INTEGRATION OF HUMAN COGNITION INTO PLASTIC PRODUCTS' DESIGN
A Decision Support System

Urška Sancin and Bojan Dolšak
Faculty of Mechanical Engineering, University of Maribor, Smetanova ul. 17, SI-2000 Maribor, Slovenia

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Abstract: Product development process is knowledge intensive engineering task mainly supported by adequate computer aids. Decision-making is a part of design process and almost never supported by computational advice or recommendation to specific design aspects. This paper is orientated at deficiencies in material selection process within a new product development process. General practice in major enterprises is represented and the contribution of proposed intelligent decision support system is introduced. Its execution and integration of human cognition in the field of Design of Manufacturing (DFM) and plastic products' design are also explicated in this article.

1 INTRODUCTION

Engineering work is computer dependent as computer aids are used from start to finish of design process. Product development is also very intensive decision-making process as designer has to provide numerous decisions in order to achieve optimal solutions and finally to present a trade product. Achieving maximal quality at minimal cost is a goal of every prosperous enterprise participating in the market. Designers are often under pressure as they have to justify management's trust in new product also supported with diverse tools for selecting and evaluating the projects (Palcic and Lalic, 2009).

Today, the computer aids available on the market does not support the designer in decision-making, although, they are of great importance to engineering design steps like drafting, modelling, analyzing, and simulating. Designers face many dilemmas linked with various aspects of the product. Thus, compromises have to be considered at every design step. In order to create as optimal compromises as possible, designers have to possess wide range of knowledge and be aware of all influential parameters, or alternatively a team of experts in various fields has to collaborate in development process (Clarkson and Eckert, 2005).

This article presents an explanation of design problems, appearing due to the difficulties at decision-making process, all collected in Section 2. Section 3 is orientated in plastic products' design, including current state analysis and presentation of the expected behaviour for some similar type of polymers by comparing one or two their technical parameters. Section 4 represents the execution of proposed intelligent decision support system for plastic products' design.

2 NEW PRODUCT DEVELOPMENT PROCESS

A product development process is also a decision-making process. The engineer has to choose the proper tools when performing the design process, such as selecting the adequate software for the initial problem and, more importantly, he or she has to make several decisions whilst working with these tools, in order to achieve an optimal solution. Human cognition plays the key role in product development, as knowledge domain is crucial during decision-making process.

Aiming to world-class product production, the enterprises congregate the experts with expertise on several different knowledge domains. The expert

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team is often numerous due to the complexity of the product as their knowledge is desirable in diverse aspects of design:

- at selection of material, tool, production process, etc.,
- at performance of analyses and simulations, at their evaluation, and consequentially, design modifications,
- at Design for X, where X resembles the appropriateness for manufacturing, maintenance, service, etc. (Huang, 1996).

Experts' cognition is a support to designer during processing though the four phases of design: task clarification, conceptual design, embodiment design, and detail design. More developed and well-provided enterprises are in better position in correspondence to Small and Medium-sized Enterprises (SME's), whose economic status does not enables hiring an expert to cover a specific design aspect.

3 PLASTIC PRODUCTS' DESIGN PROCESS

3.1 Current State Analysis

Engineer's contribution to a design results as a functional and user friendly finished product, meaning an ergonomic and aesthetic product, supported by adequate technical background. In enterprises, it is a common practice to divide a product development process into two parts:

- *ergonomic and aesthetic design*, where the outer surface is designed by industrial engineer (Gordon, 2003),
- *functional design*, where all technical criteria, along with requirements and conditions, are considered, and the process is performed by design engineer

This article is oriented into functional design, where the material selection phase is of supreme importance, therefore the ergonomic (Kaljun and Dolšak, 2006) and aesthetic values, although their contribution is not marginal, are not discussed here.

