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MULTIPLE CRITERIA ANALYSIS OF A LARGE-SCALE PRODUCT WITH THE DFx METHOD

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Abstract:
This article discusses the multiple criteria method of the development of a large-scale product in the case of mid-price range sanitary fittings using the DFx ("design for") method. The concept represents the advanced method for developing a new product in the production process. The development of a large-scale product on the basis of multiple criteria analysis allows for a more accurate simulation of the most important parameters in one centre of focus of a multidimensional character at the same time. In a multi-dimensional environment, development restrictions are placed on multiple criteria analysis; the production parameters are identified and through this, there is a possibility of reducing production costs.

The presented concept practically simulates development in the case of sanitary fittings, which are a large-scale product, suitable for product analysis with the DFx method.

Key Words: Development of products, Multiple criteria analysis, Multidimensional space, Sanitary fittings

1. INTRODUCTION

It is certain that innovations have an impact on the increase of productivity within a company. By increasing its competitiveness, a company can increase its economic effect, and, regarded from a global point of view, the employment opportunities and the standard of living will also increase. Only innovations can ensure new jobs [1]. Continuous improvements allow competitive advantage, allowing the company to survive in the most turbulent environments.

In market-oriented innovative production systems it is necessary to insure as great information integration and fast adaptation to market conditions as possible. CAD/CAM systems are now days tightly connected to assure that CAD data can be used for optimal tool path determination and generation of CNC programs for machine tools [2].

The article is the continuation and in-depth analysis of production parameters, which the authors have previously discussed (see [3]). In this part, they have presented the market and production parameters in their entirety [4]. Deep attention is dedicated to manufacturing parameters, which have been identified as crucial. With the help up multi-dimensional and multi-parameter analysis, they seek to demonstrate that the treatment of multiple parameters simultaneously, while dependent on time, allows for more precise monitoring and forecasting the future development of the product. The following methods are actively used in the product development:

- CIM (computer integrated manufacturing), which represents the greatest challenge to production systems nowadays [5],
- CAD (computer aided manufacturing),
- DFx (design for …).

When designing an article, the DFx method is used. It is divided into several target areas of treatment [6]. There are several tools for development, though in practice, they are not commonly used. Product development, as an industry, has a long history in manufacturing engineering research in terms of global industrial experience [7], design and analysis [8, 9], [10] product design [8, 11], and creativity in product development [12] The importance of new products in manufacturing and sales is an important indicator of how technologically advanced and vital companies are. Companies that are technologically advanced and whose

programs include producing new and exciting market products are much less dependent on market fluctuations caused by global economic turmoil [13]. For businesses, it is important to monitor "external" market data, as well as "internal" production data.

More integrative views on product development with the help of that concept are given in sections [3, 4, 7], with the intention of revealing the essence, methods and applications.

In past decade, organisations have realized that not all knowledge can be captured in quality systems. Organisations have begun to recognise the role of knowledge workers as crucial to organisation competitiveness. Nowhere is this more critical than in the fields of invention and innovation. Design by its very nature is firmly centred in invention and innovation [8].

When observing the requirements of the market and the recovery of that information, the power is with the operating model and innovative potential of employees to enable constant development, which is targeted with the DFC (design for customer) method. By creating a product targeted to the needs of customers, a company ensures it long-term existence and potential for growth.

2. DEFINITION OF THE PROBLEM

Analysis of the functionality of CAD/CAM systems show that level of computer aided process planning in CAD/CAM system is relatively low [13].

Development of technical product, which is produced in large batches, must be sophisticated and tailored so that its development is properly targeted to meet the technical requirements in all phases of production. It is correct to claim that the more demanding a product is, the more individual phases in the production cycle must be controlled and supervised. There are many methods for quality analysis (quality standards are ISO, DIN standards). In terms of the umbrella framework of quality, they are exceedingly worked out and accurately defined.

The DFx method is divided into the following modules [6, 13]:

- DFA (design for assembly)
- DFM (design for manufacture)
- DFS (design for service)
- DFE (design for environment)

The DFC link is added, the goal of which is to satisfy the customer. The role of consumer information is crucial to product design. The model, which is presented with mathematical contained information, can accurately identify the direction in which the product will be developed according to the most important set of arguments. In the case of sanitary fittings, large-scale products are products that exceed the annual number of a million pieces [14]. They are specific in relation to the legality of flexible cultivation systems, such as full use of the flexibility and productivity, greater utilization of the system and automatic product switching, tools, cultivation programs, monitoring programs, fixtures and measuring devices [3].

