RIGA TECHNICAL UNIVERSITY

Anita GERINA-ANCANE

APPLICATION OF PARETO PRINCIPLE IN ENGINEERING PRODUCT DESIGN AND DESIGN ASSESSMENT

Summaru of Doctoral Thesis

Rīga 2012

RIGA TECHNICAL UNIVERSITY
Faculty of Transport and Mechanical Engineering
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Rīga 2012

UDK 658.512.2 + 519.8](043)
Ge 684 p

Gerina-Ancane A. Application of Pareto Principle in Engineering Product Design and Design Assessment. Summary of Doctoral Thesis. – Riga.:RTU, 2012. – 31 pages.

Published in accordance with June, 19. 2012 resolution of the RTU Institute of Mechanics, protocol No. 22.

EIROPAS SOCIĀLAIS FONDS

EIROPAS SAVIENĪBA

This work has been supported by the European Social Fund within the project «Support for the implementation of doctoral studies at Riga Technical University».

DOCTORAL THESIS SUBMITTED TO OBTAIN DOCTOR`S DEGREE IN ENGINEERING

The Doctoral Thesis for the acquisition of doctoral degree in engineering sciences is presented publicly in the open meeting of the Mechanical Engineering and Machine Design Promotional Council of the Riga Technical University (RTU-P04), ………………………………………................
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Russian Academy of Science

Professor, Juris Cimanskis
Latvian Maritime academy

CONFIRMATION

confirm that I have developed this Doctoral Thesis, which has been submitted for review in Riga Technical University for the doctoral degree in engineering sciences. This thesis has not been submitted to any other university for the acquisition of a scientific degree.

Anita Gerina-Ancane …………………………….(signature)

Date: ………………………

The promotion thesis consists of a preface, 7 chapters, conclusions and literature references. The volume of the thesis is 118 pages, it includes 67 figures, 10 tables and literature references, containing 73 publication titles.

CONTENTS

OVERALL REVIEW OF THESIS

Relevance of the Topic

Unfortunately, majority of manufacturers in our state are not aware of the significance of industrial design and the added value, which could given to the product by attracting the work of a designer. 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 a very significant field – industrial design. If a manufacturer skilfully uses the services of a designer, he or she adds high added value to his or her production not only in terms of taste and beauty, but also in tangible sense.

The main task of this promotion thesis is to ascertain the role of design in Latvian manufacturing enterprises, as well as to perform a correct assessment of design alternatives for innovative product.

The Baltic States and the Nordic countries are located in a region with longstanding traditions of industrial design. For example, manufacturers in Sweden fight, in the most direct sense of the word, for a good specialist – designer. In Sweden entrepreneurs look for such specialist when he or she is still studying, pay scholarships to students and offer traineeship in their enterprise. The situation is different in our country. It is very difficult to find a Latvian entrepreneur who has invited a designer to participate in the initial stage of creating a product. Entrepreneurs are unaware of the possibilities, which can be offered by a designer. To a large extent, it is because of the lack of information and also because design is perceived in a very narrow meaning – only as a packaging or advertisement (Borja de Mozota (2003)).

Studies on innovations in Latvia allow drawing a conclusion that there is a very poor co-operation between industry and science/research. This fact may be deemed as one of the largest obstacles to innovations and the development of new design products in Latvia (Belmane (2004)).

Nowadays many products reach high level of technical quality. High technical quality is not the decisive factor anymore. High technical quality has become a necessary factor for each product or service, which can actually compete in the modern market. When majority of the competing products and services have the same technical quality, decisions of buyers are governed by such emotional factors as taste and symbolic value (Mollerup Designlab A/S (2004)).

In many cases the buyer does not have the possibility to assess the technical quality of products and services before he or she uses them. It increases the value of emotional and symbolic attractiveness. In some cases technical quality of products and services is not a significant factor in decisions of buyers. Buyers select products because of emotional reasons.

Objective of the Thesis

The objective of the promotion thesis is the application of Pareto theory elements, principles and efficiency analysis in the creation of new innovative engineering products and the design assessment thereof. In addition to that, mathematical object analysis, optimization and synthesis methods are improved, complementing them with Pareto and Fuzzy control elements.

Research Tasks

In order to achieve the objectives brought forward and to implement the tasks marked out, the history of design has been studied during the development process of the promotion thesis and an overview of literature on the role of design in design institutions and manufacturing enterprises has been performed. An overview of literature on application of Pareto assessments and the Fuzzy element method in engineering sciences and in process control theory has been performed.

In order to implement the practical part, the following research methods were applied: FEM, least squares method, linear and non-linear method, as well as Fuzzy element method and rating of variables. The PC Crash data base was used, MathCAD software was used for synthesis of adaptive electromechanical control system. SolidWorks software was used for statistical and dynamic calculations of gage panels, as well as for environmental impact.

For the purpose of clarity of study results tables and figures are used.

Scientific Novelty of the Thesis

Scientific and theoretical novelty of the promotion thesis – methods for assessment and designing of engineering objects have been developed. Modern methods for analysis and data processing have been used.

Pareto methodology for optimization of the task of two-variable criterion (price of commercial transport and lifetime) has been improved in the research of the value of cars. The least squares method, linear and non-linear method was used for variable criteria, and graphic curves for further approximation were obtained – the method of Fuzzy elements. In applying MathCAD software, it has been proved that the curves obtained using Fuzzy method coincide well with the conditions of Pareto frontier.

A method for the criterion for the assessment of several technical variables of commercial transport has been developed. Rating of variables has been performed in range from 0 to 1, using Euclidean space. The ranking methodology developed may be applied not only to perform an expert-examination of vehicle from the point of view of buyer, but also to assess and compare other industrial products.

Fuzzy method has been developed for adaptive synthesis of dynamic system control, using MathCAD software. In this case design should be perceived as the designing control, Fuzzy control synthesis and optimal control synthesis. The models developed confirm that “Bang-Bang” control provides good results outside steady-state motion control because controllers and actuators may operate in the switch mode with very high frequencies. The results obtained may also be used in motion synthesis of other controllable objects, for example, diving equipment, robotics, underwater robots, etc.

The variable optimization method of design shape on the basis of automotive vehicle gage panel (GP) has been improved. Use of metamodels, for the creation of which experiment planning method is applied in modelling vehicle GPs, and assigning of component shape with NURBS spline support points allows to obtain smooth, technologically feasible shapes by optimising and does not require large resources for estimates, therefore, uneven shapes as such are being excluded from the search process.

Practical Value

Perspectives of practical use – in the development and optimization of new innovative objects, in decision-making, in assessing different procurements of national scale. The application of newly-acquired methods in the development of special software as a future perspective for everyday consumer.

Propositions for the Defense

- Methodology developed on the basis of statistical data for the assessment of cars of commercial vehicles, in which expert mistakes are not necessary in determination of prices, where it is proved that Fuzzy curves coincide well with the conditions of Pareto frontier. It may be declared that Pareto frontier is almost the same as Fuzzy control.
- Methodology developed on the basis of variables of PC Crash data base for mathematical assessment (ranking) of vehicle, using rating in the range from 0 to 1.
- The developed ranking methodology is also applicable for the assessment and comparison of other industrial products.
- Using Fuzzy control elements, a new methodology has been developed, which may be used in synthesis of control of different transport system types in actual road situations, as well as in synthesis of motion of other controllable objects, for example, diving equipment, robotics, underwater robots, etc.
- New methodology for optimization of design shape has been developed, applying discrete variables for assigning of shape.

