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# JOINING STANDARD AND INVENTIVE DESIGN. APPLICATION TO INJECTION MOLDING

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## Abstract

Innovation is a key issue in current global economy, and engineering design process is one of the main components of both radical and incremental innovation. Inventive level of the technical problem design process should solve changes all along the system lifecycle. Solving this technical problem is risky, as robust technical knowledge is not yet present. Nevertheless, innovation has to be introduced. To solve this dilemma, we propose to develop a design process joining standard and inventive approaches. In this paper we show that technical knowledge can be the common resource of these two different approaches. Standard design utilises it to reuse known technical solutions, whereas inventive approach requires analysing and formulating the problem that is to be solved using TRIZ solving tools, creating either an incremental or a radical innovation. We identified that standard and inventive approaches can collaborate to initiate the system evolution and also that standard approach can be used to investigate and collect knowledge later processed by inventive approach.

*Keywords: innovation, design, TRIZ, inventive design.*

## 1 Introduction

Innovation has become a crucial ability in current industrial world. Today, competition is worldwide and innovation is needed as it temporarily puts the company in a monopole situation. This status of first-mover gives the following advantages to the company launching the innovation: the company can impose its prize as there is no competition yet, stays the reference even after followers have started the manufacturing of their own product, and can more easily reduce the cost of the product. Innovation capability is closely related to the design process efficiency: a company willing to develop an innovation strategy has to adapt its design process. The research presented in this paper mainly focuses on the design process improvement.

## 2 Objectives: three questions to answer

Many authors have studied innovation, starting from Schumpeter, [1]: he described innovation with the concept of "long waves", subsequent to each other. A technological breakthrough, also named "radical innovation", generates a new cycle and is associated with a cluster of minor innovations, also named "incremental innovations". Later researchers, like Freeman and Perez [2], described radical innovation as technical discontinuity based on new scientific knowledge, and incremental innovation as simple improvement of technical products or processes. A third typology of innovation has been proposed by Henderson and Clark, in [3], using two directions: the first is the basic concepts and components, the second is the link between the concepts and components, as shown in figure 1(a). Incremental innovation is then characterised by the reinforcement of the basic concepts and components, without changing their links. Radical innovation exists when the solutions bypass basic concepts and components, and modify links between them. Two other types of innovation are also described by the authors: architectural and modular. The consequences of a radical innovation are very important as it opens up new possibilities for long-run changes in the trend rate of economic growth. When radical innovations occur, they disrupt the existing economic structure and dependencies in the economy. With the technical system lifecycle point of view, we can summarize the differences between radical and incremental innovation, as shown on figure 1(b): incremental innovation (I) drives the system to the next stage of its own evolution, whereas radical innovation (R) gives birth to a new evolution curve. In both incremental and radical cases, innovation improves the current technical situation, introducing new technical principles in the latter case. Hence, innovation process needs a design action transforming the current system, either slightly or fundamentally, transforming the whole technological regime in the latter case.

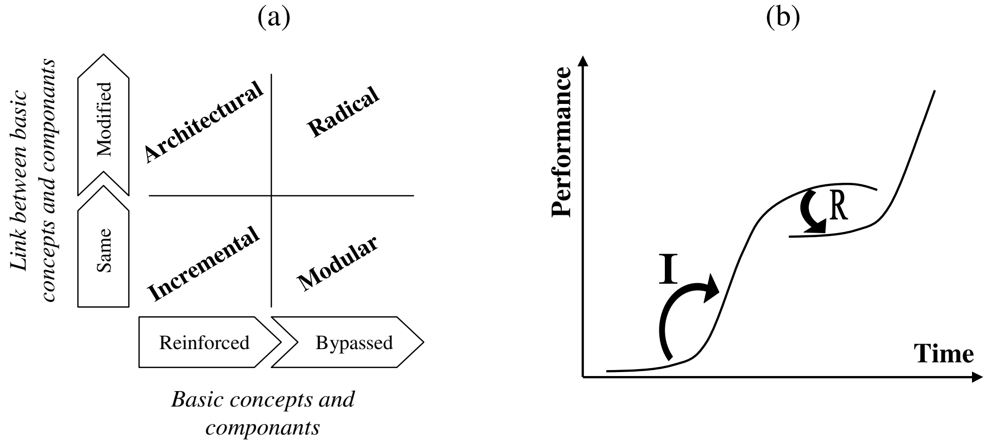


Figure 1. Innovation typology

Although innovation is unavoidable from the technical system point of view, and a serious advantage from the company point of view, it is no panacea. The idea of “risk” can precisely explain why some companies prefer the “follower” strategy rather than the “first mover” one. Innovating is risky, and four types of risk can exist. The “human risk” is linked to the motivation of the designers to struggle for developing an entirely new concept. The “commercial risk” has two dimensions: firstly, the availability of resources required to manufacture the projected solution and, secondly, the response of the market. The third risk is financial and relates to the required investments. The fourth risk is predominant in an innovation context: the technological risk. This risk exists as it is impossible to guarantee that the expected technical properties will be reached: the required technical knowledge is not yet present. Even more, innovative solutions can only be developed by gathering new knowledge or by combining current knowledge in an innovative way, [5].

