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RE-DESIGN THE DESIGN TASK THROUGH TRIZ TOOLS

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Keywords: TRIZ, task clarification, design task

1. Introduction

Systematic design refers to a design process constituted by specific steps that the designer has to follow for solving a design task. One of the the main objective of the systematic approach is to better manage and organize the design process reducing the overall resources spent to achieve the expected outcomes as well. According to this aim, during the years scholars developed several design methods, some of them refer to specific industrial sectors while others have a more general validity. Among the latter, the systematic approach suggested in [Pahl and Beitz 2007] is one of the most acknowledged design methods in Engineering Design. Indeed, it has influenced other well-known design frameworks [French 1999], [Ullman 2000], [Ulrich et al. 2003].

The recalled systematic approach is very detailed in structuring the design process and widely taught in academia. However, especially for the early design phases, its successful implementation depends also on the knowledge of specific design tools to support creativity, how they work and how they can be integrated within the systematic path. According to this evidence, we believe that any scientific contribution showing the use of the recalled design instruments within a systematic framework can provide useful elements to improve applicability, effectiveness and efficacy of these design aids.

The TRIZ body of knowledge is rich of tools characterized by a great flexibility that makes possible their application to different design tasks. Furthermore, TRIZ design instruments are deemed useful to enhance creative thinking, which is an essential ingredient for achieving successful design outcomes, especially in terms of innovation. This is the reason why TRIZ design tools can be considered as good candidates to improve the performance of systematic design processes and leverage designer's creativity. According to this evidence, some scholars (e.g. [Malmqvist et al. 1996], [Dietz 2009], [Nix et al. 2011] and [Frillici et al. 2014]) already presented possible integrations of design instruments belonging to the TRIZ body of knowledge within the systematic approach suggested by Pahl and Beitz. Furthermore, other scholars have suggested the integrated use of TRIZ and Design Optimization to improve the overall efficiency and efficacy of the systematic design process by closing the gap between conceptual and embodiment phases [Cascini et al. 2011].

In this paper, we present a step forward of the work of Frillici et al., applied to a simple industrial case study. More precisely, we show how Functional Analysis (FA) and System Operator (SO) can provide a further aid for the identification of the design task to be accomplished.

The current paper is organized as follows: section 2 presents an introduction on the factors influencing the identification of the problem to be solved discussing the main barriers that make difficult the formulation of the technical problem to be solved. Section 3 reports a short introduction about the TRIZ tools suggested to support the problem identification task. Section 4 describes a case study in detail and the related results, showing how the suggested tools have been applied. In Section 5, discussions and conclusions are reported about the application of the proposal.

2. Issues about the definition of the design task

According to the systematic approach to Engineering Design, the design process can be represented through four main phases, i.e. the clarification of the design task (TC), the conceptual design (CD), the embodiment design and the detail design [Pahl and Beitz 2007].

In the task clarification phase, information is gathered to define a first list of requirements (RL), representing both design objectives and constraints. Such a list represents the design task to be accomplished.

Subsequently, the fundamental product traits are defined during the conceptual design phase, where the functionalities of the product are defined and the implementing working principles are selected. The specific approach considered by many scholars is the so called "functional decomposition and morphology" (FDM), where functionalities are represented with a black-box (e.g. through the Energy, Material and Signal model), and the related solutions are combined (for instance, by means of the morphological matrix) [Pahl and Beitz 2007]. Such a variety of preliminary solutions are assessed through a systematic process and the preferred solutions are identified by taking into account the satisfaction of specific evaluation parameters (e.g. by the selection matrix suggested in [Pugh 1991]). The outcomes of conceptual design are sketches or rough CAD models representing concept variants, often integrated with textual comments and descriptions.

The selected concepts are further developed during the embodiment design phase where the designer considers design issues related to detailed aspects of the overall solution, such as geometrical features, materials and physical properties. Eventually, a complete product description is performed in the detail design phase to issue the needed technical documentation (drawings, manuals, etc.).

Althought the recalled phases follow a linear logic, designing a product is not a straightforward process. In fact, any type of problem may arise by the way when proceeding from the abstract level of the requirement lists to the concreteness of the technical documents, often leading to rethink the outcomes obtained in the previous design steps. These loops represent the well-known iterations characterizing any activity of the design process. Also the requirements list undergoes subsequent upgrades since more knowledge about the solution is gained step by step during the process, then some initial requirements might become meaningless and withdrawn from the objectives (or constraints) while others should be added or updated. This means that the design task itself withstands modifications during the design process.

