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POSSIBILITIES FOR OPTIMAL ASSESSMENT OF ENGINEERING DESIGN

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Abstract. *This article deals with the problems related to the development of design and evaluation thereof in the industrial design of Latvia. It has been detected that evaluation parameters and common methodology, which would result in optimal assessment of a design product, have not been developed. This article also deals with the evaluation criteria of products already developed and used in the USA. Pareto principles and Pareto optimality are also examined.*
It is recommended to develop specific parameters for the assessment of a design product and to use the Pareto method for summarisation of results, as well as to use part of the finalised parameters already developed in the USA.
Key words: *Industrial design, Pareto principle, Pareto optimality, design assessment method*

Introduction. The Baltic States and the Nordic countries are situated in the region with longstanding traditions of industrial design. It is well known that one of the most important economic components of each country is the development of manufacturing. Since the dissolution of the Soviet system this area has been paid insufficient attention in Latvia. It should be noted that recession of the Soviet manufacturing also destroyed many sectors, in which services of artists had been successfully used, creating a visual frame for the relevant engineering products.

Design is frequently associated with misleading stereotypes. It is usually presented in a narrowed sense as the arrangement of a dwelling, public institutions, garden, architectural space or is also associated with area of haute couture.

However, there is also such quite significant area as industrial design. If a manufacturer skilfully uses services of a designer, he or she adds a high added value to his or her production not only in the sense of taste and beauty, but also in tangible sense. The more beautiful the product, the larger market it wins.

There is no uniform system in Latvia for assessment of domestic products. For example, different kinds of competitions for the best product designs in Latvia take place each year; however, the basic assessment criteria in these competitions may vary vastly. This situation causes concern as regards the design assessment competence, which, in turn, may have large impact on future activities of designers and manufacturers. Particularly, if the main prize is participation in some international exhibition, in which the State of Latvia is represented.

The main objective of evaluation of engineering design would be to develop the optimal assessment methodology, which would allow timely prevention of mistakes during the manufacturing process itself and not when the relevant product has already reached the consumer.

Obstacles for the Development of Products of New Design in Latvia. The role of design in an enterprise is to create a value. The enterprise may use the design process to add value to goods, services or organisation itself. A well designed product, service or organisation is more valuable than a product with not as good as design. It has been emphasised in different reports on the development of innovation and new products in Latvia that the level of the development of innovations and new products in Latvia is very low [1].

Most enterprises use their internal competence for the development of new products. If an enterprise works as a sub-contractor for other clients, then the client helps applying its own resources. Consultants and institutions of education and science are rarely used as the resource of competence for the development of new products. Additional resources are

obtained from holdings of international companies, participation in exhibitions, information from suppliers regarding raw materials and co-operation with other enterprises.
Studies on innovation in Latvia allow drawing a conclusion that the co-operation between industry and science/research is very poor. This fact may be regarded as one of the largest obstacles for the development of innovations and products of new design in Latvia [1].

Studies show that there are the following obstacles for the development of new products and innovations in Latvia [1]:

- insufficient information regarding markets;
- restrictions of local market (too small, low purchasing power);
- high costs for development of new products and insufficiency of financial resources necessary thereto (limited possibilities of obtaining long-term bank credits, high interest rates);
- enterprises develop new technologies and products, assuming completely the risks related thereto, although frequently they do not have the appropriate experience;
- lack of external support for the development of innovations (training, advisory capacity);
- there are no financial or other support instruments necessary in order to create and develop projects for the development of innovations and new products and technologies, conduct the necessary studies; and
- there is no sufficient information regarding the modern tendencies and innovations around the world.

Existing Methodology and Criteria for Evaluation of New Products. There is no uniform methodology for the evaluation of similar design articles (products). Frequently the choice of articles is based only on the characteristics of the price and visual aspect. Such principle may be observed in the selection of everyday items, but it is not the most preferable solution upon selecting the best from several equal articles, the main function of which is the performance quality and service life. Therefore, the lowest price or visual aspect will not always be the determinant. Completely different parameters will emerge, according to which the relevant article should be selected.
26 basic parameters for the evaluation of each new design product have been developed in the USA [2], but there are no uniform basic principles or methods for more successful determination of the best article in Latvia. Frequently the thing we see does not indicate that this design product is the best in comparison with another product, which seems to us more visually inadequate, however, upon applying, for example, the aforementioned USA parameters, we may realise that the product, which seems to us more visually inadequate, is the best. The best does not mean only the visually more beautiful or the most ergonomic; many aspects such as durability, quality of materials and other parameters should be taken into account.