Innovation process appears as an integrated process of enhancing the technology frontier (technical dimension), transforming this into the best commercial opportunities (commercial direction), and delivering the commercialised product in a competitive market, with widespread use (success direction), as shown in figure 2. The fourth risk relates to this technical dimension. In this paper, we focus on this technical dimension, as it mainly depends on the design process.

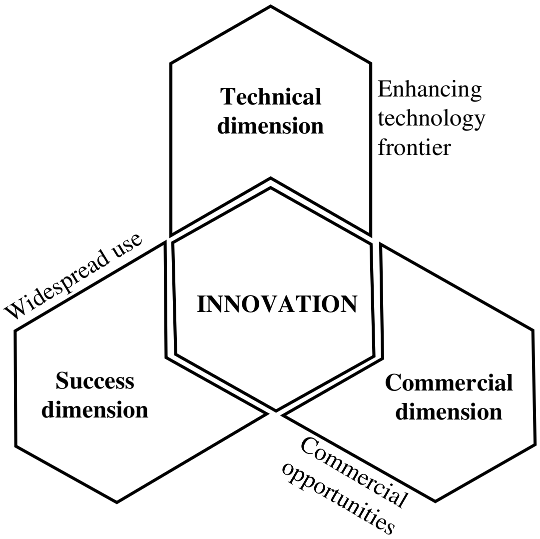


Figure 2. Three dimensions of innovation

Therefore, any design process, aiming at transforming the current system either incrementally or radically, has to deal with the following dilemma. On the one hand, the design process should only use robust technical knowledge, in order to reduce risks (the properties of the proposed system can be precisely predicted, the technologies are already optimized, etc.). Such a design process will be called "standard", figure 3. On the other hand, the design process should also be based on entirely new technical knowledge, in order to come up with new innovative solutions. Such a design process will be called "inventive", figure 3. We think that this dilemma can be solved by constructing a design process, joining inventive and standard design approach.

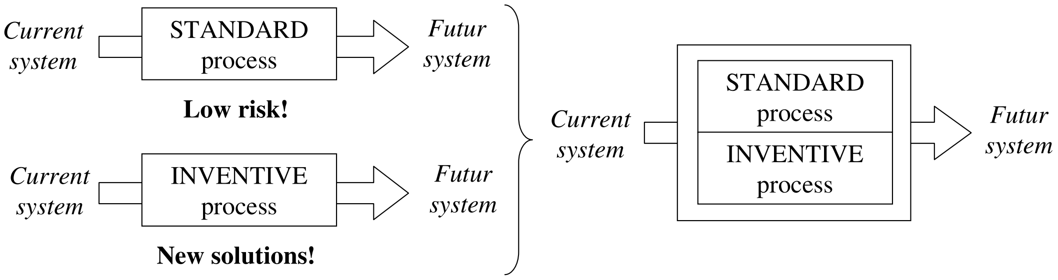


Figure 3. Joining inventive and standard approach in a new design process

The first step in the building of this new design process is to answer these three questions:

- what can be the common resource used by both inventive and standard approaches?
- how does each approach use this resource to propose new technical solutions?
- how does this resource can be used to switch from one approach to the other?

Answering these three questions is the objective of this paper. The rest of the paper is structured in three sections, as shown in figure 4. The coming section, "Method" details the steps conducted to build a first design process proposal: literature review about design and inventive problem solving (to locate what common resource they need) and innovation case study analysis. Our proposal is presented in section 3, "Results", and tested on an injection moulding case. The main outcomes are detailed. The answers of the posed questions are drawn out and synthesised in the last section, "Conclusions".

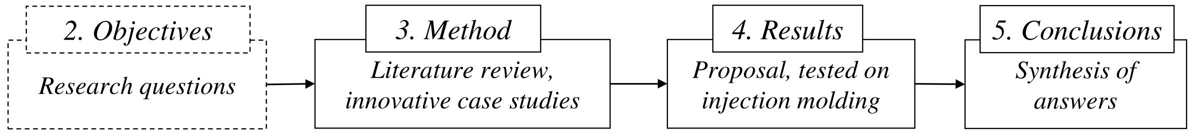


Figure 4. Paper structure

# 3 Method

## 3.1 Understanding design as a human based knowledge process

Rosenmann and Gero, in [6], describe design as a "conscious purposeful activity to arrive at a state which did not previously exist in order to (presumably) improve some (perceived) unsatisfactory existing state of affairs. Design is a human activity related to human needs regarding the necessity to change the present state of environment". We can stress two major points. The first comes out as design is purposeful: the decisions taken during the development of any artificial system have a certain goal (teleological nature of an artificial system). The second point relates to the fact that design is a human activity: the decisions are taken by human beings, and the nature of the artificial system depends only on human choices. The authors describe an artificial system in four dimensions: purpose (the human reason of the system existence), function (result of the behaviour of the system), and behaviour (describes how the system functions), and structure (what the system is). Suh developed an axiomatic view of design, [7]. His proposal is based on four domains. The first is named "customer domain", and is characterised by the needs (or attributes) that the customer is looking for in the system. The second domain is "functional": the customer specifies, in terms of "Functional Requirements" and "Constraints", how to reach the needs. The third domain, "physical", contains a hierarchy of "Design Parameters" that supports the functional requirements. The last domain, "process", is made of "Process Variables" and describes how the product can be produced. The "functional" domain (or left handside domain) shows "what we want to achieve" and the "physical" domain (or right handside space) shows "how we propose to satisfy the requirements specified in the former domain". Two axioms complement this approach:

- Axiom 1: independence axiom. This axiom states that functional requirements should be realised by independent design parameters;
- Axiom 2: information axiom. This second axiom states that the information content of the concept should be as small as possible.

