Obtaining new products in the PVC/AL joinery industry applying the TIPS method - case study

V A Ciubotariu¹, C M Radu¹, C C Grigoraș² and V Zichil²

¹ Vasile Alecsandri University of Bacau - Romania, Department of Engineering & Management of Industrial Systems, Calea Marasesti, No. 157, 600115, Bacau, Romania
² Vasile Alecsandri University of Bacau - Romania, Department of Engineering and Management, Mechatronics, Calea Marasesti, No. 157, 600115, Bacau, Romania

E-mail: vlad.ciubotariu@ub.ro

Abstract. Obtaining a new product, in the current stage, can no longer be achieved by waiting for it by chance, as it happened in the past, but by systematically, perseveringly, and scientifically looking for it. This paper is a case study on the application of a systematic methodology for generating solution concepts in the case of the PVC and AL joinery accessories industry. Considering that one of the requirements was that the new connector part should mount on several standardized profiles, by approaching the TIPS tools kit, a modular connector with superior strength characteristics (3%) and low complexity was obtained. Also, by rethinking the product, a reduction of 15% of the required material (PA type 6) was obtained, as well as a decrease of approximately 11% of the tools costs necessary for the manufacturing process. For the preliminary evaluation of the new product, finite element analysis was necessary and the SolidWorks Simulation 2019 software was used. The numerical data was compared with the experimental data provided by the beneficiary, the differences being within the limit of 3.5%. These data encourage the beneficiary to study in detail the new product from several points of view, considering the option of introduction into manufacturing.

1. Introduction

Product design / development engineers are accustomed to paradox, ambiguity and contradiction. Any technical problem has at least one contradiction and for many people it remains unnecessarily associated with uncertainty, difficulty of choice and compromise. This is unnecessary because there are a finite number of practical solutions to any contradiction, namely 40 Inventive Principles for solving problems [1]. A contradiction is a conflict between solutions, where solutions with opposite effect are desired, or if one solution improves one feature of the system, another will undergo negative changes to it. When a function of a system is presented as a good solution and the adverb conjunctive "but" is used, it means that something is wrong in that system.

The Theory of Inventive Problem Solving (TIPS), which is applied in this study, is a method specific to engineering fields where a systematic methodology for generating solution concepts is proposed. Therefore, two types of contradictions are considered: (a) technical contradictions: improving a characteristic, but another is worsening; (b) physical contradictions: opposite solutions are desired. Physical contradictions are solved by separating features in different ways that ensure the existence of both effects. Solutions can be separated according to time, space, size and condition [2].
To solve contradictions, the TIPS method holds two extremely powerful and intercorrelated tools that cannot be used without one another: *Contradiction Matrix* which is based on 39 technical parameters, used to solve technical contradictions, as in the initial version created by G Altshuller [1] or 48 technical parameters, as in the later versions of the method [3]; *40 Inventive Principles*, used to solve physical contradictions and should be separated according to the four characteristics mentioned above.

Joinery involves the action of combining pieces of material to produce more complex products. Some joints use fasteners, binders or adhesives, while others use only elements of the material. The characteristics of these joints are strength, flexibility, appearance, etc. and derives from the properties of the materials involved and the purpose of the joint. Therefore, different joinery methods are used to meet different requirements [4, 6]. For example, the joinery used to build an enclosure may be different from that used to make windows or doors, although some concepts overlap.

PVC and AL are perfect materials suitable for joineries. As a matter of fact, internal and external joineries are under the control of various types of aggression, such as bad weather, repeated handling and other types of stresses [5]. Careful choice of a good material is essential. Indeed, PVC has a high thermal, phonic and safety performances. Moreover, PVC withstands the most difficult climatic conditions and adapts perfectly to external joineries [6, 7].

Each product has an impact on the environment, and not only, throughout its life cycle. One of the main challenges for product designers is the lack of tools to incorporate environmental decisions in their designs [3]. This study aims to develop a new product, with superior strength characteristics, with a reduced geometric complexity using the TIPS principles. Throughout the product design activity, a lower geometric complexity leads to much simpler tools and devices. This has a considerably reduced impact on several components of the environment or the economy.

2. Problem context and discussion

A local manufacturer from the PVC and AL joinery industry requested that on the basis of an existing product to obtain a component that meets all the requirements imposed by this industry, but be very versatile in terms of mounting on at least three profiles made by established manufacturers in the field.