Sructure and Volume

The promotion thesis is written in the Latvian language. It consists of a preface, 7 chapters, conclusions and literature references. The volume of the thesis is 118 pages, it includes 1 supplement, 67 figures, 10 tables and literature references, containing 73 publication titles.

Thesis Approbation and Publications

Results of the promotion thesis have been reported and discussed at international conferences and scientific seminars:

- RTU 50th Student Scientific and Technical Conference (Riga, Latvia, 2009)
- RTU 51st International Scientific Conference (Riga, Latvia, 2010)
- 10th International Scientific Conference Engineering for Rural Development (Jelgava, Latvia, 2011)
- 3rd United World Congress of Latvian Scientists and the 4th Letonika (Latvian Studies) Congress: section "Technical Sciences" (Riga, Latvia, 2011)
- 9th International Conference on Advanced Manufacturing Systems and Technology – AMST"11 (Mali Lošinj, Croatia, 2011)
- 10th International Conference on Vibration Problems (Prague, the Czech Republic, 2011)
- 6th International Scientific and Technical Conference "Current Problems in Machine Building" (Tomsk, Russia, 2011)
- 11th International Scientific Conference Engineering for Rural Development (Jelgava, Latvia, 2012)
- 15th International Conference on Experimental Mechanics (ICEM15) (Porto, Portugal, 2012)

The main results of the thesis have been expounded in 12 publications and 1 scientific monograph.

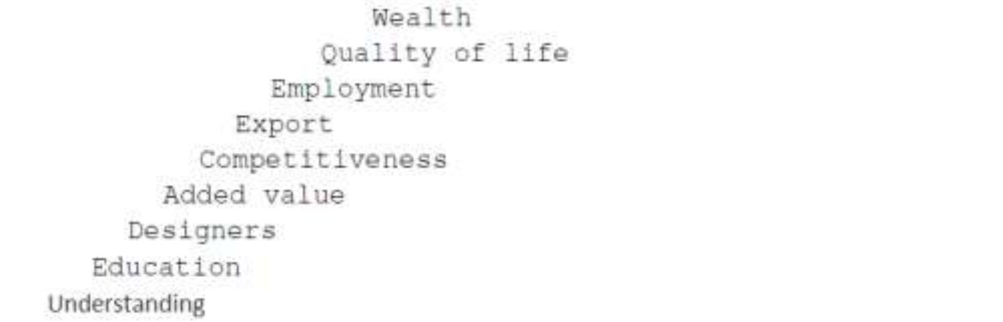
CONTENT OF THE THESIS

Chapter one – an overview of literature on the history of design, its significance in manufacturing enterprises is performed, as well as the actual situation thereof in Latvia is ascertained.

It is shown that the significance of design (correct explanation and application thereof) should be explained not only at the level of enterprise management, but also to the society at large, so that it (as the potential consumer) would be aware of the work put in by manufacturers and the relevant price of the product, which will be higher than for a poorly designed product or service.

It is scientifically proved, using arguments, that by supporting local enterprises and designers of new products – the work put in by designers, we increase the prosperity of the state, also motivating financial support by the state, and on international scale.

The majority of national policies let it be known directly that the objective of their design policy is to raise the competitiveness of enterprises and industry. Design should add value to products, services and enterprises, thus adding value to the state at large. As a result, increased competitiveness leads to increased wealth and welfare, increases prosperity or the quality of life. The objectives that appear in national design policies are hierarchically related to each other. In most cases, all objectives – other than “prosperity” – are means toward higher-level objectives, shown in Figure 1 (Mollerup Designlab A/S (2004)).



The hierarcy of design policy. **Some of the levels may vary. Wealth is always at the top of the hierarchy**

Figure 1. Objective of the national design policy

In the promotion thesis attention is paid to correct development of concept during the development process of innovative products, which would allow the manufacturers to be more successful in preventing defects of innovative product during the prototype development process itself, as well as would facilitate work in relation to the selection of several equivalent products, for example, in different procurement tenders announced by the state where usually the price is the determining factor, although the price does not reflect the true quality of the product and other important technical indicators.

Auditors detected many unsolved problems in Latvian enterprises. For example, an enterprise has a strong technological side, understands design. It tries to create a design by itself, resulting in creation of standard production, trimmed with unusual materials, or the enterprise currently has neither external, nor internal design capital developed, although the management of the enterprise is aware of the special possibilities and potential of design, as well as the significance of the design capital of the enterprise for the development of the enterprise.

26 assessment variables have been developed in the USA, according to which each new design product is assessed (Ulrich and Eppinger (2008)). Using the methodology of the USA, it may be concluded that the product, which is not as visually attractive, usually is the best one.

A positive example of designing is clearly demonstrated in the promotion thesis, developing an innovative MAZDA car, using KODO design concept.

Chapter Two is dedicated to the overview of Pareto assessment – Pareto principle, efficiency and Pareto frontier.

The results of analysis of applying the Pareto principle are demonstrated graphically, using a Pareto chart. Essentially it is a column chart, in which columns are arranged in descending order. The height of each column characterises the frequency value of each important unit of measures similarly as in a histogram. Thus, the mutual layout of columns characterises the degrees of their mutual importance. It is very useful to show additionally in the Pareto chart the weight of each column in percentage, as well as the increasing total weight of the column, taking into account the importance of the previous columns (see Figure 2).

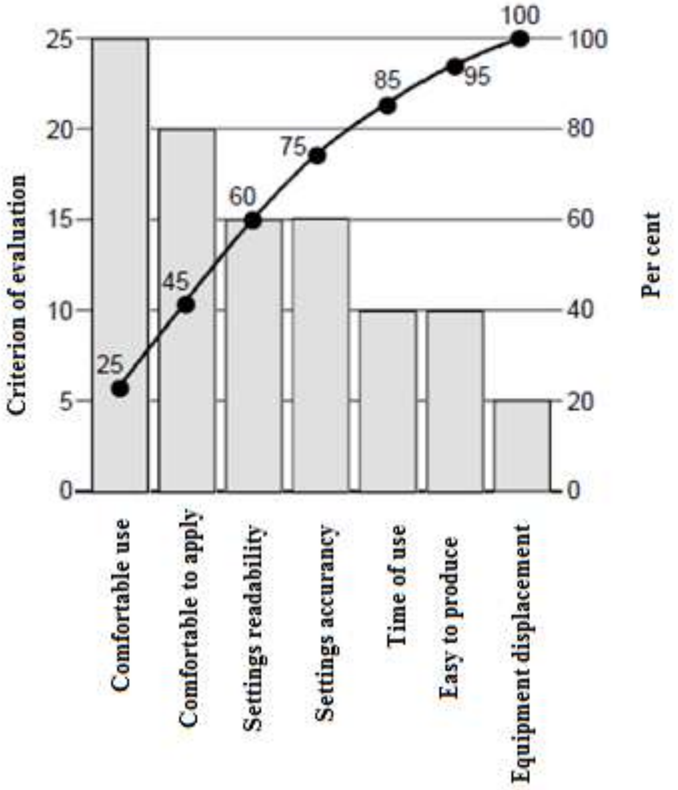


Figure 2. Pareto chart of product assessment criteria

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.

Pareto frontier is especially useful in relation to technologies: by paying attention to only such alternatives, which are efficient according to the Pareto method, the designer may perform specifically necessary changes, choosing a compromise solution, and he needs not weigh the possibilities of each variable.

Variable r determines the level of the admissible compromise – a possibility to compensate deficiencies in indicators of one quality with a larger quantity of other indicators. It is natural that it should be requested that lines of equal significance do not cross co-ordinate axes (which is an unambiguous final assumption of co-ordinate axes). Moreover, a reasonable compromise will be specified by negative variable r values (see Figure 3) (Слиеде and Эглайс (1997)).