Even though the axiomatic design point of view lacks precise processing methodology, it clearly points out that, within the same domain, the definition of the sublevel depends on the chosen mean in the right domain (zigzagging). Technical knowledge can be used to identify a mean to realise "what we want to achieve": in such an approach, technical knowledge allows the reuse of technical solutions.

The design process can be decomposed in three directions, [8]: the designing system, the design operations, and the design object. During the design process, the designing system performs the design operations and, step by step, defines features of the design object. Each design operation increases the completeness of the design object representation. Therefore, we can conclude that within the design process, the design object has only a partial definition, and that going further in the design process means fixing the features relevant to the next state of definition. The author also reminds three major knowledge processings during design: deduction, induction, and abduction. Tomiyama, in [5], mentioned that abduction is the major knowledge processing in design. Abduction generates hypothesis that should later be approved by testing, and can be illustrated with the following mechanism:

- observation: all injection moulded part have a good surface finish;
- assessment: this part has a good surface finish;
- conclusion: this part is injection moulded.

Therefore, technical knowledge is required at least to formulate a reliable initial observation. Based on these observations, abduction will lead the designing system to conclusions pushing the design object to its next stage of definition.

From a methodological point of view, the shrinking of technical system lifecycle has given birth to concurrent engineering. Within this approach, the product and its manufacturing process should be designed simultaneously in order firstly to avoid mistakes requiring time-consuming redesign and secondly to start design activities as early as possible. Following this current trend, it is obvious that the "design object" mentioned in [8] is not only the product anymore, but also its manufacturing process.

## 3.2 Focusing on the theory of inventive problem solving

The achievement of Altschuller, [9], clarifies the technological dimension of innovation we focus on. He disclosed, after having analysed thousands of patents, that five levels characterize the inventive levels of inventor's findings (patents). It was also described, in his analysis that technological frontiers needed to be enhanced towards other domains than the one the inventor was patenting. The first level relates to patents where no technical problem is solved, and which only use evident technical means. The second level is associated to a technical problem, solved with the knowledge of a single human. The third level relates to problems solved using the knowledge of a company. The fourth level is connected to problems solved with the knowledge of other industries. Finally, the fifth level is associated with problems solved with new scientific knowledge. Therefore, we can say that the higher the inventive level, the more difficult the solved technical problem. In figure 5, he graphically represents the links between this inventiveness level and the lifetime of a given main function associated with its technical systems. This curve has then been correlated with the "classical" lifecycle s-curve allowing concluding that this inventiveness did not appear randomly during lifecycle but following a certain trend.

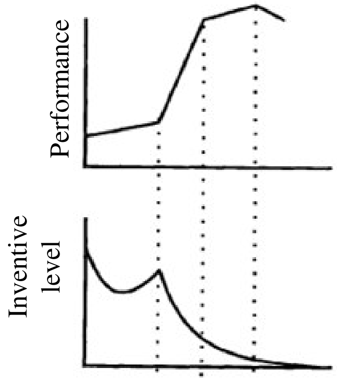


Figure 5. Inventive levels during the system lifecycle, according to [9].

During the birth phase of the system, innovations are mainly based on highly inventive technical solutions (corresponding to radical innovations); going through its rapid growth, maturity and decline stages, the system is accompanied by innovations of decreasing inventive level; at the end of the system life cycle, innovations are mainly based on very simple technical solution, resulting from a standard design approach. Therefore, innovations relate to technical problems more or less difficult to solve. For low inventive levels, mainly at the end of the lifecycle, design "enhances the technology frontier" using standard solutions to overcome a technical problem, as knowledge required to solve the technical problem is easily available. For high inventive levels, mainly at the beginning of the life cycle, design cannot "enhance the technology frontier" using standard solution as knowledge required is difficult to obtain: the technical problem is more difficult to solve. This validates the possibility to combine standard and inventive approaches within a single design process.

Any design action, ranging from very standard to very inventive, is based on two mechanisms: problem formulating and problem partial solving. Design problem is solved when the partial solving suggests a system generating no new problem. Hence, an inventive problem, treated by either standard or inventive approach, is to be processed using these two mechanisms. TRIZ is a theory supporting inventive problem solving. In current research papers, TRIZ is presented as based on three axioms: the first one state that any problem can be represented in the shape of a contradiction. The second stipulates that the evolution of a technical system should be led in accordance with objective laws. The third axiom states that problems must be solved in accordance with specific conditions of the system's situation. A graphical representation of the contradiction (according to the first axiom) is illustrated figure 6, it features a physical contradiction related to P1 and a technical between P2 and P3):

- If the value of <parameter P1> is <V1> then <parameter P2> is satisfying, but <parameter P3> is not satisfying;
- But if the value of <parameter P1> is <V2> then <parameter P3> is satisfying, but <parameter P2> is not satisfying.