In the concept advanced product development, multi-dimensional methods are used such as assistance in comparison with the conventional two-dimensional graphs, and the third parameter is used. In the presented model, the key parameter used is time, as all other parameters depend on it. Time-dependence of all parameters forms a space, which has its own volume and centre of focus for a given time period, which changes in accordance with the time. The focus of the time-dependent character gives us the direction in which it will manufacturing of the product will lean or shows which variable will gain value within each time interval.

At a time of economic turmoil, it is also possible to take into account and simulate the parameters with respect to a possible change in reality. The moment that the model used, it is relatively easy to show the centre of focus, which is linear in nature and emphasizes the individual parameter. In the continuation, a concept is presented, which includes data from the production and generates them into a model. An important limitation is that data are always on the same axis with regard to the time central axis. The analysis is the result of a

several-year monitoring of the real production data in the company, which manufactures sanitary fittings of all price ranges [4].

Most companies now see the development as a process from design to start in conjunction with engineering, manufacturing, marketing, the production and organizational development. The process from design to start thoroughly discussed in section it represents a compilation of the forces that affect product development and highlighting the opportunities for research in product development.

Developing a product based on the principle of a "funnel", into which all information is poured, represents a normal – traditional view, according to which product development is generated and developed through conceptual design and into a number of potential products to be released. In this funnel, a method is adopted – the steps of opportunity and identification, as well as the creation of ideas to develop the concept and choice, the detailed choice of design and engineering, testing and commissioning. Individual companies have slightly different descriptions of these steps, but the description of product development in the form of development steps is more or less similar.

With advanced methods, such as simultaneous engineering (SE), it is possible to test a new concept in the early stages of product design and engineering ideas. Through this type of work, precious time is saved from competition and a direct response is obtained regarding whether it is advisable to continue developing the product.

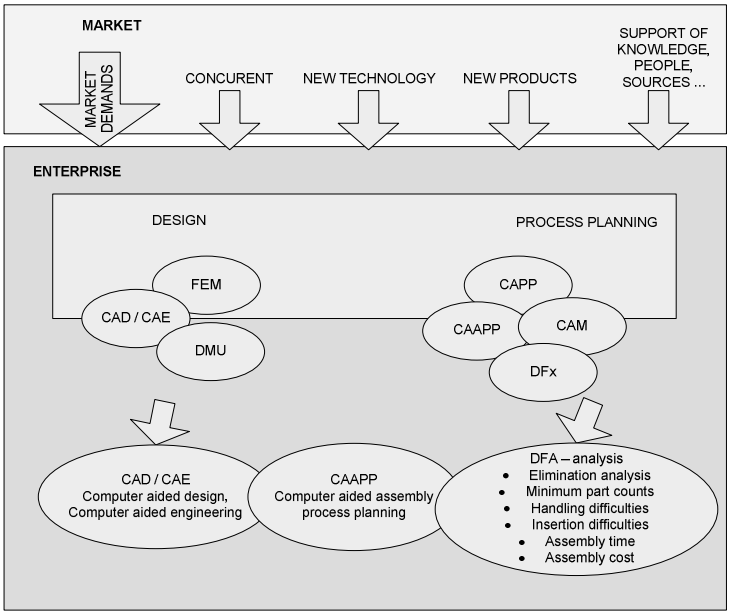

Figure 1: Functions for the CAAPP and DFA systems [6].

Figure 1 shows the common impact of the most important parameters in the company. The connection of all processes from FEM to DFx runs on the same level, but in the fields of design and the planning process. The advantage of multi-dimensional method is that it combines the current of two into a central one, which is time-dependent and targeted to meet the market needs. The figure also includes CAAPP (Computer Aided Assembly Process Planning), which introduces computer-assembly process planning, and can be introduced into the system as integrated with CAD / CAE and DFA.

Boothdroyd and Dewrust's DFMA method (Design For Manufacturing and Assembly) is a tool, which allows the simplification of the current and future design and production process with the intention of reducing management costs. It also enables the improvement of the supply chain, product quality, production quality and communication between design, production, income and management.

There is also a platform of products in the process of multiple criteria analysis of the development of large-scale products. Many industries and businesses have recognized that

it is much more effective to develop products in platforms. Specifically in the field of sanitary fittings for platform description is named - i.e. family. From the consumer aspect, platforms give companies the opportunity to adapt to their major demands and market needs [15, 16].