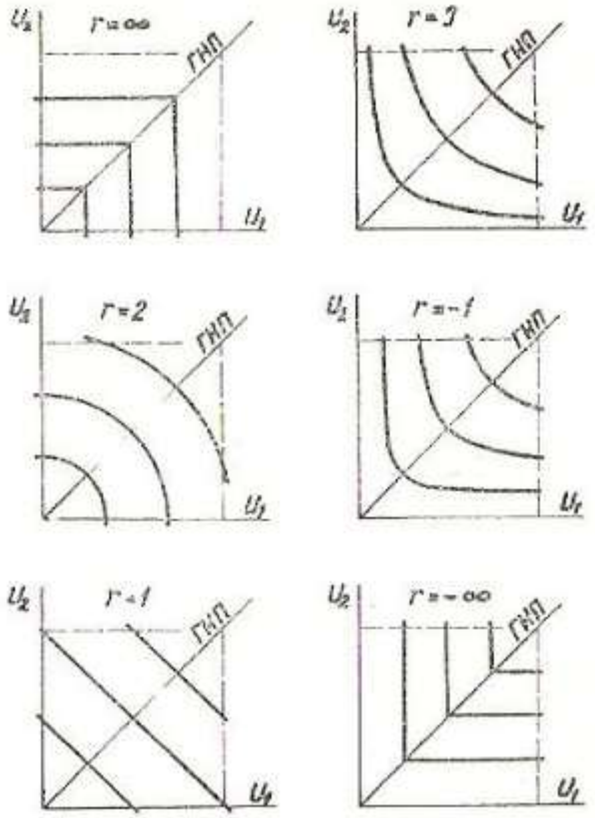


Figure 3. Lines of equal significance with two quality indicators

The Pareto frontier is defined formally as follows.
Consider a design space with n real variables, and for each design space point there are *m* different criteria by which to judge that point. Let:

$$f: R^n \to R^m \quad (1)$$

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.
An example of Pareto frontier is shown in Figure 4. 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 (Kung et al. (1975); Parke et al. (2006)).

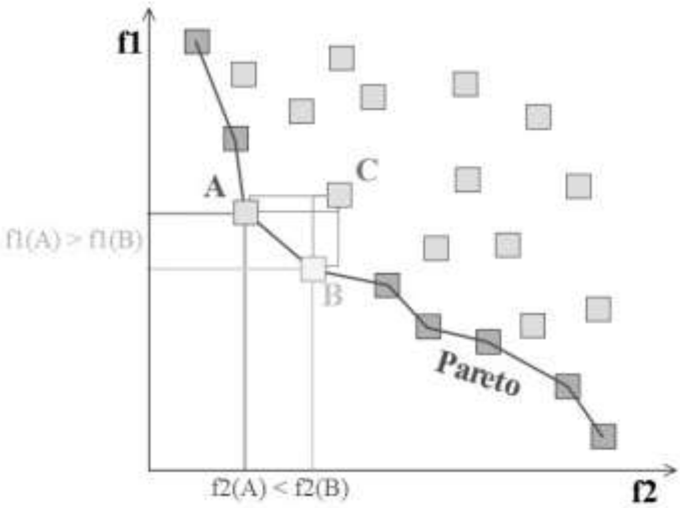


Figure 4. Pareto frontier

It is shown in the thesis that in developing new products not only the innovation of the product and wishes of consumers, but also technological possibilities of the manufacturer should be taken into account (the most essential factors should be assessed and determined in order to do that or, on the contrary, when it may be necessary to reject the previous ideas).

It arises from materials of the promotion thesis that very many methodologies have been developed in the world, which may be used as guidance, however, it is not possible to state which of them is the best one (each methodology has its strong points and may have some unnecessary elements), therefore, such methodology should be chosen as the basis, which, to our minds, has the most appropriate criteria, and it should be synthesised with the help of another methodology, thus creating one's own methodology – within the scope of an enterprise or on the national level.

It is proved, using arguments, that the most important and unique task of engineers (in developing a new product) is to identify, understand and interpret restrictions of design variables in order to achieve the most optimal result according to the potential process control.

Chapter Three – an overview of literature is performed on the application of Fuzzy element method in engineering sciences and control theory, which means that the description of a design is largely vague or imprecise (fuzzy) at the stage where technical solution concepts are being generated.

The need for a methodology to represent imprecision is greatest in the preliminary phases of engineering design, when the designer is most unsure of the final dimensions and shape, materials and properties, and performance of the completed design (Ward et al. (1994)).

Design imprecision concerns the choice of design variable values used to describe an artefact or process, then preferences are used to quantify (determine) the imprecision with which these design variables are known. In this case the choice means subjective or objective information, which can be expressed in terms of quantity and which is included in the assessment of design alternatives. This approach, which is based on the mathematics of fuzzy sets, is called method of imprecision (MoI).

The MoI begins with one or more design alternatives, at the concept level. The designer's preferences are then applied to each of the variables that imprecisely or approximately describe the design. Commonly, performance specifications will also be imprecisely described and can be elicited from customers through marker overviews, etc. The imprecise (fuzzy) design variables are then *induced* onto the performance space. The more traditional "point by point" approach illustrated in Figure 4 may be used in engineering practice. However, the following action is also possible: the design preferences induced onto the performance variables may be compared to the specifications. At that point, trade-offs, using the aggregation function) can be made between the various competing aspects of the design, i.e., decisions can be made regarding the feasibility of each alternative concept, and promising ranges or sets of design variables can be identified as illustrated in Figure 5 (Zimmermann (1999)).

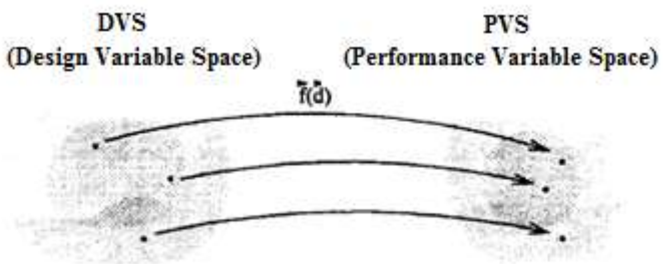


Figure 4. Evaluating individual designs one by one

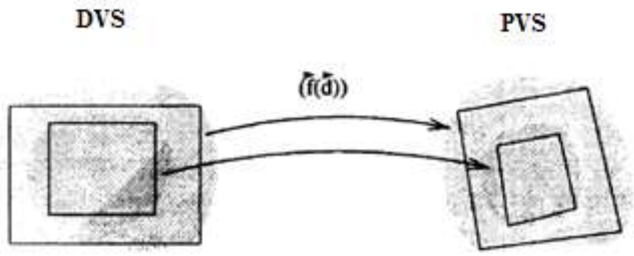


Figure 5. Evaluating sets of designs

Functional requirements and design preferences may be created as functions adherent to fuzzy sets, generalisation of preferences is the task of aggregation of fuzzy sets.

The promotion thesis also includes an overview of the development of decision theory, which is based on utility theory and probability theory. Decision theory was first applied to business management situations and has now become an active area for research in engineering design.

In the situation of *decision under certainty*, the decision maker has all the information to evaluate the outcome of her choices. She also has information about different conditions under which the decision must be made. Therefore, the decision maker need only recognize the situation in which the decision is occurring and look up the outcomes of all possible choices. The challenge here is having the information on the outcomes ready when needed. This decision strategy is illustrated in table (See Figure 6) (Dieter and Schmidt (2009)).