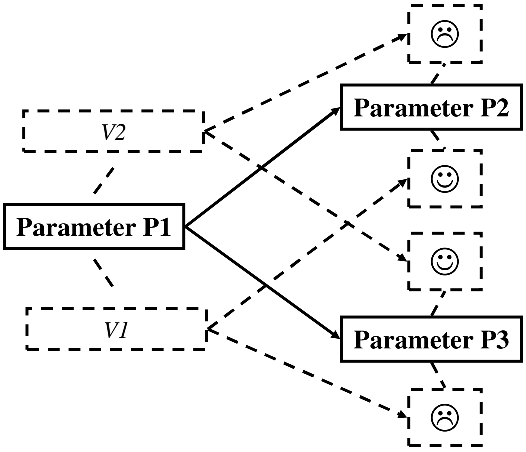


Figure 6. Contradiction pattern.

The metamodel of TRIZ proposed in [4], shown in figure 7, represents the system of elements on which the theory is based on. On the boarder of TRIZ, methods (set of procedures helping the designer in his tasks to drive a problem solving process) have been elaborated (ARIZ, Substance-Filed modelling). Then a set of constructed techniques to assist some of the steps of the methods (tools) have been designed (Matrix, standards, principles, ways to separate physical contradictions). All these elements were built upon thorough analysis of elements of knowledge (fundamental sciences, history of inventions, patents, biographies of inventors). The tools and methods encompassed in TRIZ approach are mainly useful to partially solve a previously identified problem. An obvious limitation arises: treating the complexity of the initial technical situation and converge its representation to a single contradiction has not been treated in the boarder of classical TRIZ, but has been exposed in the boarded of OTSM-TRIZ. Therefore, if TRIZ is to be used to support the inventive part of innovative process, inventive problem formulating needs to be assisted.

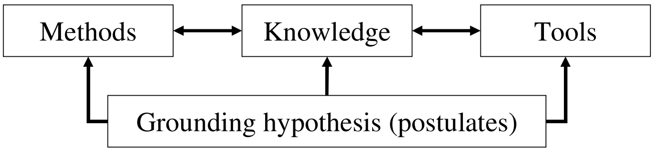


Figure 7. The four basic TRIZ components

## 3.3 Analysing five innovative TRIZ case studies

The third step of the method is to analyse real TRIZ based case studies. Five different projects were conducted in order to understand how problem formulation should be processed. A summary of the projects is shown in table 1. They were all conducted by a TRIZ expert, and one of the authors was an observer. These five case studies gave us the opportunity to analyse how, on real projects, knowledge needs to be processed in order to formulate the inventive problem. It also showed that standard solutions can be implemented to improve an inventive solution concept.

The first case study, conducted in company A, was linked to the development of a new technical way to extract the product out of its tool (during one step of the manufacturing process). The frame of this project was to develop an incremental innovation, as the solution had to be implemented with changing neither the product design nor the main manufacturing line components. In this first case, TRIZ approach was used to analyse three current alternative concepts to get a complete picture of the situation. ARIZ algorithm was later used to propose four solution concepts to the company.

The second case study, in company B, was linked to plastic manufacturing. Tests had shown that the machine was not able to reach the new expected cycle time. The company was ready to develop incremental or radical innovation. In this case study, TRIZ was used to deeply analyse the technical problem to overcome, and this analysis was synthesised to a set of three contradictions. These contradictions gave research directions to the company.

The third case study was conducted in company C, producing complete systems for car industry. The subject was about improving the ergonomy of doors, and the company was willing to develop a radical innovation, as the project was in the early development phases. Within this project, the first part of ARIZ was followed to obtain some solution concepts that were later improved (using both TRIZ tools and standard solutions).

The fourth case study was done in company D, manufacturing personal cooking devices. They were facing a technical problem reducing life time of their product. They were wishing to develop an incremental innovation, to improve this situation and drive the system to his next evolution stage. For this fourth case, TRIZ approach was used to first propose a limited number of solution concepts, and then to improve their remaining key defects.

The fifth case was done in company E, and the objective was to develop a radical innovation to replace the currently commercialised version of a car cockpit component. The goal was twofold: increase safety for the user and, from the company point of view, introduce on the market a product competing with existing technologies. For this last case, 40% of the time was dedicated to identify the particular case peculiarities and to gather expert knowledge about the specific safety issue. The rest of time was used to apply TRIZ solving tools to propose and improve solution concepts

Table 1. TRIZ case studies

| Company | Description of the study | Product / process | Radical / incremental |
|---|---|---|---|
| A | New way to extract the product out of its tool, within a step of the process (reduction of quality problems) | Process | Incremental |
| B | New component of a plastic manufacturing machine (decrease cycle time) | Process | Incremental / radical |
| C | New components of car doors (increase ergonomy) | Product | Radical |
| D | New components of cooking device (increase life time) | Product | Incremental |
| E | New component of car cockpit (increase safety) | Product | Radical |

# 4 Results

Having analysed standard design has revealed the importance of technical knowledge: reuse of known solution to an identified problem. We showed also that technical dimension of innovation process uses inventive problem formulating and solving: formulating requires technical knowledge too. Therefore, the result that helps answering the posed questions is twofold: first a way to represent technical knowledge, coherent with design theory and TRIZ way to solve inventive problems and second, the ways standard and inventive design processes treat this knowledge. These two results are applied on an injection moulding case.