Therefore, the identification of the "essential problem" to be solved, or "crux of the task" [Pahl and Beitz 2007] is extremely important for reducing the number of design iterations. There are a lot of reasons which can lead the staff of the company to "psychological inertia" during the identification of the design task. For instance, the wish of minimizing the risk of a possible product failure, prejudices and conventions based on past experiences are factors that influence the problem definition. Morevoer, sometimes the focus of the requirement specification is pointed towards a well-defined problem to be solved without considering if it is really the actual problem to be solved.

In order to overcome the risk of design fixations during the identification of the essential problem, Pahl and Beitz, and several other scholars, suggest the use of abstraction that is a process broadening the problem formulation from the specific task, expressed in the form of requirement list, to a more general one. Therefore, abstraction doesn't provide any contribution in the identification of the actual "crux of the task" and the risk exists of performing a comprehensive design process focused on a wrong objective. Moreover, small enterprises with non-structured design staff can find difficulties in applying systematic design approaches, since they can be applied and managed only by well-trained designers. Therefore, the use of tools capable to aid the staff in focusing the target, and then to support the identification of the essential design problem to be solved, is certainly desirable. In this way, also the redefinition of the requirement list become possible in early CD steps, limiting iterations in the subsequent phases of the design process and so improving the overall efficiency. Furthermore, the possibility of disccussing and reformulating the design task by removing psychological inertia, can lead to the identification of several opportunities to innovate the product.

The aim of this paper is to show and discuss the application of some TRIZ tools to support the designer in verifying the correctness of the design task during the problem formulation and decomposition. In the next section the proposed TRIZ intruments are introduced while in section 4 their application to an industrial case study is presented with the aim to show how they can be used for the purpose.

3. TRIZ tools for supporting the problem formulation

Frillici et al. [2014] proposed the use of TRIZ for supporting conceptual design processes based on FDM. More precisely, in the cited work the authors suggested the usage of the TRIZ Functional Modelling (FM) [Gadd 2011], the System Operator (SO) [Cascini et al. 2009], and the Network of Problems (NoP) [Khomenko 2007] to assist the early conceptual design phase. The recalled tools have been introduced and discussed especially for supporting problem decomposition activities.
As stated in Section 2, the outcomes of the task clarification phase however strongly influence the main problem formulation and its decomposition. In addition, psychological barriers induce the designer to tackle with unsuitable or even wrong problems. It is on the base of this observation that we infer here an additional usage of Functional Modelling and System Operator in FDM. Indeed, their specific peculiarities can provide support also for identifying the right task to be tackled. Here in the following, a brief introduction to such tools is reported.

3.1 Functional Modelling

The TRIZ Functional Modelling [Gadd 2011] allows to highlight the functional relationship between the components of the system. The system is firstly decomposed into its basic physical elements modeled by boxes, and then, they are connected by means of arrows that represent the functional interactions among them. In TRIZ terms, a function exists if the action performed by the subject modifies a parameter of the object (recipient) to which the function is addressed. Just a simple example for the sake of clarity: Marc reads a book is not a function from a TRIZ point of view since the subject in the act of reading, even if he is doing something, doesn't modify any parameter of the book. Conversely, Marc writes a letter is a function in TRIZ terms, since the subject changes the parameter content or colour of the paper. According to this definition of function, each pair of system components is analyzed in order to verify if any functional interaction exists between them, or in other words, if a triad Subject-Action-Object (S-A-O) can be formulated. Such an analysis allows to deeply investigate the way wherein the system performs its main useful function.
This model allows to identify three kinds of interactions, according to their qualitative or quantitative effect upon the recipient: the useful, the insufficient and the harmful function. A function is considered useful when the subject changes the object's parameter in a satisfactory way. While, the function performed by the subject is named insufficient when the value of the parameter is modified in the right direction (e.g. the temperature of the water is increased when it is needed to warm it) but the target value is not reached. Finally, a harmful function is a kind of interaction where the parameter is modified in the opposite direction (e.g. the temperature is decreased when it is neeeded to increase it) or when its value must remain unvaried but the subject modifies it. As depicted in Figure 1,the formalism of the model allows an easy identification of each kind of functions through different representations: a solid line for the useful function, a dotted line for the insuffcient functions and a waved line (also in a different colour) for the harmful ones.
The representation of the interactions among the system components according the the played role is very helpful because it increases the designer awareness about the system, allowing to find the core of the problem and to highlight where the causes of the system troubles are.

