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Product Development Through Multi-Criteria Analysis

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The trend regarding the development of sanitary fittings is forecasted by the use of a developed model of multi-criteria analysis. In this analysis a multi-dimensional space is used, which enables the establishment of a time argument in comparison to product parameters. The establishment of product parameters is achieved by means of internal company information and market needs. In this way it is possible to establish an innovative environment for the development of new products.

This paper indicates various ways of dealing with product development, on the basis of which the method of multi-criteria analysis for establishing future trends in product development is acquired.

Keywords: sanitary fittings, product development, multi criteria analysis, multi-dimensional space

0 INTRODUCTION

The key moment of any company's strengths lies within essential and sustainable continuous development. Modern companies require constant investment into development. The development of the equipment for product development is also very wide, while the use of such equipment is still not as widespread as it should be [1]. As a line of business, product development has played an important role in production engineering by researches within the global industry experience[2], design and analysis [3] and [4], product design [5] to [8] and creativity used in product development [9].

On the other hand, product development also includes research within the market with regard to customer needs [10], [6] and [11], product positioning and segmentation [7] and [12], product forecasting [13] to [15] and test marketing [16]. A number of applications, marked by different views, led to a deeper understanding of how to join and use the information regarding customers and product engineering in designing, testing, starting and managing new products. To further disclose the contents, methods and applications of the above, more integrative views and papers on the topic of product development were published [17]. The production and engineering precision, combined with the marketing approach, both of which were focused on customer needs and production capability, proved very successful. In parallel with the development of established equipment, researchers discovered the correlation of new product success by establishing the communication between marketing and production engineering as the most important elements necessary for success [2], [5], [10], [19] and [20]. Organisation processing equipment as are, for example, teams functioning via network [14], quality function development (QFD) and distribution [21], were all developed with the purpose of establishing a closer link between production engineering decision-making and customer needs [22]. New challenges and opportunities are reflected in global markets, global competitiveness, the global spread of engineering knowledge and with communication technologies. The use of multi-criteria analysis with product development represents a new challenge and an opportunity in design research and new product forecasting [23] and [24].

1 THEORETICAL BACKGROUND

In the last decade companies were focused on new product development on the basis of satisfying customer needs. Researchers in the field of marketing were convinced that understanding customer needs and improving the transfer of these needs to product manufacturers was the key to success.

The Kaizen method for continuous improvement helped enhance the understanding of quality in product development with improved reliability [25], with statistical-qualitative control [26], modified experimental design [20] and design for production [27] to [29]. Engineers were certain that a product of higher quality was the key to success [30].

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Both marketing and production engineering recognised that the time from conception to implementation was of key importance. The awards for the early entrants were excellent, while production engineering went through great losses by working overtime and delays. Customer satisfaction and the time from conception to marketing became the warranty for success and profit.

Both the economic and academic worlds realised that successful product development is a closely related process, which can bypass many compromises. Customer satisfaction, the time from conception to marketing and cost reduction through complete control and quality management are also important factors. However, none of them has been recognised as a warranty for success.

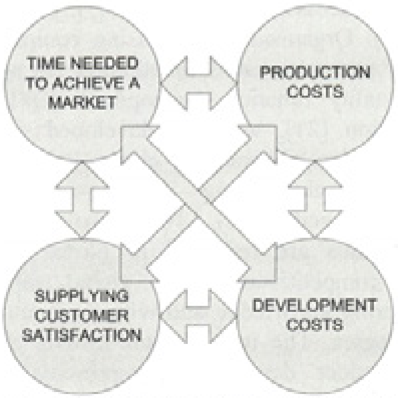

Fig. 1. *Alternatives and connections in new product development* [16]

Under unchanged conditions a product will prove profitable if it supplies customers with greater satisfaction, is among the leading products in the market, and has low production and development costs. Fig. 1 puts forward researches carried out in the field of equipment and product development methods. These researches should ensure that companies are directed towards new fields by taking into account all the strategic aims presented in Fig. 1. The concept of joint or common dealing of product parameters is included in the conjoint product analysis [13] and [31].