## 4.1 Initiating a particular injection moulding case

Injection moulding process is based on four major steps, [10], illustrated on figure 8. The first step is named “filling”: the mould cavity is fed with molten plastic, pushed by a hydraulic piston. The second step is “packing”: additional material is brought by high pressure, to compensate the later material shrinkage occurring while the plastic cools down. The third step is “cooling”: the feeding channels are solid and the material is cooled until the part is rigid enough to support its own weight and ejection forces. During the final step, “ejecting”, the mould opens and ejector pins push the part out of the mould.

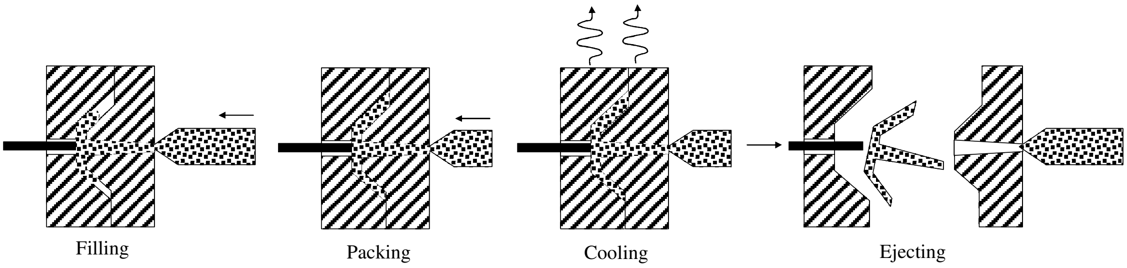


Figure 8. Four steps of the injection moulding process

Design within injection moulding requires the definition of four main entities, [10]: the plastic material, the machine, the mould, and the part. The material is usually chosen within a database of existing materials, taking into account different criteria linked to the part functionality and environment, the requested manufacturing properties, the recycling, the cost, etc. The machine is mainly in charge of generating the required pressure and melting the material. In most cases, the machine is not project-specific. However, it is crucial to use a machine able to generate enough pressure to completely fill the cavity, although the material viscosity increases during filling. A second major criterion is the available back pressure that should be high enough to firmly close the mould during filling and packing. The mould and part definition are the key components of injection moulding design. Mould design can be summarised by the two following requirements. First, from the operational point of view, the mould should be easy to operate, robust, reliable, unwearable, very simple to manufacture, capable to operate fast. Second, from the product point of view, the mould should manufacture many parts in parallel and guarantee a perfect quality for each of them. Equilibrium between these two requirements is to be found for each mould design. The part design can also be summarised by two opposite requirements. First, from the customer point of view, the part should have many different functions and a long lifecycle under the normal use. Second, from the manufacturing point of view: the part design should generate a perfect material flow (no weld lines, hesitation marks, ripples, lack of material, etc.) and avoid defects (warpage, sink marks, flashes, etc.). Again, any part design has to find a balance between these two requirements. Intensive collaboration is unavoidable in this technical field, firstly because the design of these four entities are closely related to each other, and secondly because in the current trend of globalisation, injection moulding projects involve many companies geographically scattered.

The particular project we use to process a preliminary constructed technical knowledge base relates to a part named “t-pin”, shown in figure 9(a). The product evolution is driven by cost reduction: the t-pin, which was metallic, has now to be designed with a plastic material. This material change requires incremental innovation to maintain perfect product functionality. The t-pin moves within the assembly, periodically pushing a second part and generating a rotational movement. For contact reason, surface quality of the edge touching the other part, and t-pin straightness are important. Figure 9(b) partially shows the t-pin mould design. The ejector is at the bottom of the t-pin, the material enters from feeding channels on the side of the part, and the parting line is located under the head of the t-pin. The chosen gate location is the only one which has no contact with other parts in the product.

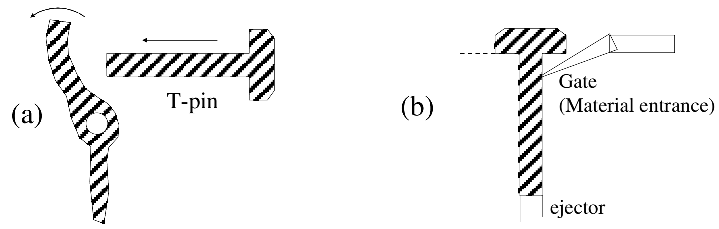


Figure 9. T-pin in action

## 4.2 Four basic components to represent technical knowledge

The technical knowledge representation we propose is based on four components: three types of parameters, and scientific laws linking them within a complex network. Figure 10 uses U.M.L. class model to illustrate our knowledge representation.