3.2 System Operator

System Operator [Cascini et al. 2009], also called Nine Screens, is a tool that allows to analyze the initial design problem from different perspectives, with the aim of reshaping it for searching different solution paths.
From the formal point of view, the tool appears as a matrix with, at least, three rows and three columns. The boxes of a column describe the same problem but from different levels of detail. The central box represents the so called "system" level, where the whole system containing the problem is considered. The upper one is called the "supersystem". In such a box all the systems forming the environment of the starting system, and all the systems which may interact with the system itself, are gathered. All the

components of the system and their characterics are collected in the lower box, called the "subsystem". For each box of the same column the problem to deal with remains the same, but it is the subjects which can solve it that changes (see Figure 2).

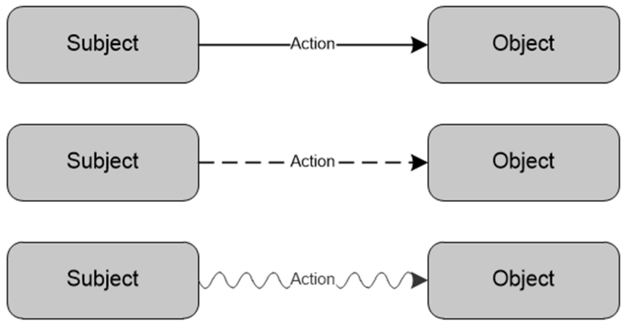

Figure 1. The graphical representation of the different functions. From the top: the useful function, the insufficent function and the harmful function

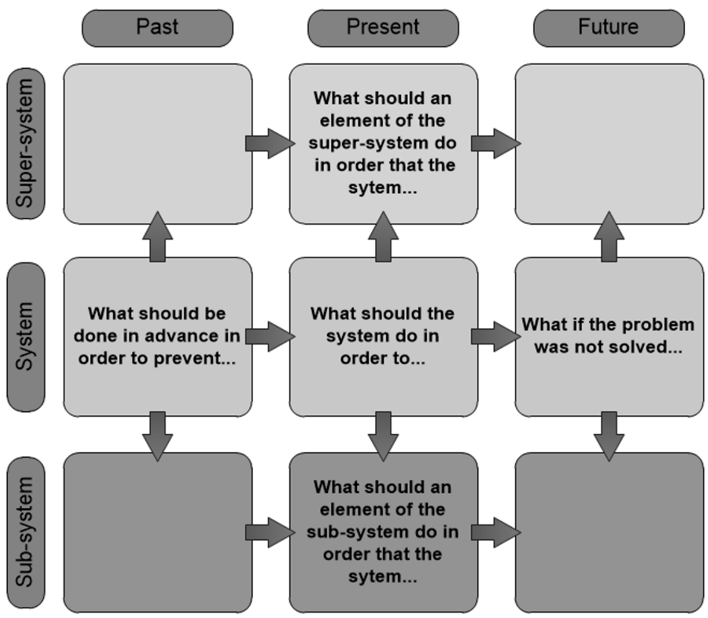

Figure 2. The nine boxes of the System Operator

The different columns, conversely, are linked by a cause-effect relationship. The initial task is reportend within the boxes of the column of the "present". Moving to the left, toward the column of the "past", means searching for the causes which generated the undesired effect. If we can solve a problem in the past we don't need anymore to tackle with the starting problem simply because it doesn't exist. On the contrary, moving to the right column, that of the "future", brings to consider the harmful outcomes arising from the missed resolution of the initial problem. The configuration with nine boxes is the standard and the minimal one, but quite often, further columns can be added to explore all the possible problem/solution paths.

Therefore, the exploration of the initial problem from different perspectives through SO can bring to change the objective of the design task radically. In fact, at least eight alternative problems can be found starting from the original one and each of them, if solved, can lead to the same satisfactory outcome. Indeed, the designer according to its own decision strategy, can choose the best task to tackle among all the alternative opportunities addressed by SO. For such a reason, the SO can be considered as a valid tool for supporting analysis and redefinition of the pre-defined design task.