Researches must prove that various perspectives with all the effective new fields of development are of key importance. If a closer look is taken at only two of the numerous aims in the development of a new product, effectiveness proves the most essential. QFD can represent the most effective way of supplying customer satisfaction by means of improved communication and coordinating the efforts of the various parties involved in the process of product development. At the same time it is necessary to stress that certain equipment might prove inefficient in saving time in the process from conception to implementation and thus increase development costs.

Most companies see product development as a process of conception and implementation and connect it with production engineering, marketing, production and organisation development. Fig. 2 shows the process that takes place from conception to implementation [16]. It is a set of strengths that influence product development and shed light on opportunities for researches regarding product development.

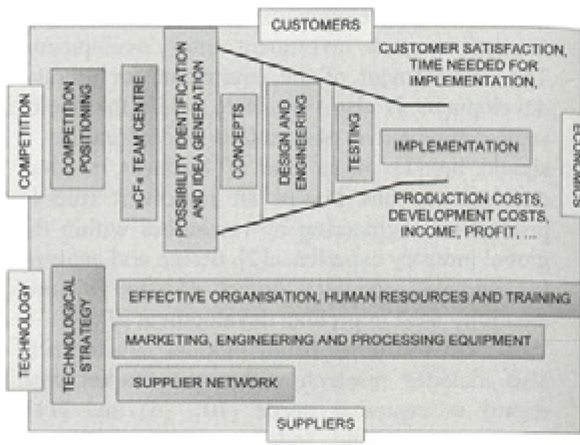

Fig. 2. *Product development: from cognition to implementation*

Instead of choosing a 3-year planning cycle it is advisable for companies to adopt a development plan which is checked on a monthly or even weekly basis. For example, a company should have a strategy for dealing with technology and with implementing methods for understanding opportunities that are to be offered to customers by means of offered products, as well as with recognising where demands and expectations are not being fulfilled. Here it is just as important to know how the competition will respond, while the supplier's chain helps and is involved in the development in order to fulfil customer demands.

Perspectives of marketing, production engineering, designing and manufacturing must be integrated for the needs of product development and show themselves as the basic network of a functional team that supports an effective organisation.

Human resources are important for the inclusion of needs for context and culture organisation understanding, as well as the need for developing human capabilities through training, information technology, and communication on the part of practice. Marketing, engineering and processing equipment enable the process of development from its conception to its implementation and support this process in being effective.

Product development, as shown at the funnel neck in Fig. 2, shows a normal - traditional view, according to which product development generates itself through idea conception and develops further into a number of potential products that are potentially realised. Within the neck presented in Fig. 2a method is adopted - steps of opportunities, identification and idea formation, concept development and choice, detailed selection of design and engineering, testing and implementation [8]. Although the context and individual companies use a slightly different description of the steps, the description of product development in the form of development steps remains more or less the same.

The basic idea of management is that it is less expensive to establish product suitability in the early rather than in later steps, and that every following step might improve the product and its positioning and thus increase its success in the market. Mathematic examples show that such a step process, which is best presented in the form of key steps, proves to be the most efficient in decreasing costs [1].

The neck in Fig. 2 also tries to show the concept of management flow by means of parallel projects that are moving through the funnel neck. However, in the steps, and in the assessment of the work carried out in each step, there is no connection between individual steps, which remains one of the greatest weaknesses of the step process. On the other hand, in the process of continuing product development in the multi-dimensional method this moment of weakness is smaller.

Often the best strategy for companies is to have a suitable number of parallel projects, since it is in this way possible to implement the project that shows the most profitable future. Fig.2 does not show clearly enough the importance of the real product development process characteristics, since certain steps are often expedited and left out.

For example, with advanced methods, as are user's and same-time design, it is possible to test the design concept already in the early steps of designing and engineering, or to, for example, present ideas already in the concept phase more effectively. Moreover, Fig. 2 does not explicitly include (co-)circumstances of the nature of the whole process [32]. Nowadays many companies use a spiral instead of line development process, since in the former products or concepts move through numerous narrower and narrower steps.

The essential difference between the neck and spiral processes is that the latter is more suitable for higher expectations in the form of a repeating return in the parallel direction through the neck of the shown funnel and leads to improvement. An interesting challenge for research would be to make a comparison of input data in the spiral and the funnel form of the process. Here could be compared which circumstances influence one or the other form of development and which is more suitable.