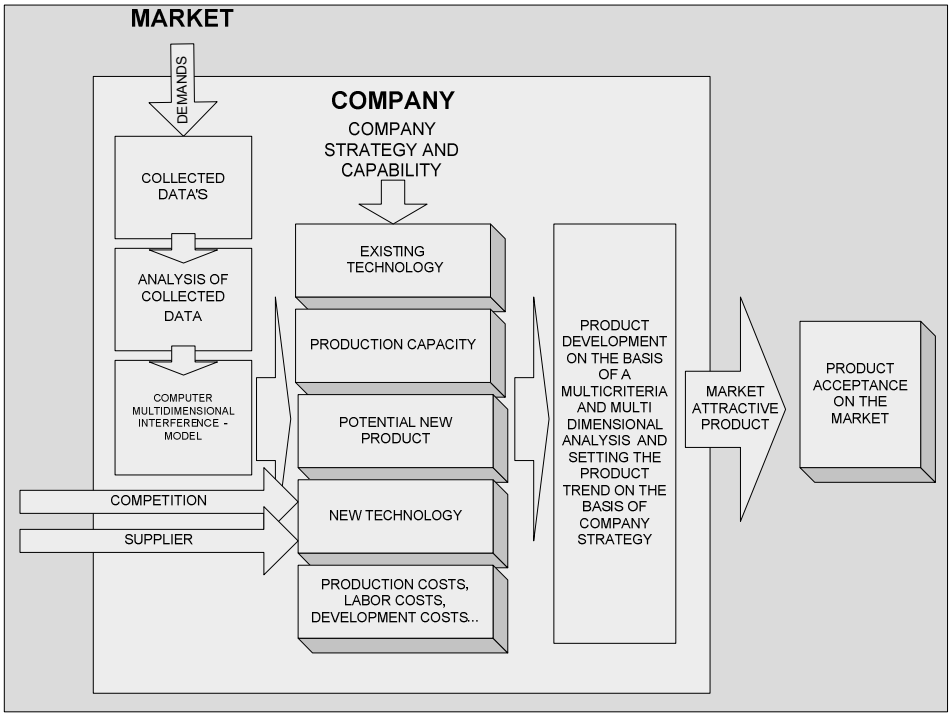

Figure 2: Conceptual design for product development.

The concept of the design of the development of a new product in the company is shown in Figure 2. For the needs of the presented concept, a form to capture the data that are most important in the development of the product is developed [14]. The data are drawn from the market and are usually in the form of requirements or a desire to resolve the problem [3]. The collection of data does not have to do with radically new information, since this cannot be produced by consumers. It has to do with small improvements and ideas, which come to the user or consumer when using the product. The company must use "sensible" enough tools to recognise these demands, collect and analyse them. Collected and analyzed information is entered into the model, into which the company strategy is additionally entered, which is limited by the available technology, the facilities, with the wishes of the owners and financial resources. Potential new products are not only the wishes of the market, but also the ability of companies to produce these new products. Financial inability to sustain the project of a new product is not necessarily the only shortcoming. A greater shortcoming is ignorance or technological complexity to solving the problem, which has a strong time component (e.g. technological innovation or invention could solve such a problem and the competition already has it). The solution is significantly easier if the problem is already solved by the suppliers. This way, the company can observe with more transparency, the extent to which it is in terms of development and up to what point it makes sense to invest financial and other resources.

Upon releasing the product, the product has a lot more opportunity this way to be a success on the market, since it already satisfied the wishes and needs of customers in the early stages. In a number of solutions offered by the competition, can be a competitive advantage, initialised by the market and addressing the problem in a specified area.

Understanding the problem without using CIM is practically impossible, as there is too much information from the market, which can be hard to identify without statistical support. The computer, as a tool with optimal software, would enable the collection and analysis of data. In the next stage, the company can process through and with the help of the set

design, which on the basis of the data would indicate the direction and determine the direction in which the product will develop. In combination with the business strategy, the company could develop an interesting market product. Upon the intermediate design of a product in the computer model of a large-scale product, the company could acquire the product through CAD, which would be designed for the consumer using the DFx method.

3. MODEL OF MULTIPLE CRITERIA ANALYSIS FOR ASSISTANCE IN PRODUCT DEVELOPMENT

The idea of a multi-dimensional analysis is presented in more detail in the article [3], so in this article, only the parameters are mentioned, which are interesting and have a productive impact on the creation of large-scale product of sanitary fittings and are treated through the concept of CIM [17]. The independent variable shows the time, dependently forming the most representative parameters of production.