3.3 Suggested use of Functional Model and System Operator for task clarification

Performing a Functional Model of a system allows the designer to investigate about all the issues behind an undesired situation. The decomposition of the system into its main phisical elements is a valid aid for understanding how the system performs both its main useful functions and, eventually, its undesired effects. Sometimes, some doubts about the functioning of the system may arise, but the functional model forces the designer to investigate them, allowing to focus the attention on the actual lacks of knowledge. In such a way it is possible to disclose the causes and the elements that bring to the undesired effects of the system. This information is very crucial for modeling a System Operator. Indeed, given a column of SO charactirezed by a certain problem, moving to the left means considering the specific cause which, if not solved, originates the problem itself. Therefore, the knowledge derived from the FM can be directly transferred into the SO for the definition of the column (or the columns) of the past.

4. Case study

The tools introduced in Section 3 have been successfully applied in a particular case study, aimed at the development of an industrial device for the production of concrete slabs for building industry. Hereafter, it is summarized briefly.

4.1 The concrete slab production plant

The considered slab production plant is constituted by different devices that serve a multi-stage rotational platform. For the objective of the case study, only two devices are considered (see Figure 3): the above mentioned platform and the dispenser for the mixture composing the rear face of the slabs.

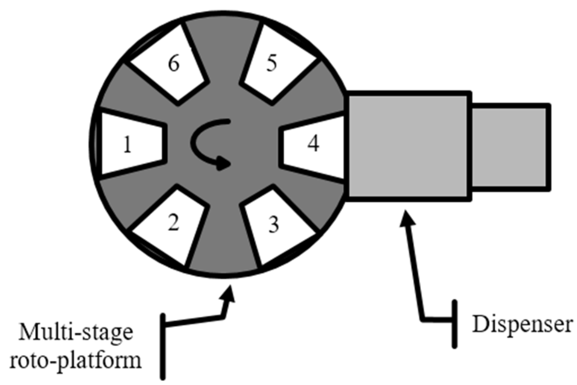

Figure 3. The parts of the slab production plant considered in this paper, represented schematically in an upper view

The multi-stage platform is consituted by six stages, where the slab is gradually formed. The mix for the "good" face of the slab is deposed into dies in the first stage. Second and third stages are devoted to shake the dies to allow the mix to take the right form and to eliminate bubbles. In the fourth stage, an external dispenser distributes the mix for the rear face of the slabs. The fifth stage is devoted to press the mixture into dies. Finally, in the sixth stage the pressed slabs are extracted from dies and sent to the subsequent production steps.

The raw material dispenser (schematically represented in Figure 4) distributes the raw material into the press dies during stage four. A hopper and a sliding distributor compose it. The latter transports the mix from the bottom of the hopper to the top of the dies, releasing the mixture by gravity. The current solution is not capable to distribute the exact quantity of mix needed to fill the dies. Therefore, it is necessary to fill the distributor with an excess of raw material, to assure the complete filling of the dies. This situation, in addition to the particular (and variable) form of the dies, implies that some of the deposed mixture has to be removed from the dies, and some other from their sides. The current solution (Figure 5) for removing the excess is quite simple, the sliding distributor is provided by a rubber-made scraper on its rear edge.

As shown in Figure 5, when the distributor performs the returning motion, the scraper pushes back the excess of mixture, leaving the dies with only the needed quantity. Since a non-negligible leakage exists between the rotational platform and the dispenser structure, some particles of mixture are inevitably lost under the device when the distributor moves toward the dies and even when it comes back to the hopper. Due to assembly needs, the gap tolerance between the rotational platform and the dispenser must be rather large. So, with this kind of solution for producing concrete slabs, an amount of mixture falls down at each cycle.

The most common solution adopted to recover the fallen particles, is to feed them back into the hopper, using simple shovels and/or conveyor belts. Therefore, the design problem to be solved centers on the fallen particles of mixture, but which is the right one?

Formerly, the firm asked for the design of a conveyor belt-like system capable of automatically recovering the falling mixture before it reaches the ground. The proposed solution is very intuitive and, at a first sight, easy to be designed. To the company, at this time, the core of the task was very specific, i.e. "to design a special conveyor belt".