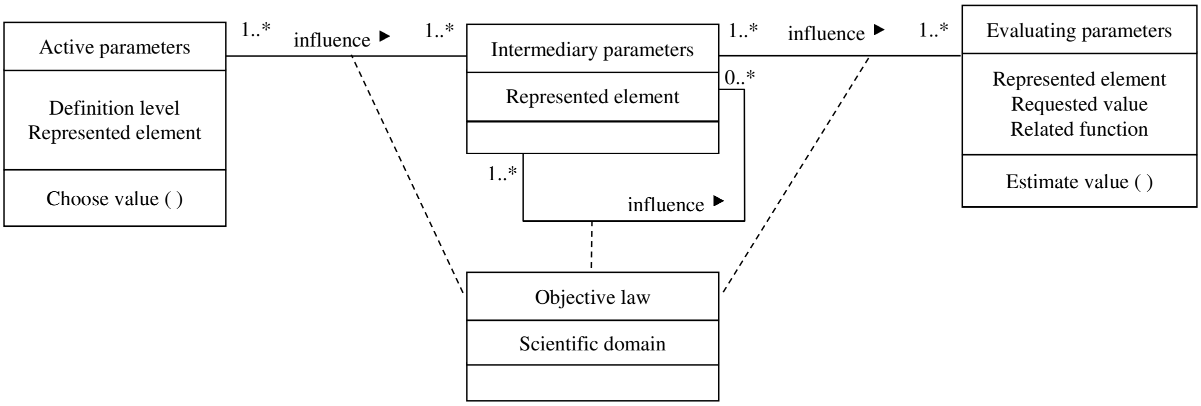


Figure 10. Knowledge representation

The first type of parameter is named "Active parameter". These parameters support the definition of the technical system under design. Therefore, within a concurrent engineering context, they support the definition of the product and any element that is designed according to it: the manufacturing and assembling tool or machine, the particular maintenance tools and services, the recycling technologies. Active parameter values describe what a particular technical system is, and only depend on designers' choices (they cannot influence each other): technical principles, components, dimension, shape, etc. These parameters are relevant to different system definition levels, from conceptual to detail. This first category of parameter differs from axiomatic design "Design Parameters", [7]: active parameters represent more than just the product, but can also represent any element that is to be designed (the manufacturing process for example). Using the vocabulary introduced in [8], we can say that they are relevant to the "design object". In the case of the t-pin, the following parameters belong to this first category: gate location, ejector diameter, ejector location.

The second type of parameter is named "Evaluating parameter". Their values describe properties of the technical system and of its environment, as they are influenced by the particular system definition. These properties can be physical (strength, temperature, speed, weight), or not (number of manufacturing operations, part look, environment harm, etc.). Evaluating parameters support only a description of the consequences of the chosen system definition. Hence, their values cannot be chosen, but only estimated. Evaluating parameters can relate to the system function (temporarily transforming the system environment) or to the criteria used to estimate technical solutions (cost, possible quality, safety, etc.). This second category differs from axiomatic design "Functional Requirements", [7]: evaluating parameters describe requested properties of the "design object" itself (the product surface finish, tool lifecycle, etc.) or of its environment (human harm, ecological consequences, etc.), hence they can relate to the required transformations (function of the whole design object, and not only of the product) or to technical solutions comparison. In the case of the t-pin, the following parameters are evaluating: surface quality, straightness and ejector lifetime.

The third type of parameter is named "Intermediary parameter". They detail the physical phenomenon with which active parameters influence evaluating ones: active parameters influence intermediary ones, which, in turn, influence evaluating parameters. A detailed definition of the physical phenomenon is obtained by using many intermediary parameters. A single intermediary parameter can be involved in more than one phenomenon. Hence, intermediary parameters form a network. This third category does not exist in axiomatic design, [7]. In the t-pin case, the following parameters are intermediary: macromolecules orientation, ejector compression stiffness.

The fourth component is the objective laws explaining the links between the three types of parameters. These laws describe cause effect relationships between the different parameters: a law linking two parameters has a direction and is not only a connection. A single phenomenon, from active to evaluating parameter, can be detailed with more than one law. A problem can then be solved by bypassing a law having harmful effects in the system. This last component is not included in axiomatic design approach. In the t-pin case, laws analysed in injection moulding researches can explain the effect of gate location on macromolecules orientation, as well as the influence of macromolecules orientation on part straightness (warpage). A well known mechanical law explains that increasing the diameter of a beam (the ejector pin) increases its compression stiffness, and then its lifetime.

## 4.3 Iterative knowledge processing for design

This knowledge representation is to be used to create a knowledge base, which is treated within a design process detailed in this section. The proposed way to process the technical knowledge is represented figure 11. This process is to improve the current system, to adapt it to the next evolution stage (either incremental or radical change). The standard approach is on the upper side, and the inventive one on the bottom side. The left diamond represents the switch between these two approaches. Each stream proposes new concepts for the designed product (either inventive or standard). The right diamond shows that this process is iterative: if one of the proposed concepts is completely satisfying, it will be accepted (future system), otherwise the process restarts. Hence, iteratively applying this process generates a "flow of concepts".