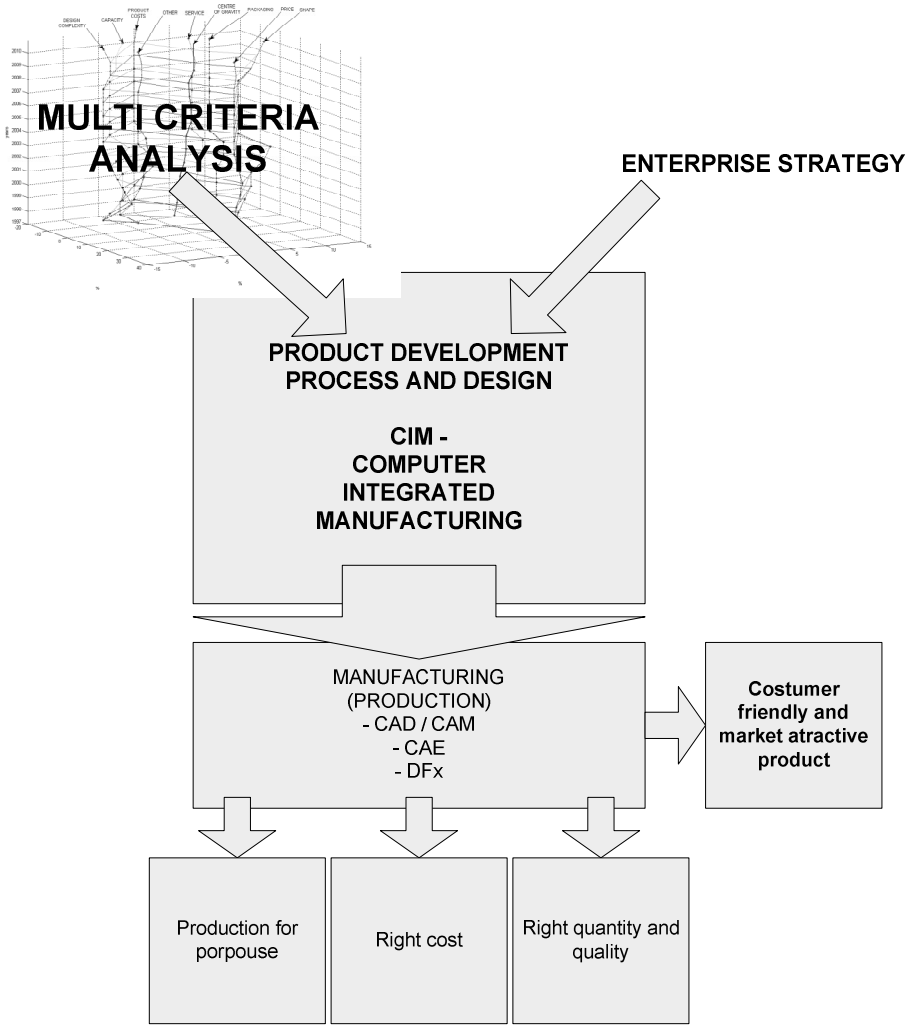

Figure 3: Design outline of model.

Today's CAD technology, for example makes it relative easy to create line drawings that represent tree – dimensional models of a part. However, simultaneously translating inarticulate customer tastes into articulate product concept, or verbal product concept into visual styling designs and numerical specifications remains difficult. Similarly, the timing of solving problem in critical, adjacent stages of development, such as prototyping or tool

building, and the number of iterations in the design – build – test cycle may affect overall lead time and development productivity [9].

The way from Cartesian coordinates to polar coordinates is given by the following equations from (Equation 1) to (Equation 3). In equation 4 it is calculated 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 (Equation 2) and (Equation 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 (Equation 5) to (Equation 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 [18].

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

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

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

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

$$T_{pol_m} = \rho_m e^{j\gamma_m} \tag{8}$$

$$\rho_m = \sqrt{x_m^{\ 2} + y_m^{\ 2}} \tag{9}$$

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

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 are 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 [4]. The year is selected as a time argument typical for the branch since the product and technology changes are relatively slow.

4. CASE STUDY

There has been no research on the theme of development of sanitary fitting products with the DFx method with an emphasis on production features. From the standpoint of a production-engineering, field research is interesting because the product is complex. The assumption is that sanitary fittings are a generic product intended for a wider range of users.

