3.6

Problem Formulating for Inventive Design
Application to Injection Molding Technology

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Abstract

Increasing competition forces companies to put products on the market as soon as possible, thus creating the need for research in concurrent engineering. Invention is the second main issue: today, products must be cheaper and better than the competition's. This requires technological invention, which in turn necessitates research in creativity and problem solving theories. Our research interests are within these two academic domains: concurrent engineering processes and inventive solutions to technical problems. Starting from the specific situation of injection molding design, we identified the need to develop a new modeling approach for product and manufacturing mold that could link the powerful OTSM-TRIZ theory with concurrent engineering. We build our contribution on the parametric design model and cause-effect relationships; we propose guidelines to analyze and synthesize the resulting complex contradiction network in a single inventive redesign task. Validation is found in a plastic valve stem design.

Keywords: concurrent engineering, injection, design

3.6.1. Introduction

The field of injection molding technology does not escape the current need for fast design processes and high efficiency of final product. As competition is very fierce in this area, those two concerns are far more important here than in any other technical domain. Because of the essence of the injection molding process, those

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two issues are seldom well dealt with. Therefore, our research started with the goal of helping companies to speed up their design process and to develop powerful technical ideas through inventive design. The paper is organized as follows: section 2 is dedicated to the description of current difficulties in injection molding design. Section 3 presents the state of the art of research in injection molding design, design process, as well as TRIZ, and points out the needed contribution. Section 4 presents our parametric problem modeling in design and its application, the use of which is shown in section 5. Conclusions and perspectives are finally detailed in section 6.

3.6.2. Injection Molding Design Issue

Injection molding technology is a widely applied manufacturing process which can rapidly produce finished plastic parts within a single process step. Plastic pellets are heated, and the resulting melt is introduced under high pressure in a metallic cavity which gives the required shape to the viscous material. After rigidifying, the part is pushed out of the cavity. Current mold functions (acting on the material) are “Distribute”, “Shape”, “Rigidify”, and “Deliver”. The part and mold design are crucial issues, and are very much related [11,12]: a slight modification of the part can significantly reduce the tool complexity (removing an undercut makes the use of simple mold possible); and a slight modification of the mold can increase part quality (adjusting the gate dimension avoids jetting). Therefore, we can say that even if some mold design choices can be made independently from part design choices (and vice-versa), cooperation is strongly required in certain situations, as shown in Figure 3.6.1.

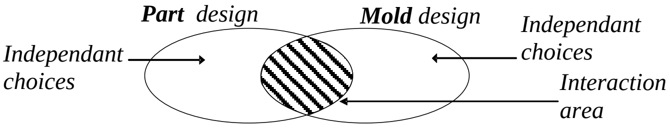

Figure 3.6.1 Independent and interacting design choices

Today, part and mold design are typically developed by two different companies [5]; mold design is introduced during the final stages of the part design process. The required cooperation described earlier creates then many iterations in this classical design process between the part designer (making mold modification proposals according to the part requirements) and the mold designer (making part modification proposals according to the mold requirements), dramatically slowing down the process. The deadline for the product to be put on the market and the fuzziness of this “interaction area” (Figure 3.6.1) are the two main reasons why designers accept compromises when technical conflicts arise. The resulting design is hence accepted although it may have some inconveniences. Inventive approaches are, therefore, particularly required in this technological field.

Therefore, we can say that, on the one hand, concurrent engineering must be implemented in this special field to decrease development time, and, on the other, that inventive design approaches must be integrated as well in order to find real solutions to technical problems rather than merely compromises.

The coming section presents the state of the art of possibly useful research, and reveals what is to be achieved in order to answer this issue.

3.6.3. Integrate TRIZ in Concurrent Engineering

The TRIZ theory has been developed with the analysis of thousands of patents; technical problem formulating and solving tools have been built, and laws of technical system evolutions have been found [1,15]. We will be interested in the problem formulating part, the basic pattern of which is the contradiction summarized in Figure 3.6.2 with the OTSM-TRIZ (Russian acronym for General Theory of Advanced Thinking) approach [9]: “Parameter A”, describing a certain “Element” should have a value V1 so that “Parameter 1” will have a satisfying value, but should have another value V2 so that “Parameter 2” will have a satisfying value. There is a physical contradiction on “Parameter A” (its value should be both V1 and V2) and a technical contradiction between “Parameter 1” and “Parameter 2” (they cannot both have a satisfying value).