The process of multi-criteria product analysis also includes product platforms. It has been recognised in numerous industry branches and companies that it is far more effective to develop products in platforms. In the field of sanitary fittings a platform carries a very specific name – family. From the point of view of customers these platforms supply companies with the possibility of adapting to customer demands and market needs [4], [17], [27] and [33].

On the right side of Fig. 2, where the process from conception to implementation is presented, an increasing trend in the direction of conventional product development is shown. When the process is exposed to various circumstances, as are functionality, teams and suppliers, the process itself becomes more dispersed and the product involved consequently more complex. This then leads to a greater need for balancing in the controlling of top management by means of their increased and stressed own engagements in the role of connecting within functional teams. To achieve such balance companies turn to a metrical approach, in which teams are measured on the basis of strategic indicators, as are customer satisfaction and the time needed for implementation, as well as production and development costs. The enumerated parameters are followed-up in the analysis covered within this article. If the ratio of these parameters is correct, then these teams can perform in the best possible way and with the greatest short- and long-term enthusiasm, and it is only in this way that the accepted decisions will lead to the best short- and long-term profits [34].

2 METHODOLOGY

The conceptual model with data capture and information flow is shown in Fig. 3. The data are collected from the market with a data collecting form and the data flows into the data collector together with the technological company capabilities (internal data). The combined data are processed in the model, and in this way the model anticipates trends on the basis of individual parameters as well as the common trend. The possibility of development determination also depends on the body's centre of gravity which is time-dependent. Possible feedback connections are also shown on the conceptual Fig. 3 and serve as corrections or modifications to the model.

3 MODEL OF MULTI-CRITERIA ANALYSIS FOR PRODUCT DEVELOPMENT ASSISTANCE

The idea about multi-dimensional analysis of product acceptability in the market was born from watching two-dimensional graphs showing the dependence of the dependent variable from the independent one. The independent variable represents time, the dependent one is derived from the observed and most representative parameters – e.g. prices, sale quantities, input into development on individual product, costs of manufacturing. Because of the incapability of demonstrating individual parameters on one graph the concept or model is presented, which could eliminate that weakness.