	State of nature		
Course of action	Θ_1	Θ_2	Θ_3
a_1	1	4	10
a_2	3	2	4
a_3	5	4	3

Figure 6. Loss table for a material selection decision

This Chapter also includes an overview of literature on analysis and synthesis where analysis is shown as a method of logical thinking, a method of cognition, which provides for division of the subject studied (in mind or practically) in elements (parts, individual signs, properties, relationship) in order to cognise each of these elements individually as a whole part of the divided. Afterwards the information thus obtained regarding each component is joined using another method – synthesis. Such joining is only possible when interrelations of components are known and this knowledge is used during synthesis.

Already at the beginning of analysis the subject of cognition has some compiled preconception of the object of cognition, which he or she uses as guidance. Afterwards, studying some components of the given design (analysis), the researcher performs generalisations of the results obtained (synthesis). It does not mean than analysis and synthesis exist in pure form, that at first one of them and than the other should be applied (Zimmermann (1999)).

Chapter Four – practical part is performed, in which methodology on the basis of statistical data is developed for the assessment of cars of commercial transport, in which expert mistakes are not necessary in determination of prices. It is shown that Fuzzy curves coincide well with the conditions of Pareto frontier. It may be declared that Pareto frontier is almost the same as Fuzzy control.

Kangoo models of Renault commercial transport with different engine capacities, years of manufacturing and price, which is offered in the market of Latvia in 2012, are used as the basis for optimisation of two-variable criterion. The year of manufacturing and the offered market price in Latvia in 2012 are accepted as the main variables. The least squares method, linear and non-linear method (Viba un Lavendelis (2006); Zakrzhevsky (2008)), as well as Fuzzy element method is applied for optimization of these variables.

The efficiency illustrated in Figure 7 as "mountain range" is used in the given calculation. The actual average price of a car, applying the least squares method, has been determined from experiments – market price value. The edges of mountain ranges are assessed, using new methodology, which includes everything from the initial price of the car even to the price of scrap. It is shown that Pareto efficiency is as the top of a mountain range from both sides. Assessments on both sides are lower than in the case of Pareto efficiency. Therefore, the assessment which is closer to tops is better than the assessment further away. The distance (closer or further away) is measured, using distance measurement of Euclidean space from the initial point of co-ordinates.

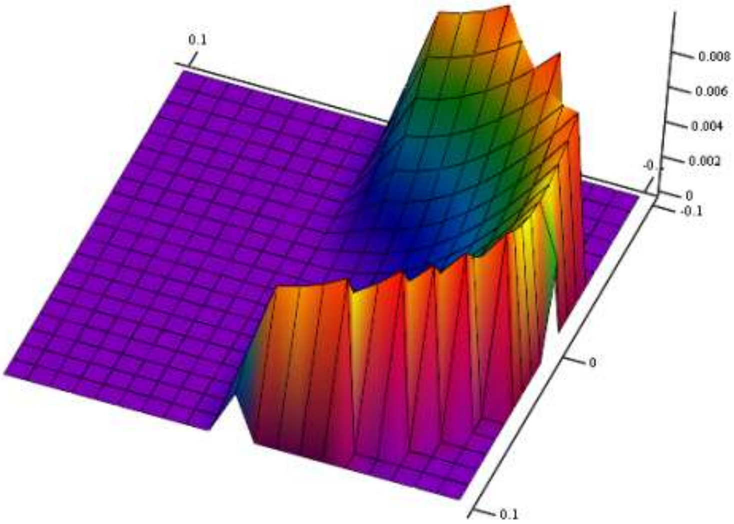


Figure 7. Pareto efficiency

Approximated data with cubic equation is used in analysis of the *least squares method*

$$f = a_o + a_1 x^1 + a_2 x^2 + \cdots + a_n x^n \tag{2}$$

where: f – price of car, a – coefficient and x – year of manufacturing of car. Then the deviation is:

$$\Delta = \sum [Y - (a_0 + a_1 X + a_2 X^2 + a_3 X^3)]^2 \tag{3}$$

Then four coefficients a_0, a_1, a_2, a_3, are found, which give the minimum value to deviation Δ. Partial derivatives according to all four constants a_0, a_1, a_2, a_3, equaled to zero:

$$\frac{\partial \Delta}{\partial a_0} = 2 \sum [Y - (a_0 + a_1 X + a_2 X^2 + a_3 X^3)](-1) = 0$$
$$\frac{\partial \Delta}{\partial a_1} = 2 \sum [Y - (a_0 + a_1 X + a_2 X^2 + a_3 X^3)](-X) = 0$$
$$\frac{\partial \Delta}{\partial a_2} = 2 \sum [Y - (a_0 + a_1 X + a_2 X^2 + a_3 X^3)](-X^2) = 0$$
$$\frac{\partial \Delta}{\partial a_3} = 2 \sum [Y - (a_0 + a_1 X + a_2 X^2 + a_3 X^3)](-X^3) = 0 \tag{4}$$

Calculation is performed as follows. Average price values for the relevant year of manufacturing of car are taken. Data are approximated with cubic equation. Fuzzy control is applied within the limit +1000 and -1000 (LVL)

$$f_2(x) = a_0 + a_1x + a_2x^2 + a_3x^3 + 1000\left(1 - \frac{x}{10}\right)$$

$$f_3(x) = a_0 + a_1x + a_2x^2 + a_3x^3 - 1000\left(1 - \frac{x}{10}\right) \quad (5)$$

The results obtained are illustrated in Figure 8.

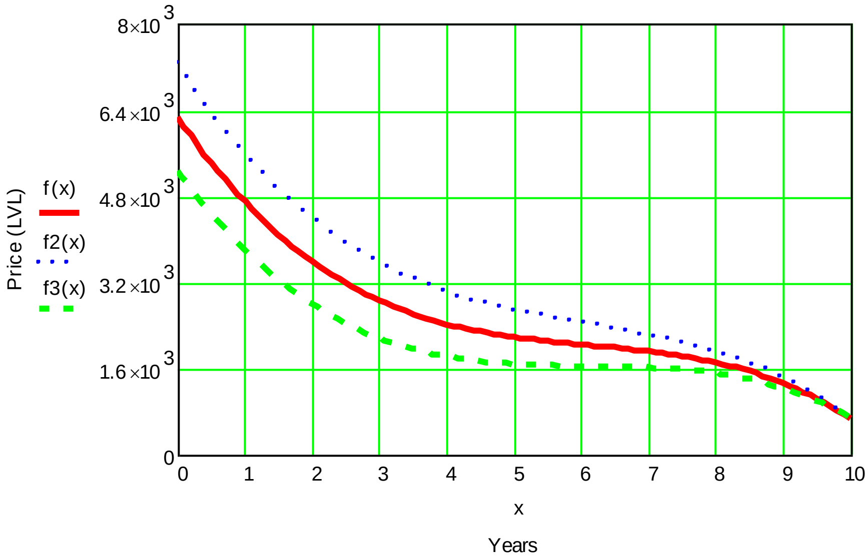


Figure 8. One compromise curve with the least squares method and Fuzzy control

In applying the *linear calculation method*, the initial sales price is taken for a new car. The subsequent price of car is taken according to the interval of 10 years, until the car reaches the verge of 20 years and already obtains the value of scrap price.

$$f = a_1 + \frac{a_2}{a_3 + x} \quad (6)$$

where: f – price of car, a – coefficient, x – year of manufacturing of car.

$$11000 = a_1 + \frac{a_2}{a_3 + 0}$$

$$11000 = a_1 + \frac{a_2}{a_3 + 5}$$

$$11000 = a_1 + \frac{a_2}{a_3 + 20} \quad (7)$$

Coefficients a_1, a_2, a_3 are detected and Fuzzy control is applied within the limit +1000 and -1000 (LVL).

$$C_2(x) = a_1 + \frac{a_2}{a_3 + x} + 1000\left(1 - \frac{x}{20}\right)$$

$$C_3(x) = a_1 + \frac{a_2}{a_3 + x} - 1000\left(1 - \frac{x}{20}\right) \quad (8)$$

I The results obtained are illustrated in Figure 9.