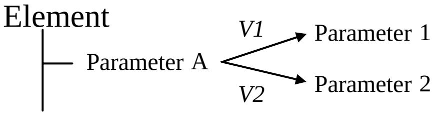

Figure 3.6.2 Contradiction representation

As the OTSM-TRIZ approach is dedicated to inventive problems, its use in the issue described in section 2 will help increase performance.

The design process has been presented in [2] as the evolution of a concept through four main steps: task clarification, conceptual, preliminary and detailed design. A resulting field of current research known as “concurrent engineering” [16,18] aims at helping designers perform all these design steps as simultaneously as possible, requiring cooperative design teams to take into account different points of view. The product and manufacturing process should be designed simultaneously [3], reducing needed time, and enhancing quality [10]. This simultaneous design is only possible with a clear representation of the links between the evolving part concept and the evolving mold concept.

Research in injection molding design usually does not make room for simultaneous part and mold design, studying either part design [4,8,11], or mold design [11,12,14]. Hence, concurrent engineering research still needs to be developed in this area.

As little research has been performed to integrate OTSM-TRIZ within concurrent engineering, the issue described in section 2 cannot yet easily be solved. A new way to model the part and the manufacturing process, through the known design steps [2], using the OTSM-TRIZ principles [9] must therefore be developed. The model requirements are: to integrate OTSM-TRIZ in concurrent engineering, to focus inventive design and to store links between part and manufacturing processes.

3.6.4. A New Model for the Design Problem

We present here our contribution based on inventive redesign with product and tool parametric modeling, as introduced in [7,13].

Parametric Model of the Design

Routine design is usually what engineers begin with; if the result is not satisfying enough, they think in terms of inventive design. Therefore, routine design has been chosen as the representation from which we will shift to inventive design. Routine design can be seen as assigning values to a set of design parameters describing a generic product or tool. These parameters can be quantitative or not, and more or less fuzzy (for example: gate diameter, part position in mold, material entrance location). These parameters belong to the four stages of concept definition proposed in [2]. We consider therefore functionality, working principle, structure, and detailed dimensions as parameters of the concept. This parametric point of view has been chosen to fit the contradiction presented in Figure 3.6.2, and differs from the axiomatic model developed in [17] as precedence links between parameters are kept, and more than one entity is considered (the part and the mold).

These design parameters influence what we call “need parameters”. Fixing a value to each of the former is done according to this influence and the desired value of the latter. For example, the value “low” is assigned to the detail level design parameter “Feature size” because it influences the need parameter “Amount of material” whose desired value is “low”. As a consequence, the design parameters of any design stage can be linked when they influence the same need parameter (being then part of the interaction area presented in Figure 3.6.1). For example, the “Feature relative positions” of the plastic part and the “Undercut release mechanism” of the mold are linked as they both act on the need parameter “Ejection deformation”. Hence, assigning a value to each design parameter is done according to at least one need parameter it influences, and to the values of possibly linked design parameters. Routine design can now be seen as assigning values to a set of design parameters, in order to obtain the best ranking of a set of need parameters. Having presented routine design with part and mold design parameters as well as need parameters, we have to explain how to answer the need detailed in section 3.6.3.

Parametric Model of the Problem

Invention is needed when the performance of routine-based design is not satisfactory. We first explain this problematic situation with our parametric modeling detailed in the section on Parametric Model of the Design.

The global need "Reach a high global performance" is what the design process should answer. It can be decomposed into a few "local needs", each being a set of desired values of need parameters (introduced in the section on Parametric Model of the Design). "Local solutions", the changing values of design parameters (introduced in the aforementioned section), answer those local needs one by one. Low performance can, therefore, be explained as follows: when local solutions require inconsistent values of the same design parameter, it is given a value that harms need parameters "neither too much, nor too few". In such cases, the sum of local solutions is not the solution to the global need (see **Erreur ! Source du renvoi introuvable.**).