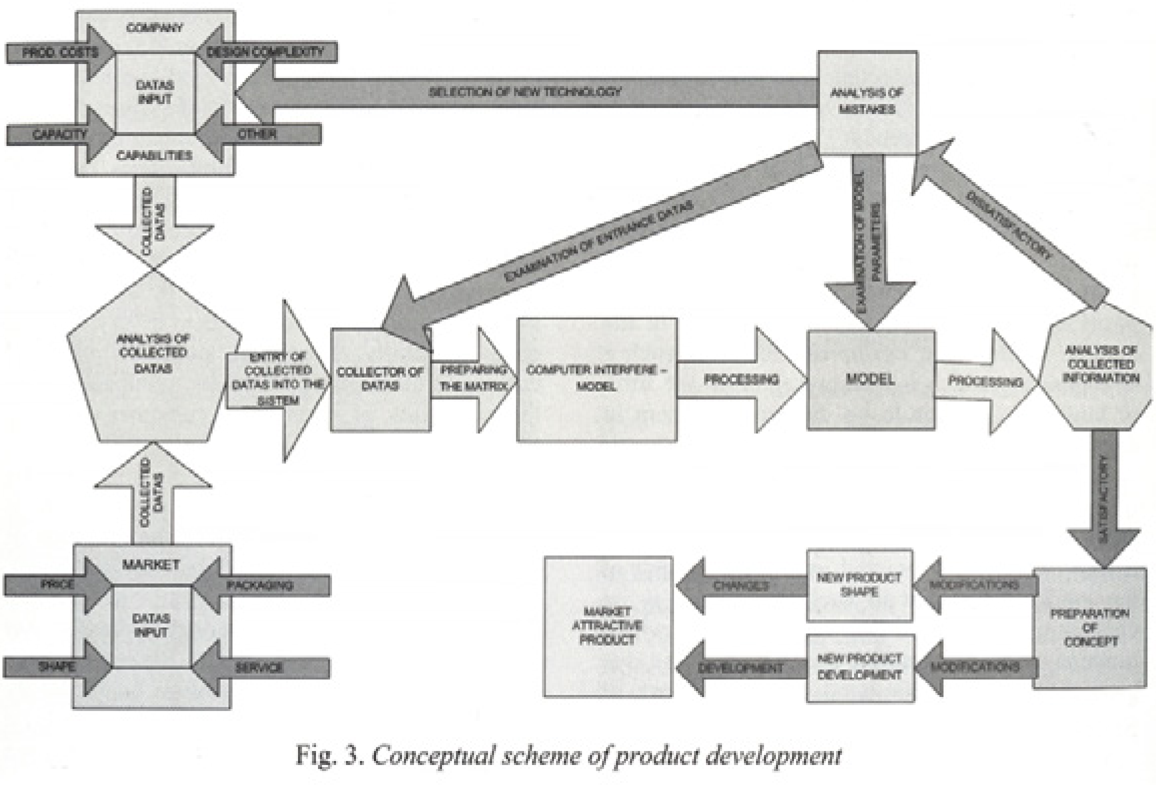

Fig. 3. *Conceptual scheme of product development*

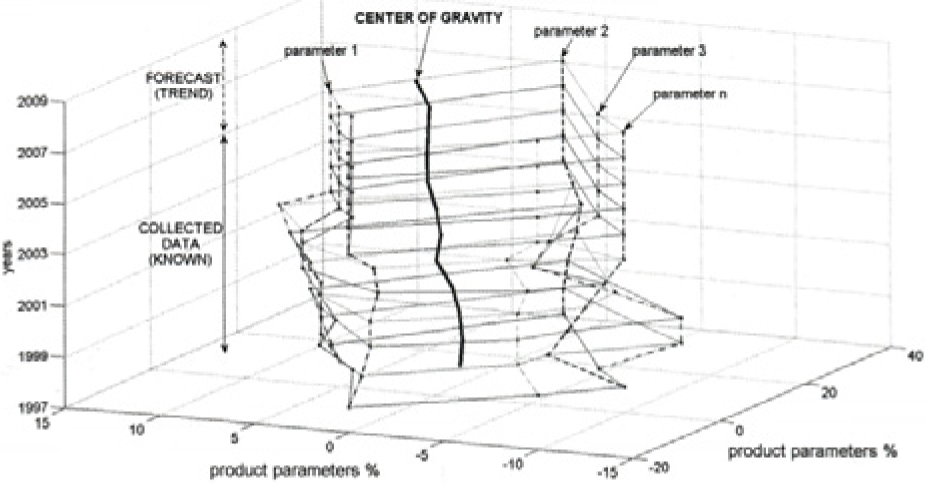

Fig. 4. *Outline scheme of the model*

Due to longer non-changeability of products and technology in the branch most of the products observed remained the same in that time or changed minimally (e.g. sanitary fittings, handles of sanitary armatures and packaging changed [35]), which is an additional confirmation of the model`s results. The calculated trend on the basis of the gravity centre is represented graphically and mathematically and applies for future years.

The transition from Cartesian coordinates to polar coordinates is given by the following Equations (1), (2) and (3). In Equation (4) we calculate the uniform distribution of the horizontal axes of observed parameters around time – central axis. This uniform way of distribution of product parameters does not emphasise only one parameter but that all parameters are equivalent Equation (6).

The representative parameters acquired from the company are evenly distributed on the circle arch of 360° with the centre in coordinate origin. The angle according to Equation (1) belongs to each parameter; parameter n means the number of representative parameters.

$$\varphi_k = 360^0/_n \cdot (n-k)\ ; \quad k = 0,1,2....n-1 \tag{1}$$

The percentage value of an individual parameter with belonging angle (Equation (1)) is converted to Cartesian coordinates upon Equations (2) and (3). On the coordinate axis "z" an independent variable time is shown or the period of watching (e.g. from 1997 to 2007).

$$x_k(\%) = Par_k(\%)\cos\varphi_k \tag{2}$$

$$y_k(\%) = Par_k(\%)\sin\varphi_k \tag{3}$$

Each parameter is represented in the form of a point, with three parameters used for representation of the results in three-dimensional space, where parameter m is the number of years observed.