Thus, for a product in the group of accessories used in PVC and AL joinery – connector – the possibility of mounting it on several standardized profiles is achievable by fastening it using screws or clips. These components must also ensure the necessary strength in operation without excessive consumption of materials or cost of tools and devices required for their manufacture.

The original part offered by the local manufacturer is a connector like the one shown in figure 1. This connector is generally used in the case of mounting PVC poles on assemblies that include AL sills. The requirement is to obtain a product which matches at least three different arrangements.

![Figure 1. Type of connector made of PVC used in the case of screw mounting of PVC poles on assemblies that include AL sills.](image)

Before exposing the problem, the manufacturer had two approaches: a new product could be made by additive manufacturing, but the production cost was much too high or the adaptation of existing products by further processing, but the appearance of the finished product was far from being satisfactory for the required level of quality.
There is a desirable needed characteristic – versatility – that appears to be associated with something costly or unwanted – weight or shape complexity – which in the field of TIPS that is a contradiction. It would appear that we are constrained to remain on a compromise area. Ideally it is wanted a component that has both good versatility and low weight or shape complexity.

3. TRIZ approach for solving the problem

In this case-study, it was decided to use one of the classic tools from the TIPS toolkit for solving contradictions: the Contradiction Matrix (figure 2). The method is a three-step systematic process [1]:
- identification of the contradictions in the problem;
- using a statistically derived look-up table – the Contradiction Matrix – to determine which generic Inventive Principle have been successfully used in the past to solve contradictions of the generic type of those in the present problem;
- taking the generic Inventive Principles suggested and apply them to the present problem.

3.1. Identifying the contradictions

In the present case-study, two initial technical contradictions were identified: a versatile product but not heavy and a versatile product which has no complex shape.

For the second contradiction it could be asked why the product has a complex shape. The answer may be related to the arrangement of the assembly where the part has its functionality or to the tools and devices used in the production process. This in turn suggests the possibility of yet another type of contradiction added to the problem: a product that is versatile but not expensive to manufacture.

These contradictions can be expressed as a graph, which typically takes the form presented in figure 3. As the versatility of the possible product is improved (marked by the “+” sign) the weight or complexity of it becomes worse (marked by the “–” sign), and the other way around. The general idea of the method is to obtain a solution which finds itself under the curve and ideally closer to the area where the two “+” signs are shown.

3.2. Using the Contradiction Matrix

Before the contradiction matrix can be used it is necessary to map the specific parameters – versatility, weight, complexity – onto the generic parameters used by this statistically derived look-up table. In the present study, the contradiction matrix is not explicitly shown because of its large display. For this particular case it was not very difficult to arrive at an appropriate mapping as:
- Versatility matches element number 35 from the Contradiction Matrix as adaptability or versatility;
- Weight matches element number 2 as weight of stationary object;

![Figure 2. TIPS - Contradiction Matrix [9]](image)

![Figure 3. Possible compromise solutions [1]](image)
- Shape complexity matches both element number 12 as *shape* and element number 32 as *ease of manufacture*.

Thus, the three real-world contradictions, when mapped onto matrix parameters become: adaptability or versatility vs. weight of stationary object, adaptability or versatility vs. shape and adaptability or versatility vs. ease of manufacture. Each of these contradictions are used with the Contradiction Matrix to obtain suggested Inventive Principles.

### 3.2.1. First contradiction

In this particular case the improving parameter or what is wanted to get better is *adaptability or versatility* and the worsening parameter or that is wanted not to get worse is *weight of stationary object*. These two parameters are used to cross-index the Contradiction Matrix to obtain the following four Inventive Principles that statistically have been found to be the most successful ways of obtaining good results [1]:
- *Periodic action* where the separation principle for solving the physical contradiction is *time*;
- *Dynamics* where the separation principle for solving the physical contradiction is *time*;
- *Pneumatics and hydraulics* where the separation principles for solving the physical contradictions are *time* and *condition*;
- *Partial or excessive action* where the separation principle for solving the physical contradiction is *time*.