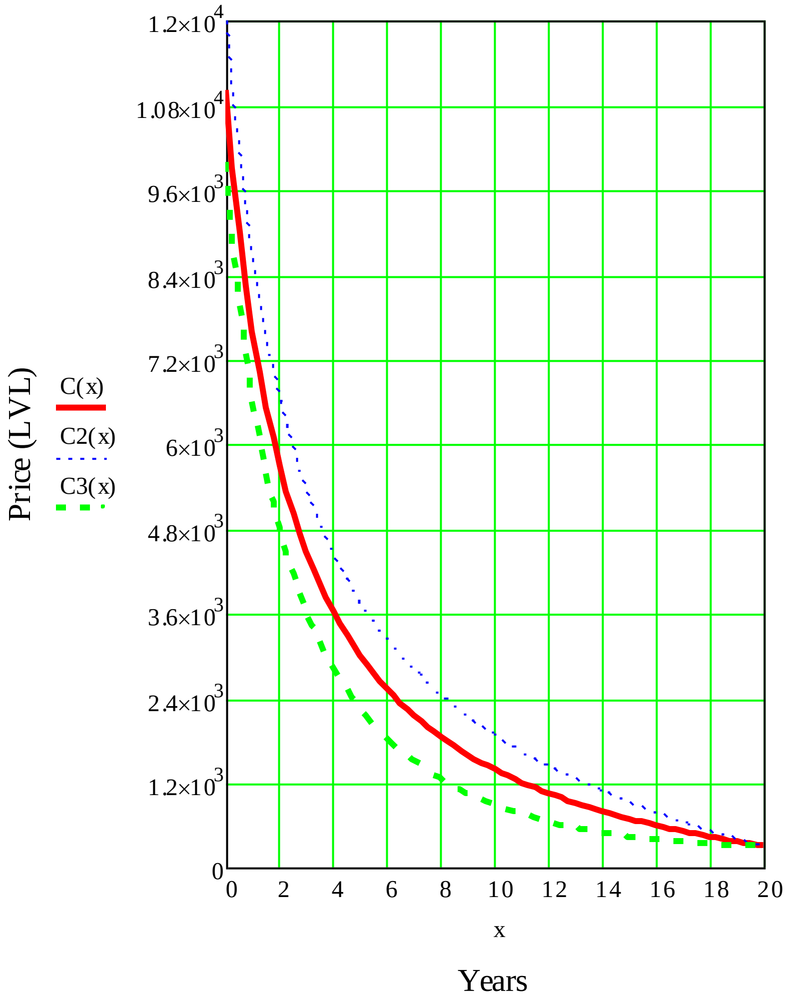


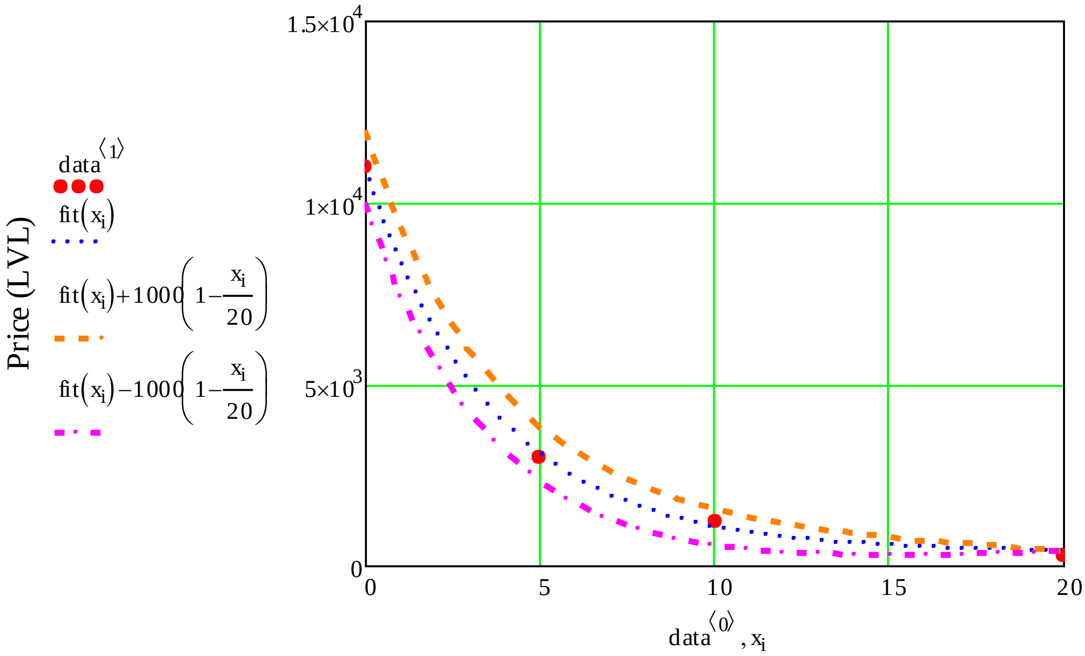
Figure 9. One compromise curve with the linear method and Fuzzy control (Fuzzy Pareto frontier chart)

In case of *non-linear method* calculations comparison of two variables (price and year) is performed, exponential function is used for Renault Kangoo. As well as the price limit from +1000 to – 1000 (LVL) of Fuzzy control is applied in relation to the result obtained. The price of a car after 0, 5, 10 and 20 years is analysed.

Exponential equation is composed where coefficients $a, b, c = 2$.

$$y = ae^{bx} + c \quad (9)$$

Calculation is performed and a chart of results is obtained (see Figure 10), using MathCAD software.



Years

Figure 10. One compromise curve with the exponential function and Fuzzy control

The method developed may be applied in the assessment of any engineering design on the basis of optimization of two-variable criteria.

Chapter Five – using PC Crash car data base, commercial transport provided for the needs of small and medium enterprises was selected as the basis, methodology for the performance of expert-examination of cars from the point of view of buyer was developed.

Three-dimensional Euclidean space is applied for the evaluation of several technical variables (see Figure 11). It may be applied, depicting assessment in a rated space, for example, when comparing commercial vehicles.

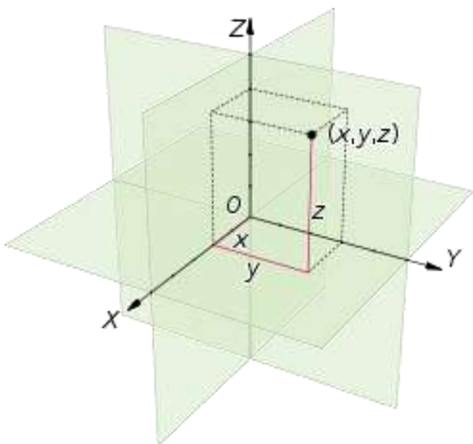


Figure 11. Determination of point with three co-ordinates (x, y, z) in 3D Euclidean space

In calculation Pareto frontier (see Figure 12) is used partially because the main objective of calculation is to compare many cases (criteria) to the "right" from this frontier. It is shown in Figure 12 that there is an exit from one side, and this differs from the case of Pareto efficiency (see Figure 7). Many points on the chart (see Figure 12) indicate that on an equivalent curve methodology for finding such curves in a space of 12 variables, applying variables of commercial transport, is developed in the promotion thesis.