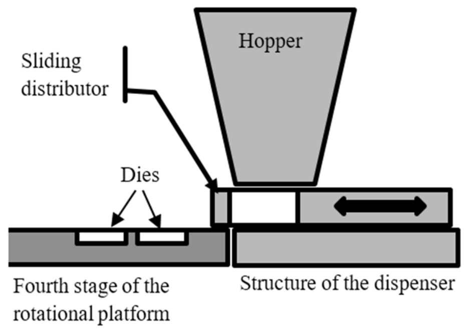

Figure 4. How the fourth's stage dispenser works. Side view

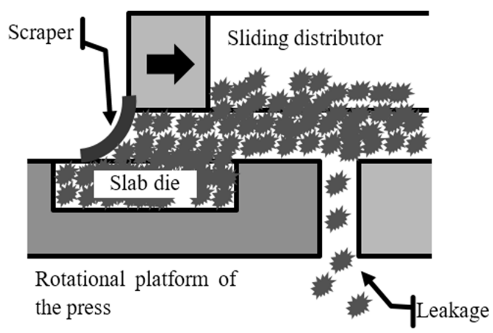

Figure 5. Schematic representation of the distributor's scraper and of the leakage between the rotational platform and the structure of the dispenser

Considering the indication of the firm, a systematic design process was implemented. Therefore, a first preliminary version of the requirement list was set up. In this way, it was possible to identify the design constraints, for example, to avoid any modification of the press. In the same way, also design objectives were extracted, allowing to perform first evaluations about the possibility to satisfy them by following the proposed task.

Table 1 reports a summary of the main requirements subdivided into design objectives and constraints, gathered in a first questionnaire session with the firm's staff. For the preparation of the questionnaires, well-acknowledged checklists were taken into account (e.g. [Pahl and Beitz 2007] and [Pugh 1991]).

The analysis of the gathered requirements suggested that the design of a heavy conveyor belt, which has to be positioned under the press, ensuring safety conditions, low maintenance, low power consumption, etc., could not be a suitable solution as, on the contrary, formerly believed by the Company.

Table 1. Some of the main requirements gathered in the first questionnaire session

Objectives	Constraints
Minimize the costs	No modification allowed on the press
Minimize maintenance operations	Maximum costs of the additional device
Ease maintenance operations	Slowing down the process is not allowed
Ease of use and regulation for the different slab types	Safety conditions must be kept
Ease of installation	Keep the mixture clean from contamination
Minimize the energy consumption	Compatibility of the hopper with its external feeder

Here, a question arose about the crux of the task initially proposed by firm: "Is the recovering of the fallen mixture the real design problem?"
Is there a possible alternative design task to be faced whose outcomes can somehow satisfies the Company needs? Furthermore, which might be the alternative design problems that can be explored to generate more suitable solutions radically different with respect to the standard one?
Without any methodological tool, ideas of various design tasks could rise up in mind, especially concerning how to prevent the mixture from falling off the platform, but it is difficult to identify the right level of detail to be considered and the right point in the sequence of operations. Indeed, even if the gathered requirements somehow limit the design space to be investigated, still many possible conceptual (and abstract) solutions may be inferred. In other words, which is the most promising crux of the task to be considered?
A comprehensive problem analysis and decomposition can provide a valid support in analyzing and discussing the original design task and, if necessary, in reformulating it. Here in the following, the application is reported the TRIZ tools recalled in the previous section, to be used in problem formulation and decomposition.

4.2 Application of the proposed tools

The application of FM and SO has been performed according to the approach previously described in paragraph 3.3.
The level of detail adopted to compose the functional model was able to describe the whole dispenser of the second layer of material, in order to collect all the potential causes of material loss. The functional model depicted in Figure 6 clearly shows that they lie in the component of the system (the drawer) that horizontally moves the material. Since the drawer does not have a bottom shutter and, at the same time, a gap between the drawer itself and the die is needed in order to avoid friction, it cannot carry the mixture avoiding the leakage. Thus, the sliding distributor performs its function in an insufficient way. The gravity field of the Earth moves the material down from the hopper to the mould (useful function) but also moves the material to fall over the plate of the rotational platform, producing an unwanted effect (harmful function). It is an important outcome of the FM, because it is not so obvious thinking that the physical principle used to deposit the material into the die is also the responsible of the main weakness of the system. For such a reason, the sliding distributor has to contain a larger amount of material than necessary. With the aim of removing the material fallen over the plate a scraper was adopted. The functional model, however, shows noticeably that the introduction of this additional component produces another undesired effect: the rubbing between the dies and the scraper causes wearing of the latter. This problem entails some other negative consequences as the unwanted increase of the required maintenance time, but these issues wasn't interesting for the Company.
After the Functional Model, SO was used in order to look for roundabout problems with respect to the initial one. Figure 7 represents the completed schema. The third column contains the starting problem proposed by the firm: they asked for a conveyor belt, i.e. a way to recover the fallen material from the ground. Therefore, translating it in the form of a question it becomes: how can the system (or the elements of the super or the sub system) recover the fallen material? The next column, called that of the future, was built considering the undesired effect deriving from the not resolution of the previous task. Therefore, supposing that the material has not been recovered, the new task consists in finding a new