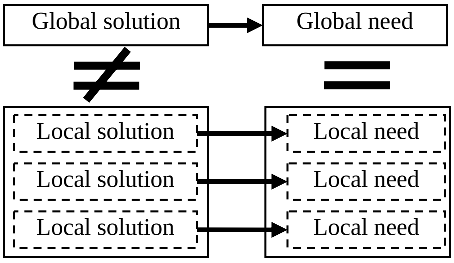

Figure 3.6.3 Global problem: the sum of local solutions does not answer the global need

The following clarified definitions introduce our problem representation:

- The local solution is a real design action that changes the values of a set of design parameters (such as "mold feeding technology", "number of cavities", "feature thickness", "location of material entrance on part", "cooling channels layout"). When a global problem arises, local solutions are "partial";
- Local need is a level of real satisfaction, represented as desired values of a set of need parameters (such as "sink marks," "cycle time," "amount of plastic material," "mold life time"). They are influenced by design parameters;
- An intermediary parameter is influenced by either a design or another intermediary parameter and influences either another intermediary or a need parameter (for example: "cavity depth," "skin viscosity," "mold core strength");
- The route from a design parameter to a need parameter is the sequence of intermediary parameters between them.

Consequently, we formulate the global problem (**Erreur ! Source du renvoi introuvable.**) as: design parameters (De.P.) influence need parameters (N.P.), directly or through intermediary ones (I.P.), within a complex network;

inconsistencies between desired design parameter values create the global problem. The base pattern and an example of a network are given in Figure 3.6.4:

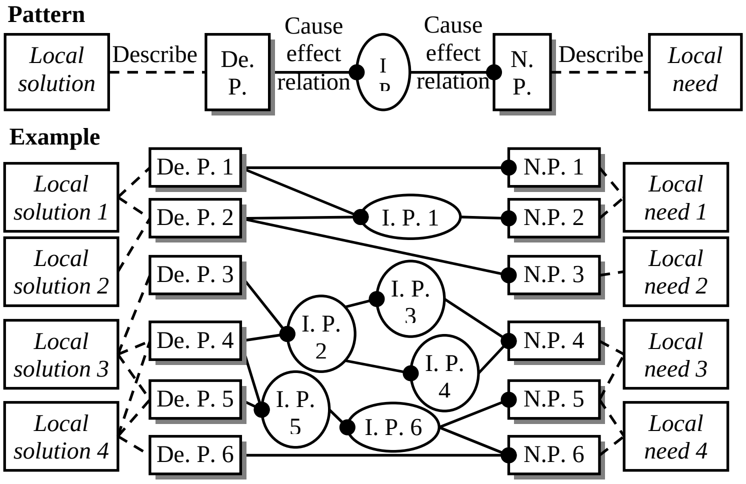

Figure 3.6.4 Pattern and example of complete network

The first advantage in decomposing the link from design to need parameter is the clear representation of connections between design parameters. For example, in Figure 3.6.4, DeP.1 and DeP.2 are connected because they both influence IP.1. The second advantage is the description of ways to break this connection if required:

- Break the effect of DeP.1 on I.P1, or the effect of DeP.2 on I.P1;
- Break the effect of I.P1 on NP.2, and create DeP.7 to influence NP.2.

The model shown in Figure 3.6.4 can be used to describe the reason of low performance design with our parametric model standpoint. In section 5, its use for OTSM-TRIZ based concurrent engineering (see section 3.6.3) is presented.

Application of the Model

We present here how the model shown in Figure 3.6.4 fits the requirement listed at the end of section 3.6.3.

Integrate OTSM-TRIZ in concurrent engineering

The representation proposed in Figure 3.6.4 enables us to find contradictions present in the design process. They are the set of different values each design parameter should be assigned in order to enhance need parameters. All along the process, designers can choose whether to solve them with TRIZ or not.

Focus inventive design

The representation proposed in Figure 3.6.4 enables us to identify the "root parameter," a design parameter, which influences the greatest number of need parameters. As its value is a key issue in the global need described in the section on Parametric Model of the Problem, the redesign task has to focus on it. It bears a poly-contradiction; it should have many inconsistent values to achieve many local needs. As it describes a certain functional physical element, pointing out routes to be kept and routes to be broken (to solve this poly-contradiction) facilitates the description of the inventive functional mean to be developed.