$$Par_{k_{kart}}(\%) = (x_k, y_k, z_m) \tag{4}$$

Presentation of results with a polar way of data demonstration is improved since it shows the trend and not just information. The centre of gravity of the surface shape enclosed by polar coordinates of observed parameters is calculated upon Equations (5) to (9). The shape contains a set of n-triangles and the sum of the n-centers of the mass of those triangles is the mass centre of one observed time parameter [35].

$$S_i = \frac{1}{2}\begin{vmatrix} x_k & y_k & 1 \\ x_{k+1} & y_{k+1} & 1 \\ x_0 & y_0 & 1 \end{vmatrix}; \quad (x_0, y_0) = (0,0) \tag{5}$$

$$x_m = \frac{\sum_{i=1,k=0}^{n,n-1} S_i x_k}{\sum_{i=1}^{n} S_i} \tag{6}$$

$$y_m = \frac{\sum_{i=1,k=0}^{n,n-1} S_i y_k}{\sum_{i=1}^{n} S_i} \quad (7)$$

An algorithm draws and calculates polar coordinates for individual periods between the year *m-1* and the adjacent variable, and the year *m+1* and the adjacent variable. The year is selected as a time argument typical for the branch since the product and technology changes are relatively slow.

The representation of the centre of mass in a polar way Equation (8) to (10) provides complete information related to an individual time period.

$$T_{pol_m} = \rho_m e^{j\gamma_m} \quad (8)$$

$$\rho_m = \sqrt{x_m^{\ 2} + y_m^{\ 2}} \quad (9)$$

$$\gamma_m = tg^{-1}\left({y_m}/{x_m} \right) \quad (10)$$

Time as the only independent variable is represented by the central axis in the graph, which is the result of model visualization. The displacement of dependent variables on time shows their importance and development upon time parameter.

There is an arbitrary number of dependent variables in the model. They are configured in the circle around time in the form of uniform distribution. For the purpose of this investigation a model is prepared where data is uniformly distributed.

In the observed changing of the trend it has been ascertained that linear accommodation is inaccurate.

These are higher order curves that are genomically imposed and on the bases of polynomial curves and Fourier rows (harmonic analysis) in Equation (11) they form a trend for each parameter separately (curve accommodation is higher than 95%)

$$s_n(x) = \frac{a_0}{2} + a_1 \cos\frac{2\pi x}{T} + a_2 \cos 2\frac{2\pi x}{T} + ... + \frac{a_n}{2} \cos n\frac{2\pi x}{T} + ... + b_1 \sin\frac{2\pi x}{T} + b_2 \sin 2\frac{2\pi x}{T} + ... + b_{n-1} \sin(n-1)\frac{2\pi x}{T} \quad (11)$$

3.1 The Use of a model in the Example of Sanitary Fittings

There is practically no research to be found on the topic of development of sanitary fittings products. The field of survey is from the production engineering point of view, which is interesting due to the complexity of the product. It is pre-supposed that sanitary fittings represent generic products which are intended for a wider range of users.

The sample on which the first model of multi-dimensional analysis is prepared with the intention of product development covers eight time-dependent variables of sanitary fittings. The products observed were sanitary fittings of middle-price range in Slovenia. The price and quality range was assumed on the basis of expert opinions from the branch of sanitary fittings production and from the branch of sanitary fittings suppliers. The number of the chosen sanitary fittings representatives comprises 95% of the observed range, that is the sixteen most representative products of the middle-priced range of recognised European trade marks that were, and still are, present in the Slovenian market. The price range of up to 110 EUR, for which certain marketing and production rules are applicable, is a so-called premium range. The characteristics that were observed in the chosen sanitary fittings were the following: price, shape, packaging, service, production costs, capacity, design complexity, and unclear influences given under the column other.