Such criteria have been developed for many years in the USA, which conform for the evaluation of technical articles. In total 26 parameters, which provide the best characterisation of articles, are offered. These parameters help to detect the weak points of articles, which should be improved during the manufacturing processes. These very parameters may be used in order to compare equivalent articles made by two or more different companies. Parameters for the evaluation and comparison of articles used in the USA are presented in the list below [2]:

1. Functionality
2. Strength/stress
3. Distortion/deflection/stiffness
4. Wear
5. Corrosion
6. Safety
7. Reliability
8. Manufacturability
9. Utility
10. Cost
11. Friction
12. Weight

13. Life
14. Noise
15. Styling
16. Shape
17. Size
18. Control
19. Thermal properties
20. Surface
21. Lubrication
22. Marketability
23. Maintenance
24. Volume
25. Liability
26. Remanufacturing/resource recovery

Some of these characteristics have to do directly with the dimensions, the material, the processing, and the joining of the elements of the system. Several characteristics may be interrelated, which affects the configuration of the total system.

The Industrial Designer Society of America (IDSA) defines industrial design as "the professional service of creating and developing concepts and specifications that optimize the function, value, and appearance of products and systems for the mutual benefit of both users and manufacturer". This definition is broad enough to include the activities of the entire product development team. In fact, industrial designers focus their attention upon the form and user interaction of products. List of five critical goals that industrial designers can help a team to achieve when developing new products [2]:

- *Utility:* The product`s human interfaces should be safe, easy to use, and intuitive. Each feature should be shaped so that it communicates its function to the user.
- *Appearance:* Form, line, proportion, and colour are used to integrate the product into a pleasing whole.
- *Easy to maintenance:* Product must also be designed to communicate how they are to be maintained and repair.
- *Low costs:* Form and features have a large impact on tooling and production costs, so these must be considered jointly by the team.
- *Communication:* Product design should communicate the corporate design philosophy and mission through the visual qualities of the products.

Whether or not the concept selection process is explicitly, all teams' use some method to choose among concepts. The methods vary in their effectiveness and include the following [2]:

- *External decision:* Concepts are turned over to the customer, client, or some other external entity for selection.
- *Product champion:* An influential member of the product development team chooses a concept based on personal preference.
- *Intuition:* The concept is chosen by its feel. Explicit criteria or trade-offs are not used. The concept just seems better.
- *Multivoting:* Each member of the team votes for several concepts. The concept with the most votes is selected.
- *Pros and cons:* The team lists the strengths and weaknesses of each concept and makes a choice based upon group opinion.
- *Prototype and test:* The organization builds and tests prototypes of each concept, making a selection based upon test data.
- *Decision matrices:* The team rates each concept against prespecified selection criteria, which may be weighted.

The concept selection method is build around the use of decision matrices for evaluating each concept with respect to a set of selection criteria.

Pareto Principle, Efficiency and Pareto frontier. Vilfredo Pareto was an Italian economist who noticed that 80 per cent of the land was owned by 20 per cent of the population. The Pareto principle (also known as the 80-20 rule, the law of the vital few, and the principle of factor sparsity) states that, for many events, roughly 80% of the effects come from 20% of the causes (see. Fig. 1).

Pareto efficiency, or Pareto optimality, is a concept in economics with applications in engineering and social sciences. The term is named after Vilfredo Pareto, an Italian economist who used the concept in his studies of economic efficiency and income distribution.

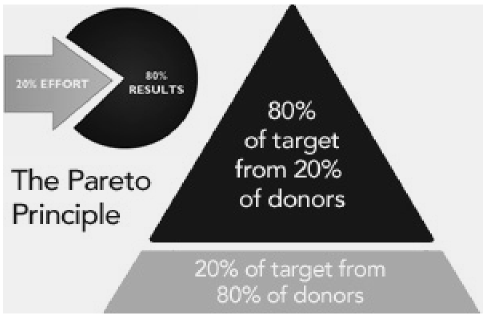

Fig. 1. The Pareto principle

Engineering is the discipline, art and profession of acquiring and applying scientific, mathematical, economic, social, and practical knowledge to design and build structures, machines, devices, systems, materials and processes that safely realize solutions to the needs of society.

The American Engineers' Council for Professional Development (ECPD, the predecessor of ABET) [3] has defined "engineering" as: the creative application of scientific principles to design or develop structures, machines, apparatuses, or manufacturing processes, or works utilizing them singly or in combination; or to construct or operate the same with full cognizance of their design; or to forecast their behaviour under specific operating conditions; all as respects an intended function, economics of operation and safety to life and property [4, 5].

If multiple options exist, engineers weigh different design choices on their merits and choose the solution that best matches the requirements. The crucial and unique task of the engineer is to identify, understand, and interpret the constraints on a design in order to produce a successful result. It is usually not enough to build a technically successful product; it must also meet further requirements.

Constraints may include available resources, physical, imaginative or technical limitations, flexibility for future modifications and additions, and other factors, such as requirements for cost, safety, marketability, product ability, and serviceability. By understanding the constraints, engineers derive specifications for the limits within which a viable object or system may be produced and operated.