Store links between part and manufacturing processes

The representation proposed in Figure 3.6.4 enables us to store the need parameters linking part and mold design parameters. A need parameter links two design parameters if they both influence it. It eases the introduction of concurrent engineering and clarifies the interaction area shown in Figure 3.6.1.

3.6.5. Validation in Injection Molding

We show in this section how our contribution is applied to a case study taken from the practicing engineer handbook [6] , p.123. The part, half presented in Figure 3.6.5, is a valve stem used to adjust water flow rate. The thread is released by rotating the part thanks to zone B, and the undercut groove by the slidings. The mold is made up of three plates, and a long core-shaped A zone. The global performance is not satisfying (mold complexity, scrap, absence of core cooling increasing cycle time and defects).

Following the steps outlined in section 3.6.4, the required invention and the effects of this case study on later concurrent engineering are explained below.

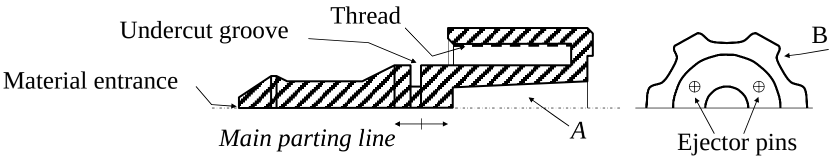

Figure 3.6.5 Plastic part

Parametric Model of the Design

Analyzing some designs shown in [6], we listed the routine design parameters of part and mold. The design steps proposed in [2] (Task clarifying, conceptual, preliminary and detailed design) are used to classify the parameters. Their values have been identified for the case study, and some of them are shown in Figure 3.6.6 and Figure 3.6.8. They are the basis of the problem model.

Parametric Model of the Problem

Need parameters have been identified by listing and analyzing the advantages and disadvantages of the part and mold design, as well as of routine alternative solutions. They have been grouped into five local needs. Current design parameters, whose values can be changed in order to answer those local needs, have been grouped into five corresponding typical local solutions. The complete network, presenting design parameters linked by need parameters and intermediary parameters, is shown in the appendix. This gives a precise evaluation of the global performance of the case study and helps to point out the inventive redesign task to increase it.

Application of the Model

We present how the complete network built in the previous section is to be used.

Integrate OTSM-TRIZ in concurrent engineering

Contradictions (see Figure 3.6.2) exist between need parameters (technical) and design parameters (physical). They are found by analyzing the network built in the section on Parametric Model of the Problem. We partly show them in Figure 3.6.5. presenting the values some design parameters should be assigned to satisfy some need parameters. For example, the “core cooling channel” should not exist at all to have good “mold manufacturability”, but, in order to avoid “shape changes after 24h”, it should be exactly consistent with the core cavity shape.

The presented contradictions have to be dealt with during the concurrent engineering process.

Focus inventive design

The root parameter influencing the greatest number of need parameters is “core cooling channel layout”. This parameter has the greatest effect on the global performance, and the corresponding functional mean has to be changed to raise it to a satisfactory level. Related routes, taken from the complete network built in the section on Parametric Model of the Problem, are shown in Figure 3.6.7 (for example, the core cooling channel layout influences cavity surface temperature, which influences specific volume homogeneity, which, in turn, influences warpage):

	Cycle time	Mold complex.	Mold robust.	Mold life time	Mold manufac.	Water leakage	Amount of scrap	Ejection deform.	Shape changes-24h
MOLD Conceptual level									
Cavity numbers	Max	Min.							
Mold struct.	Two plates	Two plates	Two plates	Two plates					
Feeding techno.		Cold runners					Hot runners		
Under-cut release mech.		No one	No one	No one		No one		At least two	
MOLD Preliminary level									
Core cooling channel layout				No one	No one	Around slide		Close under core surface	Close under core surface
Fixed cooling channel layout						Around slide		Close under fixed surface	Close under fixed surface
Part position in mold		Min. cavity depth		No under-cut				No under-cut	
MOLD Detailed level									
Gate diameter								Small	
PART Preliminary level									
Special feature								No one	
Feature relative position				Large distance between them	Large distance between them			Give rigidity	
PART Detailed level									
Feature size		Short						Thick	