After research was made in several Slovenian world-class enterprises involved in plastic products' manufacturing, the conclusions were unexpected but also reasonable. What is obvious, the material selection within a new product development, can be characterized as Selection by Synthesis (Ashby and Johnson, 2005) where design requirements appear in the form of intentions, features, and perceptions. This method is used, when knowledge of the solved cases can be exploited and transferred to other products with some features in common. In other words, the product with the same significant attributes can be used as a template. Preconceptions about the material used may be logical in some cases, as also the shortcut to the solution, however, the creativity and innovation are degraded here.

Figure 1 illustrates the product development process resembling the situation in most enterprises included in this study. Design engineers have expert knowledge about some particular materials, extensively applied in the industry, in which the company participates. Thus, the preliminary material selection is a decision without irresolution.

The design process starts with the outer design introduced by various 3D computer models performed by an industrial designer. Computer models are supported by 3D prime models produced using rapid prototyping, with the aim of evaluating the ergonomic and aesthetic design of the product. After adjustments, the most appropriate variant gets the experts' approval so the product progresses into the most complex and time consuming phase, functional design. The design engineer studies the design requirements consisting of technical criteria, safety requirements and the wishes of the management. The completed product design can again be represented by a rapid prototyping prime model in the form of a completely functional exemplar, often made of the material resembling the preliminary selected material for the finished product. Due to this fact, the testing and measuring is possible and any necessary adjustment can be performed accordingly. At this point of the design process, the designer usually provides a modification of the material based on past experiences in plastics' design. The next step includes casting simulation upgraded with appropriate production process selection and tool design, where technical parameters should be defined by considering the selected material. Casting simulation is repeated until the design engineer approves the production appropriate solution.

From Figure 1 it can also be acknowledged that without preconceptions about material selection, the material could be modified more than once throughout the product development process, as new information about the product appears at every phase of design.

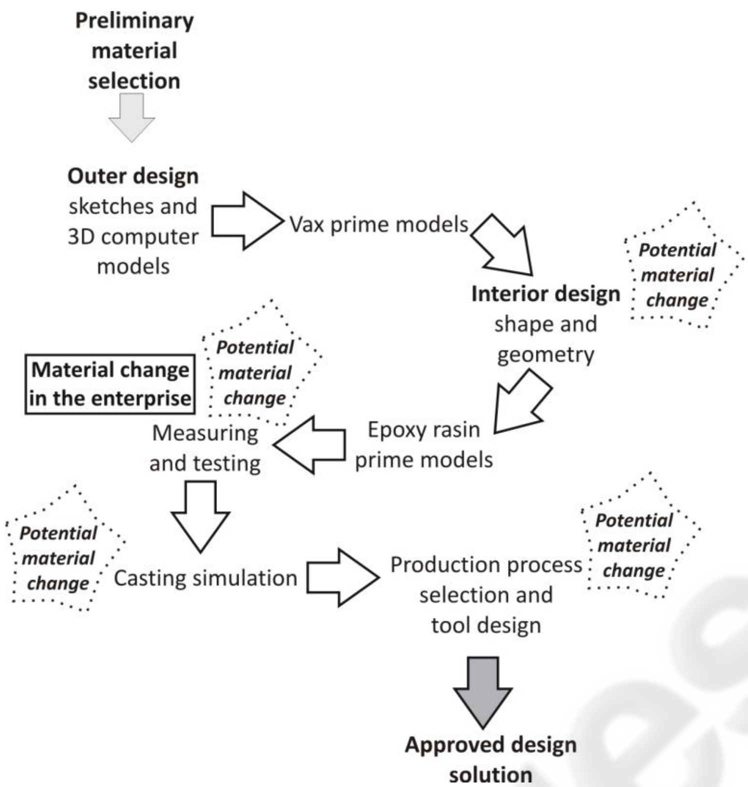

Figure 1: Potential material changes in plastics design process.

Furthermore, in every stage of design the potential material choice could be designated as optimal at that point of the design process.

In other words, if the technical and aesthetic attributes of potential material are more appropriate, the design is affected and, as a consequence, the production price could be reduced.