The Pareto frontier is particularly useful in engineering: by restricting attention to the set of choices that are Pareto-efficient, a designer can make tradeoffs within this set, rather than considering the full range of every parameter.

The Pareto frontier is defined formally as follows.

Consider a design space with *n* real parameters, and for each design space point there are *m* different criteria by which to judge that point. Let:

$$f : R^n \rightarrow R^m \tag{1}$$

be the function which assigns, to each design space point *x*, a criteria space point *f(x)*. This represents the way of valuing the designs. Now, it may be that some designs are infeasible; so let *X* be a set of feasible designs in R^n, which must be a compact set. Then the set which represents the feasible criterion points is *f(X)*, the image of the set *X* under the action of *f*. Call this image *Y*.

Now construct the Pareto frontier as a subset of *Y*, the feasible criterion points. It can be assumed that the preferable values of each criterion parameter are the lesser ones, thus minimizing each dimension of the criterion vector. Then compare criterion vectors as follows: One criterion vector *Y strictly dominates* (or "is preferred to") a vector *Y** if each parameter of *Y* is no greater than the corresponding parameter of *Y** and at least one parameter is strictly less: that is, for each *i* and

$$Y_i \leq Y_i^* \tag{2}$$

for some i. This is written as

$$Y > Y^{*} \quad (3)$$

to mean that **y** strictly dominates Y^*. Then the Pareto frontier is the set of points from Y that are not strictly dominated by another point in Y [6, 7].

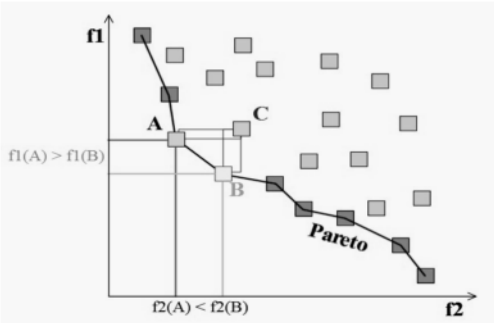

Fig. 2. Pareto frontier

Example of a Pareto frontier is given in fig. 2. The boxed points represent feasible choices, and smaller values are preferred to larger ones. Point *C* is not on the Pareto Frontier because it is dominated by both point *A* and point *B*. Points *A* and *B* are not strictly dominated by any other, and hence do lie on the frontier [6, 7].

Problem solving.

Engineers use their knowledge of science, mathematics, logic, economics, and appropriate experience or tacit knowledge to find suitable solutions to a problem. Creating an appropriate mathematical model of a problem allows them to analyze it (sometimes definitively), and to test potential solutions.

Usually multiple reasonable solutions exist, so engineers must evaluate the different design choices on their merits and choose the solution that best meets their requirements. Genrikh Altshuller after gathering statistics on a large number of patents, suggested that compromises are at the heart of "low-level" engineering designs, while at a higher level the best design is one which eliminates the core contradiction causing the problem [8].

Engineers typically attempt to predict how well their designs will perform to their specifications prior to full-scale production. They use, among other things: prototypes, scale models, simulations, destructive tests, nondestructive tests, and stress tests. Testing ensures that products will perform as expected.

Engineers as professionals take seriously their responsibility to produce designs that will perform as expected and will not cause unintended harm to the public at large. Engineers typically include a factor of safety in their designs to reduce the risk of unexpected failure. However, the greater the safety factor, the less efficient the design may be.

In analyzing and comparing offers for Master's theses of the referred to Baltech study programme in the duration of several years, such research results have been obtained, which may be useful for the industry of Latvia in the creation of new products suitable for export. In designing industrial articles, it is very important to have an understanding of their target market. Sectors of the market of Latvia are relatively transparent; we have sectors, in which the potential for the implementation of scientific research and engineering work allows to engage in the development of articles of small size and mass, but with high added value. If the engineering products offered in the study papers drawn up during the time period of 3 years are to be divided in sub-groups, their types are as follows: A) household appliances, B) study/research equipment models, C) audio/video equipment, D) computer peripherals, E) luxury articles, F) specialty instruments, G) spare parts of technical systems. The Pareto chart (see Fig. 3) reflects the distribution of the offers of students; Figure 4 shows one of the household appliances offered - a sketch of an appliance for processing - flattening - of plastic bottles [9, 10].