The questionnaire that was carried out in the market and among the Slovenian producers of sanitary fittings showed the information represented in Table 1. The key moment belongs to 'product' and 'product characteristics'. On the basis of this key moment the carrying out of the analysis covered the most important parameters of the product in each time period for the observed group of sanitary fittings (herein parameters). These parameters do not change through time intervals. The concept of the information analysis is based on the observation of the product in each of the given time periods. However, trend forecasting for future time intervals is based on statistical analysis by means of an approximate function that is designed as development simulation. The information that was not gained empirically is subject to the joint evaluation of experts in the field of sanitary fittings. In 1997 the characteristics of the product in the market were the following: 30% of its value was represented by price, 10% of the overall product was represented by the importance of its design, 5% was represented by its packaging, 5% by service, 20% by production costs, 10% by capacity, 10% by design complexity and 10% by other characteristics. The total of the observed and covered parameters lies in the centre of a polygonal form of the observed characteristics.

In 1998 the same market and the same product were analysed. However, the latter included new characteristics this time. This paper represents the same number of variables for each year, with the intention of showing the functionality of the system.

The established algorithm was modelled in the Matlab programme version 7.6.0.324. This programme enables easy and transparent recording of algorithms. By means of Matlab computing language, which contains a number of other functions for three-dimensional presentations of objects, three-dimensional programming was also performed.

4 RESULTS AND PREPARATION

The established model has eleven years' worth of recognised parameters (Table 1), which develop partly independently from one another. Even though the reviewed parameters do not have much in common, they represent one product and development path within one time determinant. The combination of market data and strategic know-how of the company are thus presented in a graphically simple, transparent manner and within a mathematically ascertainable system. Polynomial interpolation and extrapolation allow the adjusted trend to offer values of individual monitored parameters based on a set time-frame. In polynomial interpolation, we find the polynomial which corresponds to function f at given points.

If we are presented with N points, we require a polynomial at N-1, so that the set polynomial is uniform. Some functions may be interpolated well by using polynomials, while others pose more difficulty. Calculation of polynomial interpolation is carried out by using Neville's algorithm. The trend determined in such a way will confirm future parameter values with a probability higher than 2 sigma. These values, moreover, represent changes in product development throughout future time-frames.

There is an indication of which way the product will lean towards and which parameters will be emphasised. This will give designers of new products in the company guidelines for development, which will not be limited solely by the market, but also by the company. The combination of the company's internal – economic arguments and external data obtained from the market, is presented as key in the literature [6], [10], [27] and [35].

Table 1. *Information gathered from the market and company*

Time (years)	Observed parameters								
	Market information				Manufacturer information				
	Price	Shape	Packaging	Service	Production costs	Capacity	Design complexity	Other	Total
1997	30	10	5	5	20	10	10	10	100
1998	30	11	6	7	17	8	6	15	100
1999	31	12	6	6	15	8	7	15	100
2000	33	12	6	7	15	8	8	11	100
2001	34	14	7	8	13	9	9	6	100
2002	32	15	6	7	14	7	8	11	100
2003	34	16	4	6	12	8	9	11	100
2004	36	18	4	4	11	7	10	10	100
2005	37	19	3	3	11	7	7	13	100
2006	38	19	2	3	10	8	6	14	100
2007	43	17	2	2	12	8	8	8	100

The observed model shows the aggregate variable to be the centre of gravity. Analysis of data in the future allows linear review or quadratic review of the trend, including an arbitrary form of establishing a trend based on lines of respective independent variables.

The common trend of spatial lines allows for analysis of a common product development trend. It depends on the respective field whether data from the market or from the company is more important. When the model is ideal, all dependent variables may be presented arbitrarily at optional angles, and further broken down into their dependent variables. When reviewing independent variables this may be done in a classical circle diagram.

The system is limited by the values of the dependent parameters of the product, which represent the limit value. This limit value is the limit which the company is not allowed to surpass in a respective product development in considering the model, as doing so would impair its competitiveness, which must be monitored with regard to all parameters of the product. In this part the model looks to the finite elements analysis, where outer limits are recommended for development and establishment of individual product parameters - summarised according to [22].

Fig. 5 shows the "skeleton" multidimensional graph of product development. Limits to the system are set uniformly with boundary lines of observed parameters. The central axis is represented by the centre of gravity, which is the aggregate variable, and indicates a trend, which is presented in greater detail in Fig. 6 and Fig. 7.