3.2 Resembling Polymers – Technical Parameters' Comparison

In present time, more than 120.000 diverse polymers have been discovered, some with specific characteristics, offering the designer a wide range of choices whilst a design process (Ashby and Johnson, 2005). Major difficulties appear at designing as engineers cannot master such extensive amount of polymers' knowledge therefore, they rely upon experiences and their expert knowledge of several already known materials. All this can lead into a questionable material selection decisions, regardless the company's designation as optimal.

There are diverse plastic materials on the market with similar technical features. The scientific research on thermoplastics' technical parameters, made in our laboratory, shows that Actrylometril-butadiene-styrene, abbreviated to ABS, high density Polyethylene (PE), Polypropylene, and Polyamide (also called Nylon) have resembling overall characteristics. However, the range is significantly wider at certain parameters.

As the elastic modulus is a material parameter with high significance to design, it was chosen to be a basis of a comparison of four materials already mentioned. We can observe from the chart at Figure 2 that Polyamide has the greatest extent of elastic modulus values, while Polypropylene has the smallest. Some versions of high density Polyethylene are reaching the lowest values of elastic modulus in contradistinction to the highest Nylon variations. However, all studied materials are well represented in the range between 1.10 and 1.55 GPa. Hence, any query about a material selection based on the Selection by Synthesis is justifiable as no evaluations were done for other competitive materials, such as those included in this study.

Furthermore, all four thermoplastics evaluated here, can be processed by injection moulding (Mok, Chin and Hongbo, 2008, Wang and Zhou, 2000). Due to the size and geometry of the product, injection moulding is often the most appropriate solution as it enables large series production. Another advantage is the ability to produce relatively small and precise plastic products, as low tolerances and slight roughness can be achieved.

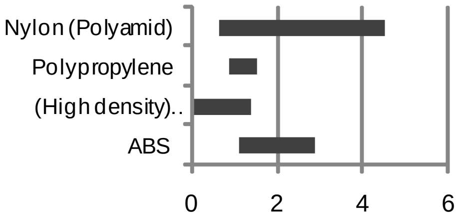

Figure 2: Elastic modulus for thermoplastics [GPa].

In addition, the material price is an increasingly important parameter of the design process, especially in mass production where small savings per part can become significant, when they are multiplied the number of produced parts. The diagram on Figure 3 shows that Polypropylene, high density Polyethylene, and ABS can have a much lower price than some versions of Polyamide.

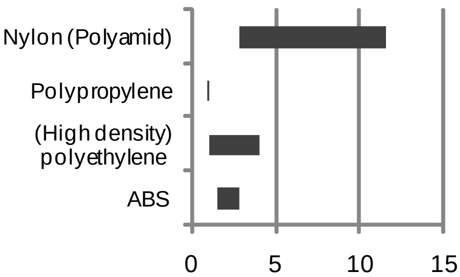

Figure 3: Price for thermoplastics [$/kg].

It is necessary to explain that a higher price is sometimes justified due to the acquisition of other design components of the product, such as e.g. the possibility of smaller wall thickness, which leads to a reduction of the material needed for production of the manufactured goods.

On the other hand, the designer has to evaluate numerous, and for the final product design crucial parameters within the development process by considering all the materials available on the market, with the aim of achieving optimal results, which can sometimes be an almost mission impossible.

Younger inexperienced design engineers have major difficulties regarding material selection, thus, in order to overcome this barrier, the intelligent advisory system for plastic product design is proposed. This computer aid will offer recommendations and guidelines according to the required parameters, shape or/and function of the product and could also be helpful for experienced designers using the system as a verification tool.

4 IMPLEMENTATION OF DECISION SUPPORT SYSTEM FOR DESIGNING PLASTIC PRODUCTS

The decision-making process is a constant for every designer aiming at a successful and efficient performance. Alternatively to experts' acquired domain knowledge, we decided to develop a decision support advisory system (Turban, Aronson and Liang, 2004, Novak and Dolšak, 2008) in order to overcome the bottle neck - plastics material selection (Ullah and Harib, 2008). Figure 4 shows the expected data flow, where input data are a significant factor for intelligent module performance, the results of which depend on knowledge base content. The main objective of the proposed system is a consultancy with the designer in order to obtain the output, containing the most appropriate material for the product application, product design guidelines, etc.

