Important with positive or negative impact.
"3" and "-3" High important with positive or negative impact.

Based on these evaluations, the choice of solution is the designer's choice.

In Table 5, we choose a solution in which the criteria for the high degree of importance is selected. Solution 1 has the highest degree. Hence, we validate this concept solution "S1".

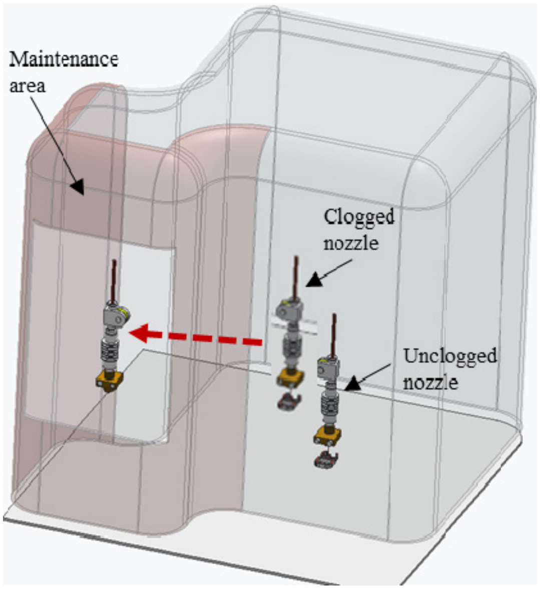

Figure 9. Structure of the proposed solution 2

Table 5. Comparing of the proposed solutions

Solution concepts	Evaluation			Degree of Importanc
	Cost	Time	Usefulnes	Tot
S1	-2	2	3	**3**
S2	-3	1	2	0

Once the solution has been analyzed, the modern CAD design systems and the CAE systems will be verified and prototype it.

5. CONCLUSION

We have proposed a systematic approach for solving contradictions resulting from integrating Lean functionalities into the design phase.

In this paper, the integration of some functionalities of SMED and 5S tools from the early design phase is presented. Then we used IDM-TRIZ, to identify, model, and solve contradictions resulting from converting internal operations into external operations. This allows us to find the optimal technical solutions and therefore minimize the number of tasks that require system shutdown.

A case study has presented to illustrate the usefulness of the proposed method.

There are some limitations of the proposed approach, which can be improved in our future works to enhance the work and make it easier for the designer to use our method.

Perhaps, the main limitation of this paper is that the generation of the solution concept depends on the methods, tools, knowledge, and skills of the designer. Also, for this moment, we do not evaluate the degree of the ideality of the proposed solution according to the ratio of the number of useful functions and their possible effects to apply and validate the proposed solution. This last point is the subject of our future work.

Despite the presented pedagogical case study, the effectiveness of this approach cannot be sufficiently guaranteed without the complete development of the module or software, to be applied to a complex case study. So, our future work will be on the integration of almost Lean functionalities from the early design phase in the context of Industry 4.0.

Our focus will be on improving our approach by developing an algorithm that allows software users to consider Lean functionalities during design phases, which gives a more automated process that combines in real-time the formulated problems, and web-based data (Machine Learning) to more and more simplify the work of the designer. We aim also to validate the approach on a more complex and complete real industrial case.

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ОКВИР ЗА РЕШАВАЊЕ ПРОБЛЕМА КОЈИ ПРОИЗИЛАЗЕ ИЗ LEAN ИНТЕГРАЦИЈЕ У РАНИМ ФАЗАМА ДИЗАЈНА 3Д МАШИНЕ ЗА ШТАМПУ

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Циљ истраживања је побољшање перформанси производне машине (уштеда времена, флексибилност, исплативост, безбедност) почевши од раних фаза дизајна. Lean интеграција у раним фазама дизајна могла би да представља адекватно решење, али и извор неких противречности у вези са перформансама машине и захтевима коришћења. Предлаже се приступ базиран на методологији lean и инвентивног дизајна којим би се идентификовале и решиле ове противречности помоћу lean интеграције и тиме обезбедила иновативна техничка решења. Приступ је илустрован интегрисањем функционалности метода „један минут размене матрица“ и „5S“ од раних фаза дизајна. Студија случаја о „запушеној млазници 3Д штампача“ описује изводљивост предложеног приступа.