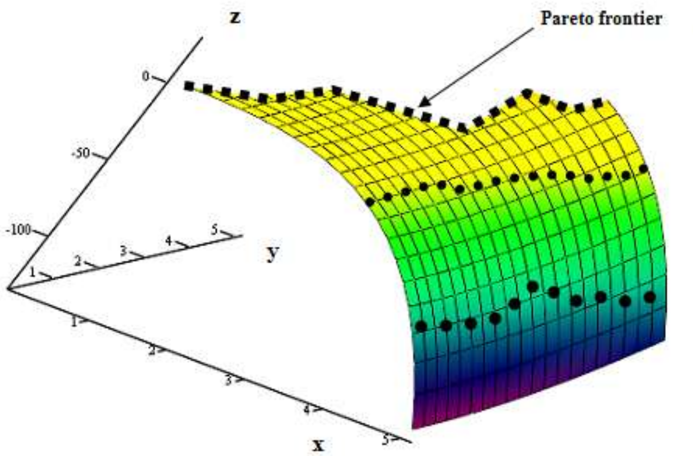


Figure 12. Pareto frontier

12 different variables for 53 cars are selected for calculation from the vehicle data base (PC Crash), and rating from 0 to 1 is applied to them, resulting in a table of rated results (see Table 5.2 of the promotion thesis) illustrating the best and the worst commercial vehicle. The results obtained are illustrated in Figure 13. One obtained rating result is left remaining of axes x, y and z.

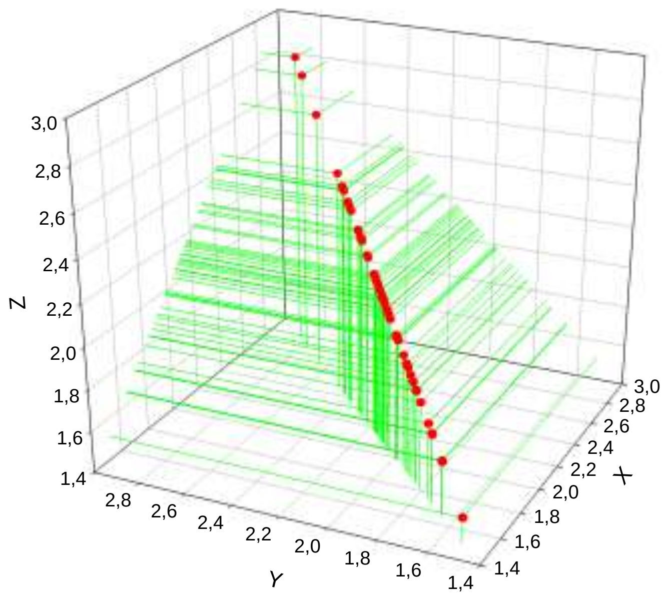


Figure 13. Rating chart of commercial vehicles in 3D Euclidean space

The best commercial vehicle according to the rating in the 3D Euclidean space is Citroen Berling 2.0 (No. 38 – see Table 5.2 of the promotion thesis), which is illustrated in Figure 9; the worst results are noted in relation to car No. 26 (see Table 5.2 of the promotion thesis – Opel Combo 1.6).

The ranking methodology developed is also applicable to the assessment and comparison of other industrial products.

Chapter Six – using Fuzzy control elements, new methodology is developed, which may be used for synthesis of control of different transport system types in actual road situations. In this Chapter term "design" means design control, fuzzy control synthesis and optimal control synthesis. Calculation of the motion of car is performed when the car is driving up the mountain. All calculations were performed, using MathCAD software.

The equation of motion, simplified differential equation of a vehicle (car) along given 3D space trajectory may be formulated as (see Figure 14.a)):

Figure 14. a) Car motion along given trajectory

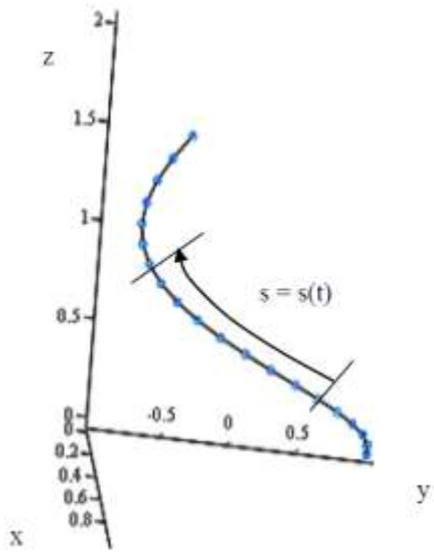


Figure 14. b) Car motion chart

$$m\ddot{s} = -F[s, \dot{s}, sign(\dot{s}), V, \varphi(s,t)] - mgsin\big(\alpha(s)\big) - R(t, s, \dot{s}) + u(t, s, \dot{s}) \qquad (10)$$

where: m – car mass, $s, \dot{s}, \ddot{s}$ – curvilinear co-ordinate, velocity and tangential acceleration, $-F[s, \dot{s}, sign(\dot{s}), V, \varphi(s,t)]$ – all resistance forces, including wind velocity V with action angle φ, g – free fall acceleration, t – time, α – slope angle, $R(t, s, \dot{s})$ – rough road interaction force, $u(t, s, \dot{s})$ – control action. Therefore for object control action $u(t, s, \dot{s})$ can be synthesizing (see Figure 14. b)).

Usually control systems are based on mathematical models, for which control system has not been described, using one or several differential equations that determine system response reactions to its own resources. A proportional–integral–derivative controller (PID controller) is often applied to such systems. PID algorithm may be written as follows:

$$u(t) = MV(t) = K_p e(t) + K_i \int_0^t e(\tau)d\tau + K_d \frac{d}{dt} e(t) \qquad (11)$$

where: K_p – proportional increase of regulation variable, K_i – integral increase of regulation variable, K_d – derived increase of regulation variable, e – $Error = SP - PV$ (SP – setting; PV – – process variable or procedure value), t – time or momentary time.
It should be noted that, in applying PID control algorithm, it does not guarantee optimal control system or system stability.

Differential equations are used for calculations; cases of harmonic and biharmonic control are reviewed.

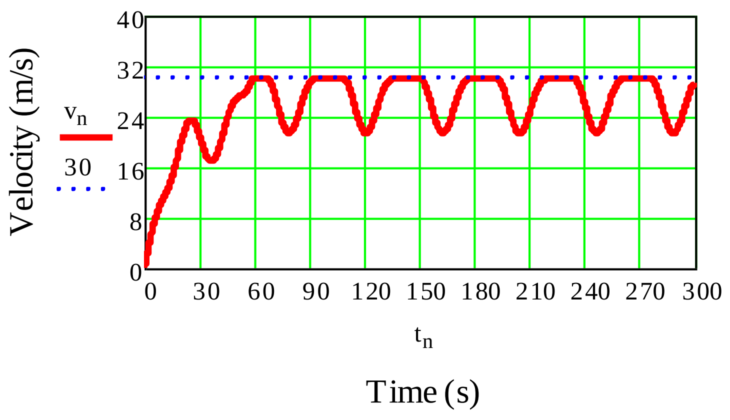
Optimal control shows that any time interval can move object back to steady-state position with formulated velocity. If control $u(t, s, \dot{s})$ has limits (see Formula 8) with limit

$$u_1 \le u(t, s, \dot{s}) \le u_2 \tag{12}$$

$$\begin{pmatrix} x_{n+1} \\ v_{n+1} \end{pmatrix} = \left[\begin{matrix} x_n + s v_n \\ v_n + \frac{s}{m}\left[-b(v_n)^2 sign(v_n) - F_b sign(v_n) + \right. \\ +P_0 sign(v_n)\big(0.5 - 0.5 sign(v_n - 30)\big) - P_1 sign(v_n)\big(0.5 + 0.5 sign(v_n - 30)\big) + \\ \left. +H1\left(sin(\omega t_n) + 1 sin\left(2\omega t_n + \frac{\pi}{2}\right)\right)\right] \end{matrix} \right] \tag{13}$$

Using MathCAD software, calculation has been performed and a result chart has been obtained (see Figure 15).