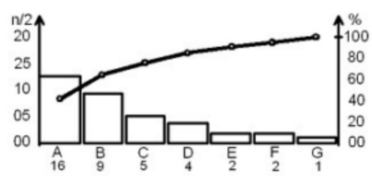

Fig. 3. Pareto diagram

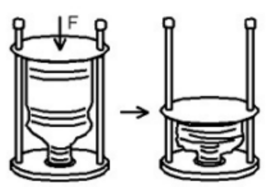

Fig. 4. Plastic bottles appliance

Within the scope of the BALTECH Programme, the task of 9 students was to develop a device for cutting up PET bottles, which could be used in household. The main criteria, according to which a decision is taken regarding the industrial manufacturing of the alternative of a specific device, are related to the evaluation of conformity of the alternative with the requirements of the potential users and the place of technical characteristics thereof among competing devices. There is a potential possibility to create up to 36 devices for cutting up the material of PET plastic bottles with different structures. Therefore, a question arises: which of the alternatives of the device should be recommended for industrial manufacture. There are approximately seven methods or approaches known for solving of this problem. The decision matrix method, which was already mentioned and implementation scheme of which is presented in Figure 5, may be named as the best and the most impartial method [10].

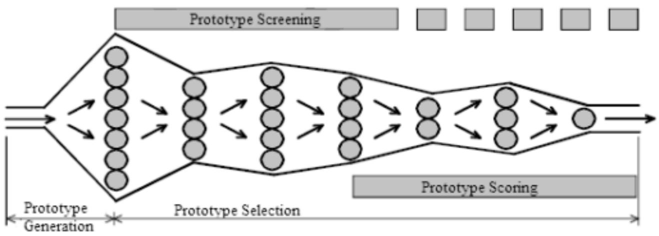

Fig. 5. Concept selection diagram

The process begins with the comparison of each alternative of the device according to specific criteria with a specially selected reference alternative of the device. The process of selection is divided into two stages. The process of quick evaluation of alternatives (simple rejection) involves the evaluation of approximate conformity of the device to be developed with the reference device in relation to each criterion (better, worse, the same). The positive sum of evaluations allows pushing the alternative of the analysed device to the next stage of accurate evaluation of alternatives. The stage of accurate evaluation includes the use of weight coefficients of specific criteria specified by experts for comparison of devices and the numerical evaluation of the property of the device to be analysed for a specific criterion. By using formula it allows calculating the evaluation of the alternative as the sum of evaluation points

$$S_j = \sum_{i=1}^{n} r_{ij} w_i \,, \qquad (4)$$

where

S_j - the number of points for alternative j;

r_{ij} - evaluation of the sequence of criterion i for criterion j;

w_i - weight coefficient for criterion i;

n - number of the criterion.

The selection of the alternative of the device, using the decision matrix method, allows clear documentation of the taking of the decision, simulation of taking of the decision, changing the numerical evaluation of experts for selection criteria, which should be regarded as an advantage of the method [10].

The study of failed products is known as forensic engineering, and can help the product designer in evaluating his or her design in the light of real conditions. The discipline is of greatest value after disasters, such as bridge collapses, when careful analysis is needed to establish the cause or causes of the failure.

Conclusions. In drawing conclusions regarding the method for the evaluation of articles used in the USA, we see that it conforms to the needs of manufacturers and allows to eliminate the deficiencies of articles and to improve the manufacturing process thereof. These parameters may be used also by professional experts in order to compare similar articles of several manufacturers. In turn, these parameters are not suitable for everyday consumers and people who make small purchases. This would require the development of much simpler system for the use of parameters, and this system should be based on small number of parameters.

It is intended to use the results of the presented studies and analysis for the development of methodology for enterprises of Latvia in order to create competitive production.

The use of the Pareto method would allow specifying more precisely the parameters, which would be necessary during the development process of any engineering product. It is also useful to take into account, for the needs of Latvia, the experience of other countries, as well as the evaluation methods and, most importantly, the parameters developed by these countries. Maybe not as many as 26 parameters, but, probably, for example it would suffice with 8 parameters – more or less, which would be appropriate for any product manufactured in order to help the manufacturers to eliminate the weak points of the product, thus helping to compete with the manufacturers of other countries. It is possible that some parameters will have to be added, as appropriate, in order to perform more accurate evaluation of similar products of different manufacturers.

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ОПТИМАЛЬНЫЕ ВОЗМОЖНОСТИ ОЦЕНКИ ИНЖЕНЕРНО-ТЕХНИЧЕСКОГО ДИЗАЙНА.

Геринь-Анцане А. *(Латвия)*

Аннотация: *В статье обсуждаются проблемы связанные с развитием дизайна в Латвийской промышленности и дана его оценка. Констатировано следующее: нет разработки оценки параметров и единой методологии, в результате чего отсутствует оптимальная оценка дизайна продукта. В работе рассмотрены применяемые критерии для оценки промышленной продукции, которые уже разработаны в США. Рассмотрены принципы Парето и Парето оптимальность.*

Рекомендовано: разработать конкретные параметры оценки дизайнерского продукта. Для обобщения применять метод Парето, а также использовать часть готовых параметров, которые разработаны в США, и создавать новые.

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