way to use it laying on the floor by using the resources at the system, super system or sub system level. Going to the left of the starting column, we are going to tackle with the causes, which generate the problem. FM highlighted that the drawer cannot dose the right amount of material into the die causing the likeage. In Figure 6, indeed, the drawer performs two insufficient functions with respect to the material: the "dosing" function is insufficient because the drawer releases an incorrect amount of powder into the die; furthermore, also the "moving horizontally" function is insufficient because the drawer has not a bottom shutter and the gap, between the drawer itself and the die determines the material loss where it is unwanted. Thus, the first question to answer considering as subjects the resources of the three detail levels, concerns the recovery of the material fallen out of the dies but always over the press plate, so to avoid its falling down. With the same logic, shifting again to the left, the problem entails finding a system able to provide all the powder within the dies avoiding any material loss.

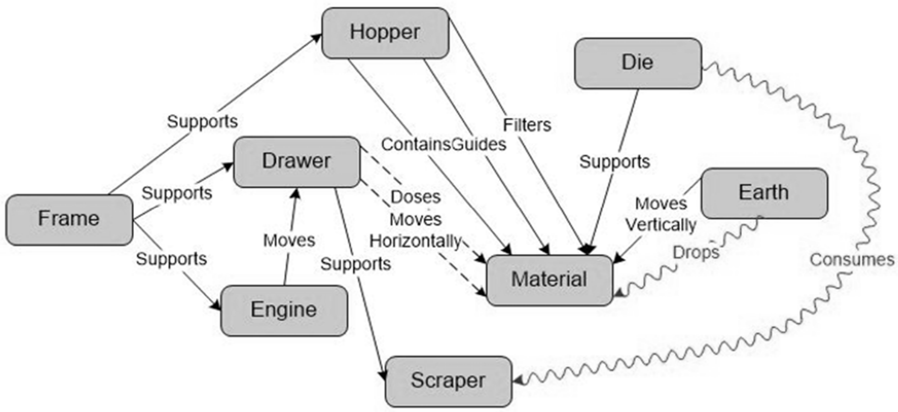

Figure 6. The functional model of the current mixture distributing system

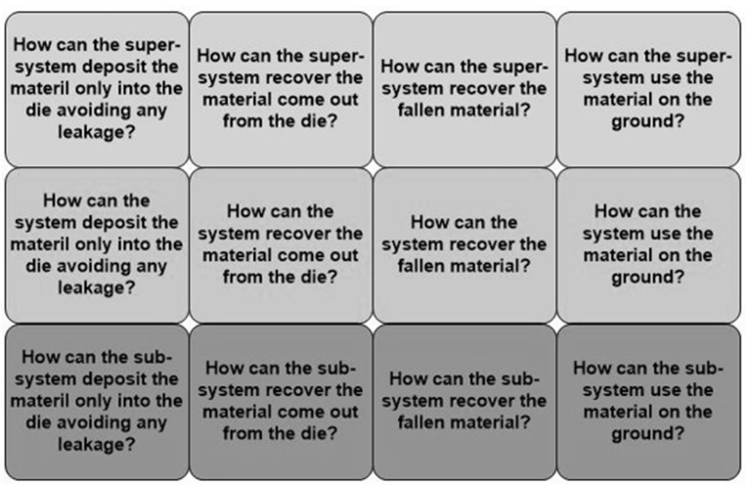

Figure 7. The System Operator schema. The starting problem is depicted into the third column