Figure 15. Velocity as time function in interval 20 – 30 m/s



Linear control is rated here so that there would be no need to write the mass of the particular car and other values. Linear control uses only one reversible coefficient C, as the difference from the velocity specified at 20 m/s and the current velocity v_n.

$$\begin{pmatrix} x_{n+1} \\ v_{n+1} \end{pmatrix} = \left[\begin{matrix} x_n + s v_n \\ v_n + s[-b_0 sign(v_n) - b_1 v_n - b_2 (v_n)^2 sign(v_n) - b_3 (v_n)^3 + \end{matrix} \right.$$

$$+\left(-H_0 + H_1 sin(\omega t_n)\right) + C(20 - v_n)]\Big] \tag{14}$$

Calculation was performed and a result chart was obtained (see Figures 16, 17).

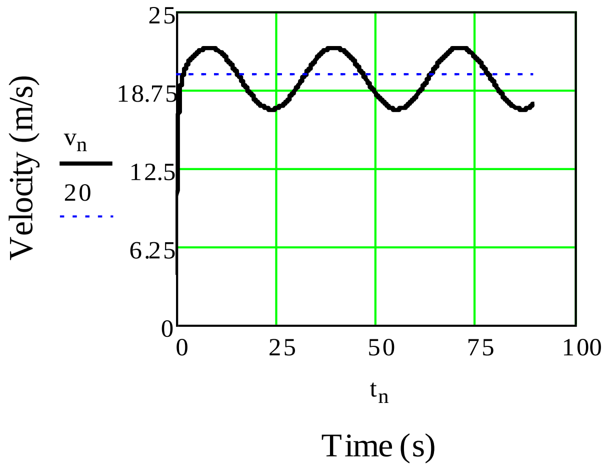


Figure 16. Velocity as time function according to the specified velocity 20 m/s and current velocity

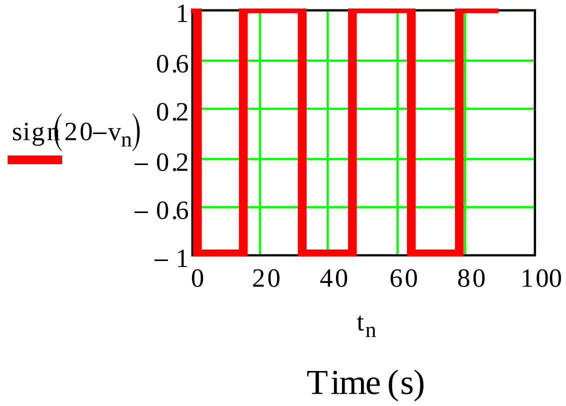


Figure 17. “Bang-Bang” control action in the time period when velocity is 20 m/s and the current velocity

Flat control. In this case control is rated so that there would be no need to write the mass of the particular car and other values. In this case modelled motion of the vehicle is induced by biharmonic random range, control is stable. Control operates only in the range from 10 to 15 m/s.

$$\begin{pmatrix} x_{n+1} \\ v_{n+1} \end{pmatrix} = \Bigg[\begin{matrix} v_n + s[-b_0 sign(v_n) - b_1 v_n - b_2 (v_n)^2 sign(v_n) - b_3 (v_n)^3 + \\ x_n + s v_n \end{matrix}$$

$$+\left[H_0\left(0{,}5 - 0{,}5 sign(10 - v_n)\right)(1) - H_2\left(0{,}5 - 0{,}5 sign(15 - v_n)\right) + \right.$$

$$\left. +H_1\left(1 + rnd(10)\right)\left(sin(\omega t_n) + 2 sin\left(2\omega t_n + \frac{\pi}{2}\right)\right)\right] + 0\Bigg]\Bigg] \tag{15}$$

Calculation was performed and a result chart was obtained (see Figure 18).

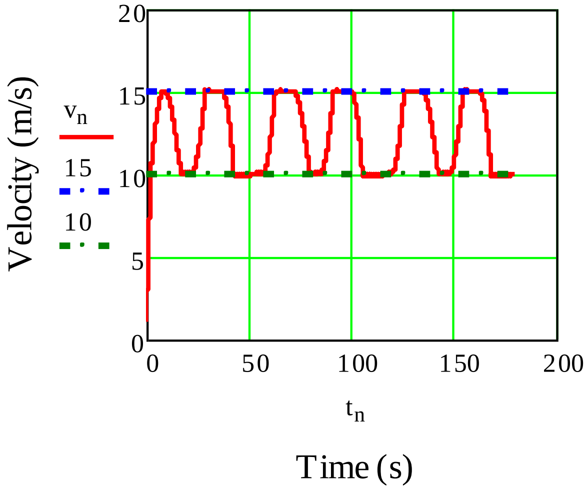


Figure 18. Velocity as time function in interval 10 – 15 m/s

Analysis of the developed models shows that “Bang – Bang” control provides good results outside steady-state motion control because controllers and actuators may operate in switch mode with very high frequencies.

The results obtained may also be applied in synthesis of other controllable objects, for example, diving equipment, robotics, underwater robots, etc.

Chapter Seven – application of highly efficient methodology (Janushevskis et al. (2010); Янушевскис et al. (2011)) is analysed for optimization of the shape of automotive vehicle gage panel (GP) block elements, which must meet the following requirements: strength without exceeding the admissible level of stress, stiffnesses, appropriate characterization of weight and accuracy, as well as they must have minimal environmental impact. A 3D model of the GP is developed, which is graphically shown in Figure 19, static and dynamic properties are calculated, as well as its environmental impact as total energy consumed, carbon footprint, air acidification and water eutrophication are evaluated. Using different criteria of indicators, it is possible to obtain the relevant optimal solutions for GP block shapes.

Figure 19. Design of the gage panel (GP) of enterprise *Merpro*, designed as AMO PLANT and 3D geometrical model

As the model of the whole object is sufficiently complicated and calculations are labour-consuming, metamodels of optimization design models are used instead of optimization design models, for the creation of which experiment planning method is applied (Auzins and Janushevskis (2007)). Application of metamodels allows performing multiobjective optimization of the object with stochastic global search procedure (Janushevskis et al. (2004)).

The problem is stated as follows:

$$\min_{x} F(x) = [F_1(x), F_2(x), \dots, F_k(x)]^T \quad (16)$$

ja $g_j(x) \le 0$, $j=1, 2, \dots, m$, un $h_l(x) = 0$, $l=1, 2, \dots, e$;

where: k – the number of objective functions F_i, m – the number of inequality constraints, e – the number of equality constraints, $x \in E$– a vector of n design variables.

The strength of the GP design is checked on special vibrostands, subjecting it to different dynamic loads. For example, vibrostability of the GP is checked in the frequency domain from 10 to 250 Hz. The GP is also tested in relation to shock resistance under acceleration level $a = 10g$.