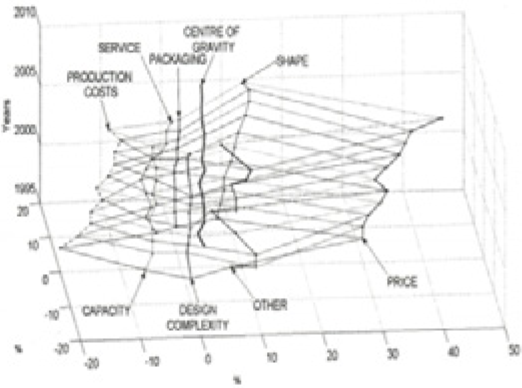

Fig. 5. *Overview of links between individual product parameters and the aggregate variable – the centre of gravity*

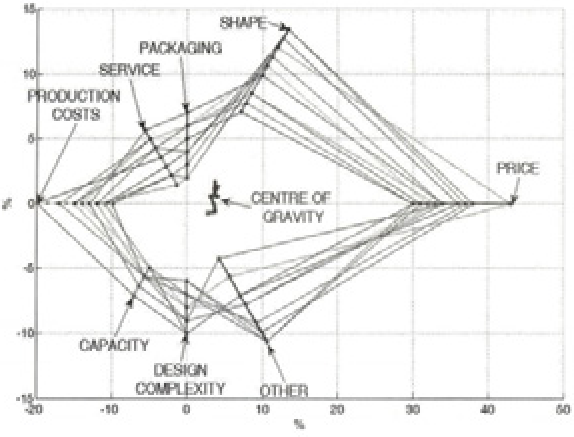

Fig. 6. *The ground plan of the graph shows deviation of the centre of gravity to the desired product parameters*

Fig. 6 shows a view of the polar graph through various time-frames. The centre of the graph is the point of time with coordinates T (0, 0, 1997). The whole display otherwise presents the development of individual product parameters and their mathematically ascertained trend.

The polar diagram shows shifts in the gravitational centre from 1997 until 2010 – Fig. 6 and 7. The path travelled by the aggregate parameter, comes from the direction of different characteristics, which substantially mean unchartered territory for the product in the direction of the product design.

These data are appropriate and also logical considering that the industry is an unknown variable. Development departments in the company will thus have a goal to design an armature that will be interesting and demanding from a design point of view. The direction of development would be further improved by conducting an analysis of the sense of design and thus obtain the desired values. It is presumed that the product design in the observed class will summarise the features of design in the higher class, which generally dictate the direction of development of lower and less demanding products in terms of quality. They would also discover whether they are able to achieve the desired market design with the given technology and production costs, which would give the model a moment of strategic decision-making with regard to product development.

Fig. 8 gives us the opportunity to observe a multidimensional curve, which is defined by the absolute value of the angle of aggregate indicator of the trend of the centre. These curves show a linear trend which, in the coming years, moves the centre of the observed products towards the importance of product design.

5 CONCLUSION

Life cycles of technologies, products and processes are becoming ever shorter, so technological foresight is a very important aspect of their planning. In a time when foretelling the development of products is difficult and the price of error as steep as it is, the article offers a solution for the development of products through multidimensional analysis. An alternative manner of product development, it is based on a simple premise that an individual product in a certain time consists of separate parameters, which make a whole.

The presented concept can be developed and adjusted towards all dimensions of modern forecasting of the development of middle range sanitary faucet products, which will, through time, show a deviation from the orientation towards unexplored elements towards product design.