### 3.2.2. Second contradiction

What is wanted to get better is *adaptability or versatility* and what is wanted not to get worse is *shape*. These two parameters are used to cross-index the contradiction matrix to obtain the following four Inventive Principles that statistically have been found to be the most successful ways of obtaining good results [1]:
- *Dynamics* where the separation principle for solving the physical contradiction is *time*;
- *Thermal expansion* where the separation principle for solving the physical contradiction is *time*;
- *Segmentation* where the separation principles for solving the physical contradictions are *space*, *time* and *scale*;
- *Anti-weight* where the separation principle for solving the physical contradiction is *scale*.

### 3.2.3. Third contradiction

In this particular case the improving parameter is *adaptability or versatility* and the worsening parameter is *ease of manufacture*. These two parameters are used to cross-index the contradiction matrix to obtain the following three Inventive Principles that statistically have been found to be the most successful ways of obtaining good results [1]:
- *Segmentation* where the separation principles for solving the physical contradictions are *space*, *time* and *scale*;
- *The other way around* where the separation principles for solving the physical contradictions are *space* and *scale*;
- *Porous materials* where the separation principle for solving the physical contradiction is *condition*.

### 3.3. Applying the suggested Inventive Principles

Having derived some suggested generic Inventive Principles, the next task is to apply these to the particular problem. This is part of a recurring theme in TRIZ where the specific problem is extracted, it is generalized in order to access known generic solutions and finally the general solution is applied to the particular problem.

As Inventive Principles *Segmentation* and *Dynamics* were suggested by the Contradiction Matrix twice, particular attention was given to this as a solution trigger for this problem. The following step in the problem-solving process is to fully understand these suggestions. The names of the 40 Inventive Principles are just convenient labels and it is important to appreciate the full definition of each principle before attempting to apply it.

Analyzing the first inventive principle – *Segmentation* – it must be taken into account that it refers mainly to the following:
- division of an object into independent parts;
- making an object sectional – easy to assemble or disassemble;
- increase the degree of fragmentation, etc.

In the same way, the second inventive principle – *Dynamics* – refers mainly to the following:
- change the object or outside environment for optimal performance at every stage of operation;
- divide an object into parts capable of movement relative to each other;
- change from immobile to mobile;
- increase the degree of free motion, etc.

Following the analysis and revision of all the suggestions extracted from the Inventive Principles, a potential solution materialized in the construction of a connector consisting of two distinct components, each having its role in the final assembly. The two components are assembled to each other by using clips, and through a smaller number of screws the final assembly that includes both the PVC pole and the AL sills is made.

Because the local manufacturer indicated the fact that the interior vertical restraint of the initial part is actually not necessary and makes the assembly sequences mandatory in a specific manner, the new product has no such restraint, making the tools necessary in the manufacturing process much simpler, therefore more efficient cost wise.

The modular connector proposed to solve the local manufacturer's problem is shown in figure 4, and an overall example in which the proposed solution could be integrated is shown in figure 5.

![Figure 4. Modular connector proposed as solution for the problem in discussion.](image1)

![Figure 5. Example of assembly in which the modular connector could be integrated in.](image2)

4. Numerical evaluation of the new product

Regarding the in-service behaviour of the new product, the aim was to carry out a comparative study between the data provided by the local manufacturer and those obtained by using finite element analysis. The numerical evaluation was performed through the SolidWorks Simulation 2019 module, which is an extension to SolidWorks package.

Given the fact that the local manufacturer has requested certain tests to verify the behaviour of the proposed product, the following are the general data included in the finite element analysis. Therefore, at the suggestion of the local manufacturer, the new product was subjected to just two analysis as follows: a nonlinear static analysis and a drop test study.

The comparison between the two products takes into account the mass of the components, the complexity of the geometric elements and the results obtained from the numerical analysis.
4.1. Simulation setup
The material used by the local manufacturer for such components is generally PA Type 6. The mechanical properties of this material are shown in table 1. The material in question is a polymer assumed to be linear elastic isotropic.