Using the programme SolidWorks (SW), a 3D GP calculation model was created, which is shown in Figure 20, and strength calculations were performed. It consists of 18 parts: 6 deformable bodies and 12 standard accessories, which are interpreted as rigid bodies possessing certain inertial characteristics.

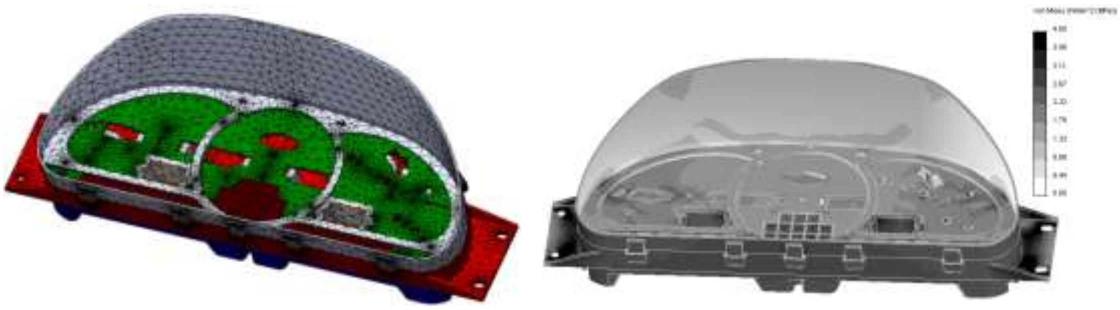


Figure 20. Meshed 3D model and von Mises stresses distribution in initial design of GP

The cross-section shape for bracket's strengthening is defined by the 3 knot points of NURBS, shown graphically in Figure 21. Design parameters are co-ordinates of the knot points varied in the following ranges: $3 \le X1 \le 6$; $2 \le X2 \le 5$; $0 \le X3 \le 3$. As a cross-section profile is defined, the 3D-shape is created using the path curve, shown in Figure 21. b). The same shape for strengthening is created on the second bracket of the GP frame component. As a result of minimizing the maximum equivalent stress with constraint on the total material volume ($v < 665200mm^3$), the gauge panel obtained the shape of a bracket as shown in Figure 21. c).

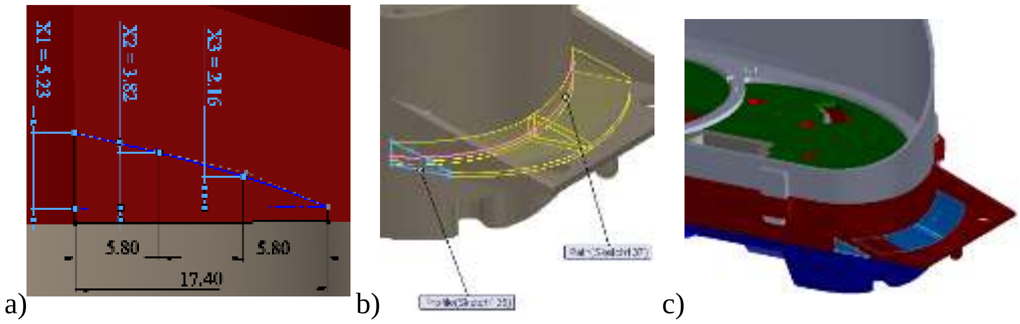


Figure 21. Shape definition of bracket: (a) cross-section shape; (b) 3D shape creation through path curve; (c) shape optimization result.

Optimal solutions obtained using metamodels are verified in case of both determined and random excitations by analysis of the full FEM model. Figure 22 shows spectral density functions of vertical displacements in characteristic points of the GP caused by random excitations applied in places where the GP block is fixed to the vehicle block.

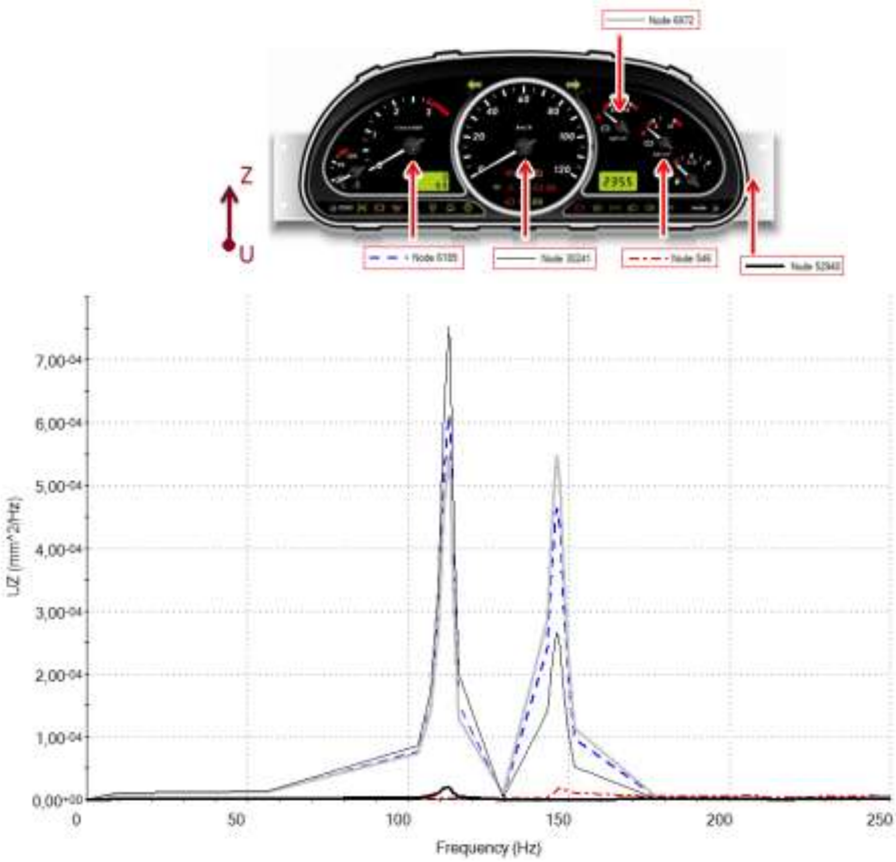


Figure 22. Spectral density of vertical displacements in characteristic points of the GP

In co-operation with *Merpro* Ltd. also the design of a gage panel (GP) was developed, some visual examples were created (see Figure 23), using SW Photoview360 software.

Figure 23. GP developed in co-operation with *Merpro* Ltd.

CONCLUSIONS

1. In the promotion thesis a comprehensive analysis of literature on the application of Pareto assessment and Fuzzy element method in engineering sciences and control theory is performed.
2. A method for optimization of multiargument criterion for evaluation of a whole range of different car brands was developed.
3. Pareto optimization method was applied for the development of two-variable compromise range.
4. For the first time application of Fuzzy elements in the development of an object (car) motion control method was implemented among scientists at Riga Technical University.
5. A completely new methodology for finding the shape of an object (automotive vehicle gage panel) was developed, using variable optimisation method, the development of theory of which was commenced at the RTU Machine & Mechanism Dynamics Research Laboratory.
6. Modern analysis and data processing methods were applied:
    a. the least squares method, linear and non-linear method, as well as Fuzzy element method was used in relation to optimization of variables;
    b. rating of variables;
    c. synthesis of adaptive electromechanical control system, using MathCAD software;
    d. application of metamodels, for the creation of which methods of experiment planning and analysis were used;
    e. environmental impact as total energy consumed, carbon footprint, air acidification and water eutrophication, using SolidWorks software.

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