Figure 3.6.6 Contradiction table

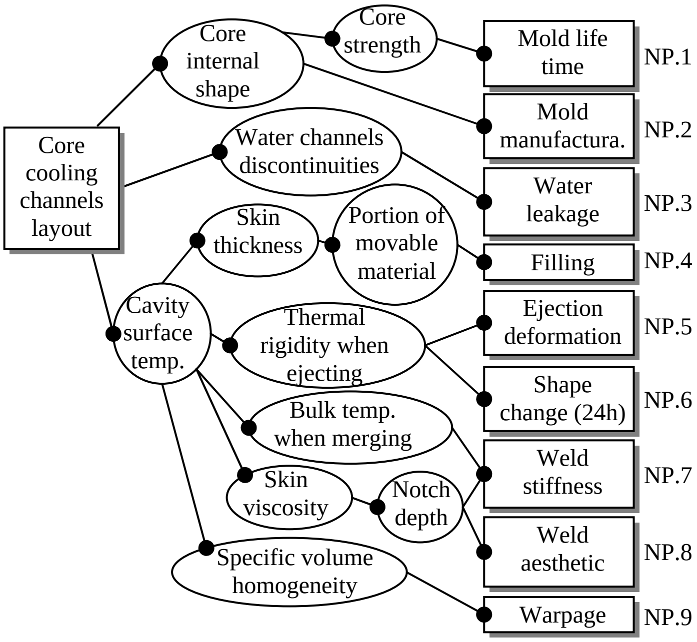

Figure 3.6.7 Need parameters linked to the most influencing design

The function of the core cooling channels is to rigidify the melted plastic after it has been correctly shaped. It is realized by running water in holed metal. The inventive functional mean has the following description:

- Do not change core internal shape (NP.1 and 2);
- Avoid any channel discontinuities (NP.3);
- Do not increase skin viscosity and thickness before end of filling (NP.4,7,8);
- Give thermal rigidity when ejecting (NP.5,6);
- Do not reduce bulk temperature before merging (NP.7);
- Increase specific volume homogeneity (NP.9).

Classical TRIZ tools can be used to further develop this description.

Store links between part and manufacturing process

This case study has identified a first vision of links between part and mold. They are shown in a chart where need parameters connect part and mold design parameters.

	PART P. level			**PART D. level**
	Special feature	Feature relative positions	Material entrance location	Feature size
MOLD C. level				
Number of cavities				Mold complex.
Mold structure		Mold life time	Runner fillability	Mold complex.
Feeding technology			Filling	Mold complex. Filling
Undercut release mechanism	Ejection def.	Mold life time Ejection def.		Mold complex. Ejection def.
MOLD P. level				
Core cooling channels layout	Ejection def.	Mold life time & manufa. Ejection def. Weld stiffness & esthetic Warpage	Weld stiffness & esthetic Warpage Filling	Ejection def. Warpage Filling
Fixed cooling channels layout	Ejection def.	Ejection def. Weld stiffness & esthetic Warpage	Weld stiffness & esthetic Warpage Filling	Ejection def. Warpage Filling
Part position in mold	Ejection def.	Mold life time Ejection def.	Runner fillability	Mold complex. Ejection def.
MOLD D. level				
Gate diameter			Jetting & Filling Sink marks	Jetting & Filling Sink marks

Figure 3.6.8 Couples of parameters linked by common need parameters

For example, this chart can be used to know beforehand that if a “special feature” (like a thread) is added to the part, the “part position in mold” must be verified (because of their common effect on “ejection deformation”). The values of those parameters should be determined simultaneously.

3.6.6. Conclusion and Perspectives

We have shown in this paper a new model of part and tool in injection molding, based on four entities: part design, mold design, intermediary and need parameters. We have given guidelines to apply the model in order to converge the unsatisfying routine-based design into a single inventive redesign task, and to store data for later OTSM-TRIZ based concurrent engineering.