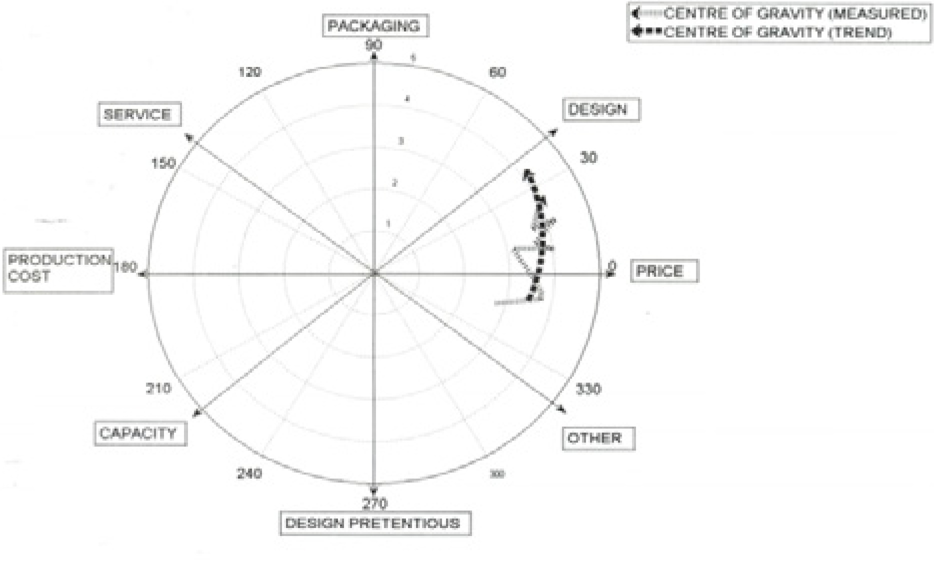

Fig. 7. *Polar graph of the movement of the centre in the observed years*

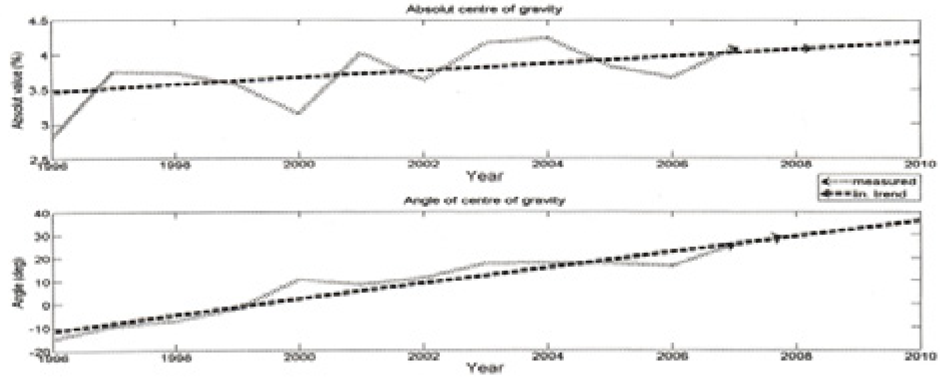

Fig. 8. *Variation of the absolute value and angle of the centre in the observed time interval*

Advanced options of the defined model are:

- The introduction of virtual reality into strategic product development, which would allow a multilayered and even spatial analysis of the outer limits of the system, which delineate the logical scope of development of a single product.
- A comparison of the development of two competing products through time, which would show the differences and similarities of products and highlight the advantages and disadvantages of an individual product through an analysis of 10 parameters.
- An opportunity to improve the visualization of the advantages and disadvantages in the business area the product is placed in.
- An opportunity to link the model directly with production and computer prototyping.
- Trend forecasting on the basis of extensive experience.
- An opportunity to analyse the internal characteristics of the company and gathered external data. The internal data gathered within a company and market research data allow simple and straightforward development of a concept of further company development, and enable the assessment of separate parameters through simulation. This is very important considering the fact that the limitations of production are equally or more important than market demand (high tech products), which enables us to enforce the claim calling for a technology "push" and marketing "pull".
- Computer models include a data entry interface which allows entry of data for instantaneous analysis in the model, thus effectively simulating whether further improvements remain reasonable [36].
- Analysis of separate parameters with the aid of approximation of existing movement by the movement of the aggregate central variable; a joint concept would provide more detailed data about product development as it would allow double simulation.
- An opportunity to analyse the shift of the aggregate variable of the body centre and its deviation towards individual dependent variables represents the quality of such an analysis.
- Another option is the representation of the "onion" product strategy – on a model where the basic demand for the product is fulfilled and its transfer into higher levels improves the product.
- Choosing shorter periods of time would not allow for such detailed data. The line between both time intervals can be an approximated value, which would indicate seasonal movement of product parameters.

The developed model of product design through multi-criteria analysis can be used in the development of virtually any mass produced product.

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