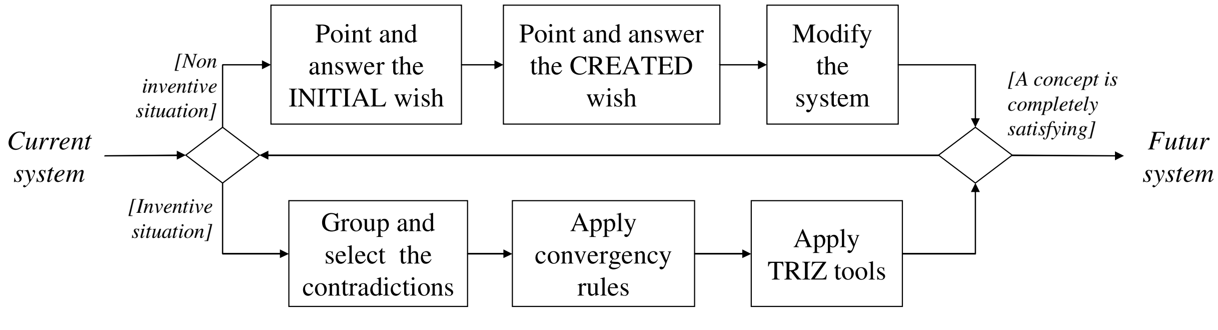
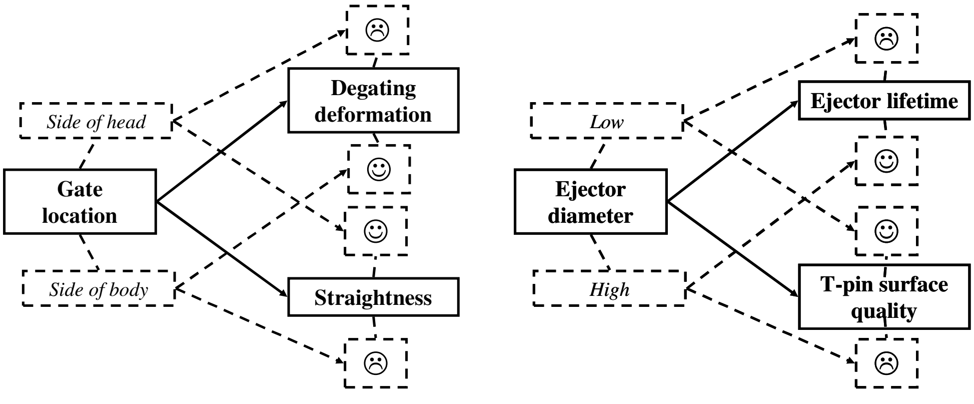


Figure 11. Proposed technical knowledge processing steps

The first stage (left diamond) of the process is to choose whether the situation is inventive or not: engineers have to evaluate whether or not their current technical knowledge can drive the current system to the future one. The initial t-pin situation is estimated not inventive: the standard approach will be developed first.

The first step of the standard design approach is to point and answer the initial wish. This which exists as the current system is no longer adequate for the next evolution stage, requiring either incremental or radical change. This identification is done using evaluating parameters: designers point out parameters which values, within the current system, are not satisfying. For the t-pin situation, they are: straightness (current gate location generates warpage, figure 13(a)) and surface quality (current ejector location creates flashes, figure 14(a)). The way to answer this initial wish is identified step by step, using intermediary parameters to go back to key active ones. Doing so, engineers identify possible system modifications. For the t-pin situation: straightness is influenced by macromolecules orientation, influenced again by gate location (gate location should be moved to the side of the head, to improve straightness, figure 13(b)); surface quality is influenced by ejector diameter (ejector diameter should be reduced, to improve contact through better surface quality, figure 14(b)).

The second step is to point and answer the created wish: if the initial wish is answered by changing identified active parameters value, another wish might be created. This wish is identified through intermediary parameters step by step, starting from active parameters of the modifications proposed in the first step. A high degating deformation will occur if the gate location is the side of the head; if ejector diameter is reduced, ejector pin compression stiffness will be reduced, and its lifetime will be reduced. Using first step results, two contradictions relating to the current system are then constructed, figure 12, based on identified active and evaluating parameters. Identifying a mean to answer the created and the initial wish are similar. Degating deformation can be improved by using a pin point gate with a self degating geometry (figure 13(c)); no known solutions exist to improve ejector lifetime.



(a) (b)

Figure 12. The two contradictions.

The third step proposes to synthesise the system modifications identified within the two first steps. Hence, the result of this third step is a set of active parameters which value should be modified to improve the current system: gate location will be the side of the head, the gating scheme will be pin point, with a self degating geometry. Within this “improved current system”, ejector diameter is high, hence surface quality has to be improved and the conflict on ejector diameter remains: the procedure should be restarted (right diamond of figure 11).

Starting the procedure again, designers have to decide again whether the new situation is inventive or not (left diamond). If a standard solution can transform the new concept (or a concept proposed within an earlier iteration) in a completely satisfying one, standard process is to be used. In the opposite case, the inventive approach is advised. For the t-pin situation, inventive approach is used to improve the evaluating parameter "surface quality".

The first step of inventive design approach proposes to group all the contradictions formulated during preceding standard approach. The obtained list of evaluating parameters is then used to rank all the preceding concepts and to select one of them. The set of contradictions relating to the chosen concept is more or less complex. For the t-pin situation, the "flow of concepts" is simple: the "current system" and the "improved current system". The latter is selected as it is an improved version of the former (evaluating parameter "straightness" has been improved). The contradiction to be solved is about active parameter "ejector diameter", figure 12(b).

The second step proposes to use convergence rules, when the contradiction set is too complex. These rules suggest ranking evaluating parameters according to their priorities or functional level and active parameters according to their definition levels. A single intermediary parameter can also be used to represent more than two evaluating parameters. The t-pin situation does not require this step, as there is a single contradiction to solve.