Even if our results are already applicable as shown in a case study, further research has to be performed in the following directions:

- Test other rules to identify the root parameter, and to find the most effective way to increase performance (Focus Inventive Design section);
- Clarify the frontier between generic and specific contradictions shown in the Integrate OTSM-TRIZ in concurrent engineering section, to focus the general applicability of our model.
- Adapt classical TRIZ tools to our model, in order to integrate problem solving approaches rather than only formulating them.

APPENDIX

The network of local needs and solutions, design, intermediary and need parameters is presented below.

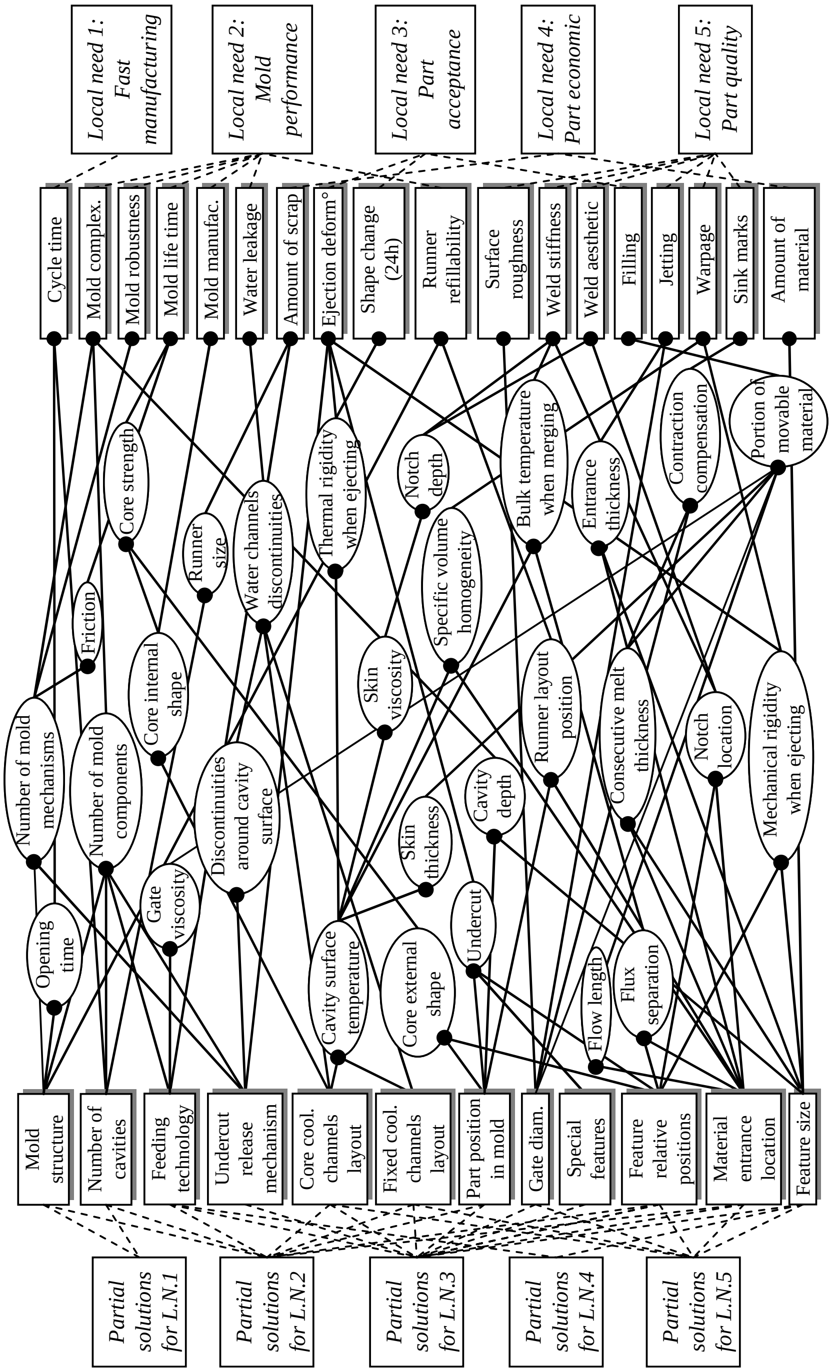

Figure 3.6.9 Complete network based on the specific case-study

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