The sample, according to which the multi-dimensional analysis model for product development was prepared, including four time dependent variables of mid-price sanitary fittings in Slovenia. The price-quality range was based on the opinion of experts from the branches of production of sanitary fittings and sanitary fittings service branches [3]. The characteristics that were observed in selected sanitary fittings are as follows: the cost of production capacity, design complexity and unexplained effects or different range.

The questionnaire, which was carried out at a Slovenian manufacturer of sanitary fittings, obtained the information contained in Table I. A more detailed analysis of all the market parameters is included in the article [4]. The total sum of all the parameters in any particular year is optional, as only production is analysed - internal data. The observed data in 1997 represented half the total product; in 2007, it was only 36 % of the same one. From this perspective, it can be concluded that the product is already in a maturing period of development and competitive in this time of technological development and that production capacities have been updates. Impact on the product has been transferred from production to the consumer. Selected and observed parameters within intervals are not altered and have a constant position in the polar position. The concept of data analysis is based on observation of the product in individual time periods. Forecasting the future trend for the time intervals, is based on static analysis through the approximated functions, designed in the form of simulation development. The data that have not been empirically derived are subject to the common assessment of experts in the field of sanitary fittings. The characteristics of the product in the company were for example, in 1998, as follows: 17 % of the importance was represented by the cost of production, 8 % capacity, 6 % the complexity of the design and 15 % of other features. The combination of observations and the parameters covered is the focus of multi-angle character of observed features. Others mean obtained information, which is harder to identify and can are partially of market origin.

The set algorithm was developed in Matlab version 7.6.0.324. The program enables a simple and survivable record of algorithms. With the help of Matlab programming language, which contains a multitude of functions for the 3-D-out-buildings, three-dimensional programming was also carried out.

Table 1: The data collected by the market and by the company [14].

Time (year)	Production costs	Capacity	Design complexity	Other	Total
1997	20	10	10	10	50
1998	17	8	6	15	46
1999	15	8	7	15	45
2000	15	8	8	11	42
2001	13	9	9	6	37
2002	14	7	8	11	40
2003	12	8	9	11	40
2004	11	7	10	10	38
2005	11	7	7	13	38
2006	10	8	6	14	38
2007	12	8	8	8	36

The algorithm draws and calculates the polar coordinates for a specific period during the year n-1 and the adjacent variable, as well as during the year n+1 and the adjacent variable. The year was selected as the time argument, typical of this sector, since the change of products and technologies is relatively slow.

"Product excellence" is much broader than basic functionality or technical performance. Customer who have accumulated experience with a product and become sensitive to subtle differences in many product dimensions demand total balance of numerous product characteristics, including basic functions, aesthetics, semantics, reliability, and economy. The extend to which the totality of a product achieves this balance and attracts customers in a measure of product integrity [9].

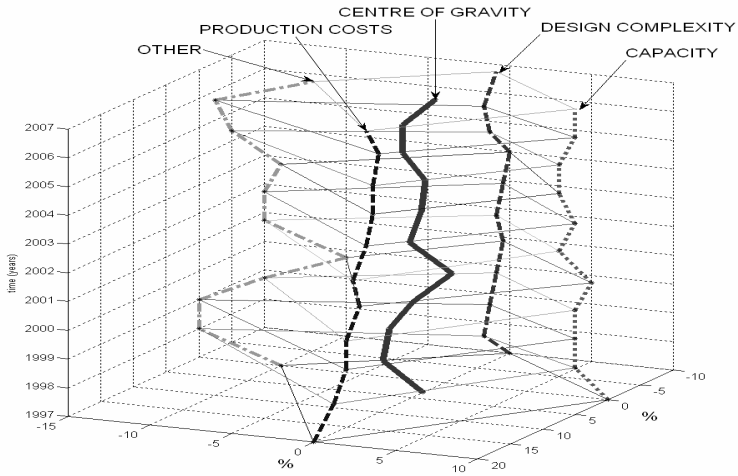

Figure 4: Multidimensional motion of product parameter focus of a large-scale product.

In Figure 4, a multi-dimensional graph is displayed, in which each parameter in Table 1 has its own dimension, which is polar defined. The movement of data for each parameter is independent of other parameters, but they all describe a single product. For this reason, the common centre of focus is a generic indicator of the movement of production parameters for the evaluated product. In Figure 4, all the Formulas from (1) to (10) are connected. Within the multi-dimensional display, the important lines are the ones in bold. In the polar view in Figure 5 the movement of focus in a particular direction and certain intensity. In the analysis, the argument presented that production costs are of crucial importance, is completely valid, but other parameters "play" an important role and the intensity of focus has shifted to the centre, and balanced all parameters. The response to whether or not the balanced method is

appropriate for the product, according to the trend, which indicates the direction of design complexity, is affirmative. In this way, the company has the opportunity to address the design complexity and make progress in this field. With the DFx method, a company can direct its efforts towards the designing of products.