4.3 Results

The adoption of FM allowed to analyze thoroughly the operation mode of the system, and to identify all its criticalities, many of them not having been initially considered. The original problem, as stated by the company, concerned only a means to remove the unwanted effect of the material fallen to ground. The company had never analyzed or studied the causes that originate this loss, but due to the mental inertia, the system architecture was always considered as immutable. The FM, on the other hand, allowed to increase the awareness of the system dynamics also to the firm technicians which will facilitate future system changes. Thus, for instance, it has been clarified that the drawer can be

considered as a critical element, since two of its three functions, among which also its main useful function, are not satisfactorily performed. This information, accordingly with the evaluations of the technicians, would not have emerged without this systematic investigation. Moreover, we want to emphasize that SO, gave a wider and a clearer description of the feasible strategies. By means of these data, the engineer can better choose between a more radical redesign or, on the other hand, a narrower effort.
After several design review sessions aimed at carefully evaluating the different alternatives highlighted through SO, as a result the attention of the Company has been drawn to a different design problem. More specifically, instead of finding solutions able to recover the fallen material, the design effort has been focused toward a way to deposit the material only within the dies avoiding any leakage. Therefore, a new mixture distributing system has to be designed, which is a radically different design problem with respect to the development of a conveyor belt for the recovery of the fallen material.
The original requirement list was no longer sufficient to define the new design task and, consequently, to describe the essential problem since it referred to the design of a conveyor belt. Therefore, a new questionnaire has been submitted to the firm, which led to a new RL. Eventually, more detailed information was necessary for the definition of design objectives and constraints related to parts of the plant, which, in the former conviction of the firm, were not important (i.e. the distributing system).

5. Discussion and conclusions

Many reasons could led the firm to the definition of the first, very specific design task. Maybe, if following a systematic approach (e.g. Pahl et al. 2007) a more abstract essential problem would be considered. However, it is hard to believe that only with a general broadening of the problem formulation, the firm's staff could be capable of radically change the main problem to be solved. Indeed, by following the Pahl and Beitz guidelines, the essential problem can be expressed in a more abstract form, but its roots remain the same.
In other words, if the initial task is focused on picking up something from the ground (or near it) and to transport it into the hopper, the tools provided by the recalled systematic approach do not foresee to discuss if something has actually to fall. Instead, it has been shown here that some specific TRIZ tools can bring a valid support for doing that in a systematic design process. Indeed, as schematically represented in Figure 8, the application of the TRIZ tools to the considered case study, simply led to an iteration between task clarification and the first step of a generic conceptual design processes based on FDM.

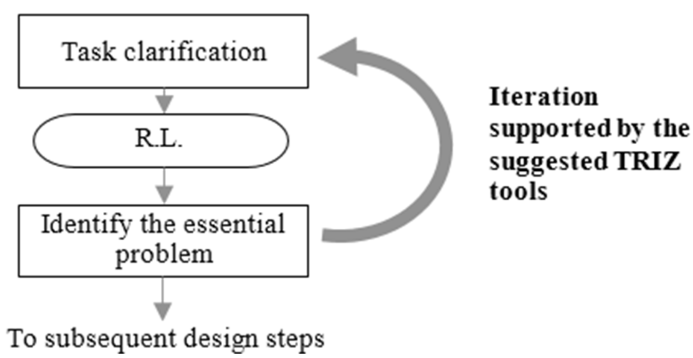

Figure 8. The first requirement list, focused on preliminary firm's indications, can be upgraded by new insights spurted from the application of the suggested TRIZ tools during the very first step of a general systematic conceptual design phase, i.e. the identification of the essential problem to be solved

Furthermore, the use of the suggested tools led to investigate several innovation opportunities for the Company, since the identification of an alternative task brought to a radically different set of solutions with respect to the ones offered by the competitors.

Concluding, the work presented in this paper proposes the use of some specific TRIZ tools for supporting design task discussion and redefinition.
A small and quite simple industrial case study has been considered for presenting the proposal. The obtained results demonstrate that the application of the TRIZ Functional Modeling and the System Operator, led to a complete redefinition of the design task formerly indicated by the firm. In other words, it has been shown that the proposal supports the iterations between the Task Clarification and the early Conceptual Design phases of the systematic design model (Figure 8). In future works, authors intend to continue their investigation about the possibility to improve the design process with TRIZ. For that purpose, the results presented in this paper, will form the groundings of this research. For some readers the outcomes of the proposed approach may not seem so astonishing because someone can immediately think to some solutions that can avoid spreading the material out of the die. But it is important to note that such a proposal make the process more systematic, and it guarantees that any information for solving the problem is avalaible, and all the possible alternative problems have been considered.
Eventually, just for the sake of clarity it is worth to highlight that the set of generated solutions have not been reported in the paper for two main reasons: the first one concerns the disclosure agreement with the company, which doesn't allow the dissemination of the obtained results. The second one lies in the paper objective that is focused on showing and discussing the use of TRIZ tools suggested to redefine the design task within a FDM framework.

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