The development methods included in this research are a combination of human cognition in the field of design knowledge (Chen, Sheu and Liu, 2007) and special domain knowledge expertise in the field of plastics. The knowledge base will contain human cognition useful for problem solving in the form of relations considering modern plastic materials' selection and correlated manufacturing processes, assisted by the Design for Manufacturing (DFM) methodology (Molcho, Zipori, Schneor, Rosen, Goldstein and Shpitalni, 2008). Different approaches to knowledge acquisition and the appropriate formalisms for the presentation of acquired knowledge (Valls, Batet and Lopez, 2009) within the computer program will be of special importance

The potential for transparent and modular IF-THEN rules, whose advantage is neutral knowledge representation, uniform structure, separation of knowledge from its processing and possibility of dealing with incomplete and uncertain knowledge, is planned to be compared with more flexible knowledge presentation systems, such as fuzzy logic (Zio, Baraldi, Librizzi, Podofillini and Dang, In press), where fuzzy sets and fuzzy rules will be defined as a part of an iterative process upgraded by evaluating and tuning the system to meet specified requirements.

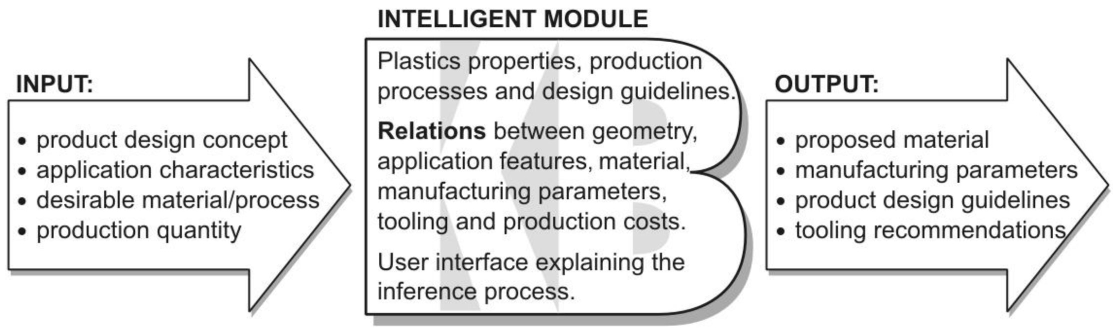

Figure 4: Expected data flow at intelligent advisory system for plastics' design.

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The user interface will be developed with a special attention, in order to enable transparent and efficient system application. Two different application modes have been anticipated, in regard to the type of input and output data. Guided mode (question and answer) will be used mostly at the beginning, when the first set of parameters has to be presented to the system. During the data processing phase, the system may present additional questions or ask for more parameters. In this case, guided and graphic modes will be used to present the problem to the user. The solution in the final phase will also be presented in graphic mode, if possible.

5 CONCLUSIONS

Performed analyses show the unexploited potential of wide spectrum of polymers available on the market. It is a fact, that designers cannot master such extensive amount of plastics' knowledge thus, the consequence is understandable. Usage of Selection by Synthesis method at designing with known, tested plastic materials could results good product with marginal technical and economical risk, nevertheless, the innovation and progress are degraded here. What is more, designers with experiences and expert cognition are favourites in contradiction to young inexperienced designer on the beginning of their careers. They are kept in the background just like SME's as their personnel and financial capacities are not competitive according to leading enterprises on the market.

Acceleration at plastics' discovery and development is enormous and for humans almost impossible to follow. In order to overcome this barrier, the computer software support in the form of decision support system is going to be developed. The decision support advisory system for designing plastic products proposed in this paper is an attempt at collecting, organizing and defining human cognition in form of a knowledge base, and comprehensive data in a data base, in order to build the foundation for an inference engine of intelligent decision support advisory system. Design guidelines and recommendations acquired whilst plastics' design are anticipated to be a major contribution to engineer's work, particularly to decision-making process.

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