Through the simulation of various parameters, in the future, with a model, a company can sufficiently indicate the direction in which a product will be developed. Depending on their abilities, especially in terms of production, it can assess whether its development and investing in it make sense and to which extent this is profitable. Considering the direction of product development, it makes sense to create a prototype and test it on the market. The impact of the tests can answer in detail, whether or not the decision is appropriate. It is interesting that the overall analysis of the parameters in article [4] showed that the market trend is also directed towards product design. The key parameter is therefore the complexity of the design model, which emphasizes the use of "different" forms, which should be further explored and determined on the market. A proposal to finding a solution might be a change in the housing design or a change in the approached to sanitary fittings.

With the help of CAD/CAM, the DFx method has obtained a new dimension in the development of new products. In the formation of ideas, it can serve as a key path. The trend, which gives the answer in this case, is linear, but roughly approximated. The movement of the centre of focus is spiral and addressing the trend of this spiral would give a more detailed response to individual parameters within the time of analysis.

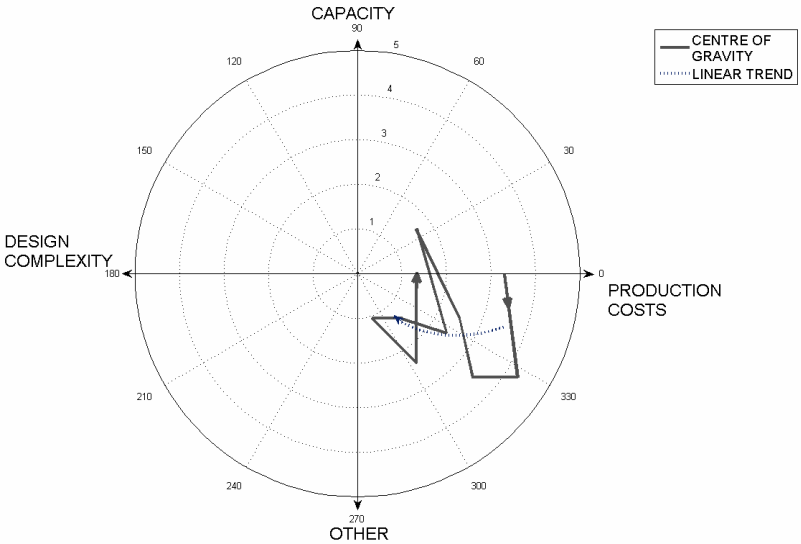

Figure 5: The polar centre of focus based on the several-year observation of parameters.

5. CONCLUSION

Life cycles of technologies, products and processes are becoming shorter, so it is very important to predict the technology for their planning [7]. An alternative form of development of the product incorporates a simple position, in which is a single product in a given time consists of various parameters, complete the whole [4].

The above concept can be developed and completed in all dimensions of modern forecasting product development of mid-range sanitary fittings, which according to mathematical evidence and in accordance with time change, move from the direction of unexplored elements to the direction of product design [4].

Use of the DFx method is aimed at the consumers and the fulfilment of their needs. In the presented case, the fulfilment of requirements within a company is not viable or technologically possible, capacities are not achieved or it is not in the strategy of the company. The graphic display makes it easier to show the direction of movement of the most important parameters within the company through visualization of the problem.

The presented model has advanced features that would allow:

- the possibility of improved visualization of shortcomings and advantages in the industry in which it is located;
- the possibility of directly introducing CIM methods into the system of developing new products;
- forecasting the trend based on years of experience;
- the computer model is prepared so that information can be entered through an interface, which can assess that model within a minute; this way, we could actually simulate, whether or not there is a point to further improvements;
- analysis of individual parameters with the help of approximation of earlier movement to the movement of the centre of focus of the aggregate variables; a grouped concept would give accurate information regarding product development, as it would allow dual simulation;
- the possibility of analysis of movement of the centre of focus of the aggregate variables and their deviation to the direction of dependent variables represents the importance of it.

The designed model for developing products through multiple criteria analysis is useful in the development of almost all serial products.

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