The third step is dedicated to the use of TRIZ tools. In the t-pin case, the first principle for physical contradictions elimination can apply on the physical contradiction: separation of conflicting properties in space. The diameter can be low and high in two different zones. Principles for technical contradictions elimination can also be used, thanks to Altschuller's matrix. While improving the surface quality (amount of substance, parameter number 26), the ejector rigidity is worsen (strength, 14). The first proposed principle is named "14: spherical shapes". Combining these two principles, a solution concept is proposed (figure 13(c)). Integrating this new proposal on the "improved current system" creates a completely satisfying concept: each evaluating parameter has a satisfying value and the process ends.

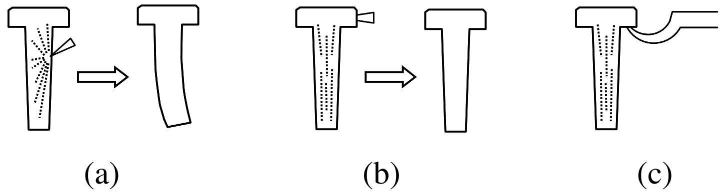


Figure 13. Three possible gate locations.

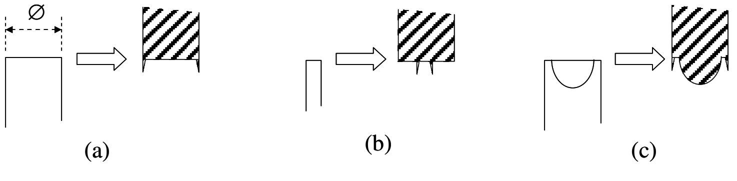


Figure 14. Three possible ejector configurations.

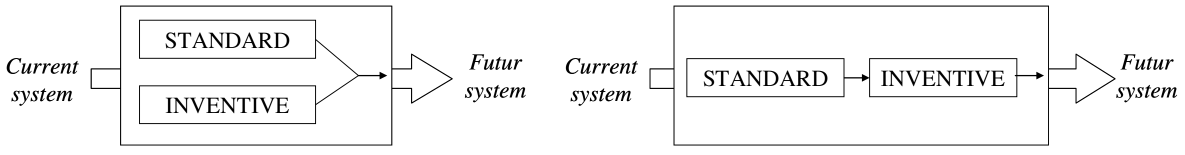
## 4.4 Main outcomes : three answers

The main outcomes detailed in this section have two origins. The first is the use of our proposed approach to analyse the five TRIZ based case studies presented in section 3.3, and the second is the use of our approach on the t-pin case presented in section 4.3. These outcomes are presented as answers to the three questions driving this article.

The common resource used by both inventive and standard approaches is the technical knowledge, relating to the industrial field. This knowledge is represented by parameters (three different types) and objective laws linking them. It groups standard system description (active parameters), known criterias according to which systems are estimated (evaluating parameters) and description of physical phenomenon taking place in the domain (intermediary parameters).

Within standard design, technical knowledge is used to locate the evolution wish (through evaluating parameters or intermediary ones, as the latter can be used to describe it precisely). Knowledge is then used to find “means” to answer this wish: intermediary parameters are used to “step back” from evaluating parameters to active ones. Technical knowledge is also used to identify, step by step, the potentiel drawback of standard mean (from active to evaluating parameters, through intermediary ones). Through practice, we also noticed that intermediary parameters are used by engineers to keep in mind important points. Hence, we can say that within standard design, technical knowledge is used to answer the question “how” (to answer the different wishes). Within inventive design, technical knowledge is used to analyse the situation and formulate the problem to be solved with inventive tools. This is a crucial difference: in standard design, knowledge is used to describe what should be changed in the system whereas in inventive design, it is used to describe the starting point of the solving process. Each of the three parameter types is used to synthesise the problem description and only key parameters are kept. Within inventive design, technical knowledge is used to answer the question “why” (do the situation is a technical problem).

Inventive and standard approaches switch the one to the other the following way. Standard approach is developed first: identified applicable solutions are to be integrated, answering a part of the initial wishes; for wishes that standard approach cannot solve, the result of the analysis is used as a raw material for the inventive approach. In such case, the inventive approach uses all the different parameters that have emerged from standard design trial, and synthesise the contradictions in a single one, on which TRIZ tools can apply. Therefore, this switch can have two different natures: standard and inventive approaches collaborate (figure 15(a), collaborative switch) or the standard approach serves the inventive one (figure 15(b), chronological switch). The sequential switch from inventive to standard can happen if the inventive proposal can be improved by well known solutions. Nevertheless, this switch might require completing the knowledge base used to formulate the inventive problem.



(a) (b)

Figure 15. Collaborative or chronological switch.

# 5 Conclusion

The objective of this research was to initiate the construction of a design process joining inventive and standard approaches. Technical knowledge appears as a common resource that can be this process input. We represented knowledge with three different types of parameters (active, intermediary, evaluating), linked by objective laws of the industrial domain. The result is an influence network, treated on a particular case by a short design algorithm: standard approach reuses known technical solutions (how to transform the current system in the future one?) and inventive approach gathers precise technical data (why does the current system have to be modified?). The two approaches can be used in parallel (they both improve the current system), or sequentially (standard approach gathers data that inventive process can use; one approach further improves the system proposed by the other one). In later research, we will investigate how Artificial Intelligence tools can exploit the proposed knowledge representation to help the management of the knowledge base changes (required when an inventive solution is proposed) and to treat more complex case studies.

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