In the case of the nonlinear static analysis the boundary conditions are shown in figure 6 for the initial part and figure 7 for the proposed part respectively. The curve which best describes the time varying load applied on the analysed parts is shown in figure 8. The constraints are applied to all screw holes intended for fastening onto the support assembly.

| Property               | Value | Units  |
|------------------------|-------|--------|
| Elastic Modulus        | 2620  | MPa    |
| Poisson’s Ratio        | 0.34  | -      |
| Shear Modulus          | 970.4 | MPa    |
| Mass Density           | 1120  | kg/m³  |
| Tensile Strength       | 103.65| MPa    |
| Yield Strength         | 90    | MPa    |
| Thermal Conductivity   | 0.233 | W/(m·K) |
| Specific Heat          | 1601  | J/(kg·J) |

Figure 6. Boundary conditions for the analysis of the initial part
Figure 7. Boundary conditions for the analysis of the new proposed part
Figure 8. Time curve for nonlinear variation of the load applied on the vertical restraints of both types of analysed parts.
A curvature-based mesh was used and the specific parameters were as it follows: maximum tetrahedral element size was 4 mm, minimum element size was 0.8 mm, minimum number of elements in a circle was 8, the element size growth ratio was 1.6 and the number of Jacobian points was 16.

Regarding the modelling of the new proposed part, two components were used. The contact conditions between these two components are of the “no penetration” type, taking into account a coefficient of friction of 0.2. The mesh interaction between the components is of the "surface to surface" type.

Regarding the drop test analysis, the time varying stresses and deformations due to an initial impact of the part with a rigid planar surface are calculated. As the part deforms, secondary internal and external impacts are also calculated, locating critical weaknesses or failure points, as well as stresses and displacements. The maximum gravitational force equivalent, or g-force, experienced by individual part is one of the primary unknowns before a drop test. This is a critical parameter since many mechanical parts are not rated for further use above a specific maximum g-force. Therefore, the time varying accelerations at any location within the part can be measured [8].

In the drop test study, the height from which the parts are dropped on a rigid floor is considered to be 1500 mm from the centroid of the part. The only loading applied on the parts is the gravity. Both products were considered to be dropped on the side towards the aluminium sill.

4.2. Results and discussions

Regarding the quantity of material used for designing the new part, the software estimate is 16.10 grams in comparison with the initial part which has 19.02 grams. Therefore, the new part uses with 15.35% less material.

Taking into account the input size of tetrahedral elements, the initial part was discretized with a total number of 19956 elements, while the new part was discretized with a total number of 17373 elements.

In the case of nonlinear static analysis, both connectors were subjected to the same loading cases. Figures 9, 10 graphically describe final results of the analysis regarding von Mises stress. Even though the new modular connector has only 2.72 MPa decrease in stress values (96.68 MPa) as opposed to the initial part (99.40 MPa), the decrease in weight also suggests better results in operation. An explanation for this can be given based on the asymmetry of material distribution, especially in the case of the original part.

Numerical analysis does not detect any stresses affecting the sitting surface of any of the products. The final results of the analysis regarding displacements indicate that the new part has a maximum displacement of just 4.01 mm, while the initial part has a maximum displacement of 7.32 mm. Therefore, a decrease of about 44.8% of the total displacement was obtained with the new part.

![Figure 9. von Mises stress result in nonlinear static analysis of the initial part.](image-url)
Figure 10. von Mises stress result in nonlinear static analysis of the new proposed part.

Regarding the drop test analysis, figures 11, 12 graphically describe final results of ESTRN: Equivalent Strain. Lower maximum strain values found (0.035) suggest that the new part seems to be stiffer. This effect may occur due to the lower overall mass of the new part as well as the somewhat symmetrical distribution of mass over the entire width of it.

The maximum values of displacement caused by the drop, show that the new part presents 5.26% higher values (0.40 mm) than the original part (0.38 mm).

Figure 11. ESTRN: Equivalent Strain in drop test analysis of the initial part

Figure 12. ESTRN: Equivalent Strain in drop test analysis of the new proposed part

5. Conclusions

The decrease with 15.35% in weight of the new modular connector and the decrease in stress values with 2.73% as opposed to the initial part, suggests better results in operation of the new product in terms of the loading generated by the PVC column. Also, from the drop test analysis, the decrease with 35.16% of the maximum strain values found suggests that the new part seems to be stiffer.

The local manufacturer analyzed the proposal for the new product and estimated a cost of production tools with approximately 10.8% lower in comparison to those used for the initial product. Also, from the experimental tests, the company concluded that the difference between experimental and numerical analyzes is between -1.28% and 2.22%.

Therefore, by using certain elements of the TIPS method, such as the Contradiction Matrix and the 40 Inventive Principles and also taking into account the requirements of the beneficiary, a new modular product with superior technical characteristics and much better economic efficiency was possible to obtain.
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