Transdisciplinary Engineering: A Paradigm Shift
C. Chen et al. (Eds.)

doi:10.3233/978-1-61499-779-5-757

A Value-Oriented Methodology for Cost-Oriented Re-Engineering in the Packaging Sector

Margherita PERUZZINI[1] and Marcello PELLICCIARI
Dept. Engineering "Enzo Ferrari", University of Modena and Reggio Emilia, via Vivarelli 10, 41125 Modena, Italy

Abstract. Anticipating the analysis of cost and performances before the detailed design stage is difficult, but possible thanks to a synthetic analysis of the manufacturing knowledge, a successful collaboration among the numerous actors involved, and a methodology able to highlight the cost issues and to guide a cost-oriented machine design. This paper presents a methodology integrating Design for Manufacturing and Assembly (DFMA), Design To Cost (DTC), and Value Analysis (VA) to support companies in cost-effective machine design and cost-oriented re-engineering. This paper demonstrates the validity of the proposed methodology by an industrial case study focusing on packaging machines, developed in collaboration with a world leader company in tissue packaging machines. Thanks to the proposed approach, the company was able to identify those parts to be re-engineered (e.g., oversized parts, parts with unnecessary tolerances, similar parts to be merged into a unique one, common groups to be reused in similar machines, parts or material substitutions, wrong suppliers' selection) and possible technological improvements. A significant cost optimization and global machine sustainability improvement were achieved on a specific packaging machine line, mainly due to product structure simplification, part reuse, improved design solutions, and optimization of selected manufacturing processes.

Keywords. Cost optimization, Value analysis, Design for Manufacturing and Assembly, Design To Cost, Sustainability.

Introduction

One of the biggest challenges in machine design is to achieve the trade-off between cost and performances. According to a traditional approach, costs are completely defined at the end of the design stage and only at that time compared with the obtained machine performance. However, the majority of the product and process characteristics are already fixed by their design and late changes are very expensive and time-consuming. Anticipating the analysis of cost and performances before the detailed design stage is difficult, but possible thanks to a synthetic analysis of the manufacturing knowledge, a successful collaboration among the numerous actors involved in cost and performance evaluation, and a methodology able to highlight cost issues and guide a cost-oriented re-engineering.

[1] Corresponding Author, Mail: margherita.peruzzini@unimore.it

Traditionally, the target product cost is defined at the beginning of the design process and verified at the end of the detailed design process: whereas it is not respected, design is iteratively changed in order to find a compromise between performance and cost objectives by minor incremental improvements and long optimization loops [1]. Studies in literature and practical cases from industry demonstrated that a large percentage (at least 70% up to 80%) of the product cost is already determined during the conceptual design phase and, once the product concept is defined by product architecture, assembly procedure, quantity of components and their related manufacturing process, and costs for the following product modification grow exponentially along the development process stages [2].

Today several methods and tools are available to assist product managers in decision-making to evaluate the cost of alternative design solutions [3]: for instance, Design for Manufacturing and Assembly (DFMA) allows assessing the product cost by analysing the production processes when the product is designed in details, while Group Technology (GT) and Computer-Aided Process Planning (CAPP) can manage the knowledge connected to cost definition. However, such tools are usually "static" tools suitable for validation and verification, not really for Design To Cost (DTC) purposes, and they require a lot of information to provide a clear cost structure, so that they can hardly be used from the preliminary design stages. Moreover, the concept of "value" is not usually considered in technical design, by introduced only later on for business and marketing evaluations.

At the present moment, the most common tool adopted by companies all over the world for early cost estimation and optimization is represented by excel worksheets supporting the experience of very skilled people able to make the right assumptions. However, such an approach is highly time-wasting and subjective, and not fully reliable due to the necessary approximation and the possibility of human errors.

According to these evidences, the present paper proposes an integrated method that combines different approaches to practically support companies in cost-effective design and cost-oriented re-engineering of complex products. It includes Design-To-Cost (DTC) approach to estimate the product cost and compare with a target cost, Design for Manufacturing (DFM) to model industrial processes and create a structured process knowledge base, Design for Assembly (DFA) to model the human-related actions and create a structured human knowledge base, and Value Analysis (VA) to assess if the production cost for the product functions is respected by the value perceived on the market. Finally, it adopts Feature-Based Costing (FBC) principles to fasten the analysis by recovering the 3D geometrical features and link them to the related processes, both machining and human-driven, to predict the final costs.

1. Cost optimization in the packaging machine sector

The study focuses on the packaging machine sector, which has experienced an annual growth rate of 2.6% in the five years, from 2006 to 2011, and underwent a further acceleration from 2012 to 2016 with a growth of 3.1% annually worldwide. It means that is a very promising market, but very little research has been done in packaging machine cost optimization. The three main packaging sectors (i.e., food, beverage, and tobacco) realize over 90% of the world packaging machine volume. In particular, some specific areas such as tissue, Hygiene, and beauty & personal Care recorded higher growths (3-4%) [4]. In the packaging industry the demands for performance have increased over the years. This has led to research and development of products that are more effective and less costly. In particular, in the market, the growing need for enhanced performance, environmentally friendly packaging materials, hermetic seals for the tissue area, food and pharmaceutical and cosmetic sectors, have imposed a gradual path of specializations for technologies and application areas [4]. The actual value and the packaging function are hardly perceived by the consumer, but it represents a fundamental aspect for any finished product, whether it is a container, coating or packaging. Packaging must be economical, therefore, will not unduly affect the final cost of the product but rather will enhance the content so as to justify their purchase by the customer. It must be easy to work but at the same time durable, lightweight, easy to transport, store and use. The identification of a product, in fact on the packaging are shown a series of useful information for the consumer such as additives present, the mode of use, the amount or expiration date. One of the main roles of the packaging of the products is to contain food, to protect the product from contamination by chemical and physical lengthening preservation, or to convey to consumers the product information.

With regard to the packaging industry, the innovation required for packaging manufacturers focus primarily on cost reduction and sustainability. Nowadays they ask more and more lightweight packaging, an increase in productivity in applications (e.g., balers, moulding, labelling), a reduction in waste throughout the production process (e.g., production of the print media, printing and processing, packaging), recyclability and reusability extended the raw materials used for packaging. With regard to the main needs of automatic machines the main value is created by the obtained process speed, the possibility of managing several films (with variety of dimensions and thickness of the film), the creation of totally integrated lines, the high dosing precision, the high productivity rate, compared with the final machine cost. A peculiarity of packaging machines is given by high performance with low investment without, however, regardless of the quality of the final product. All these features, as required by the market, imply that companies producing packaging machines have to pay more and more attention to the industrial cost. A robust and structured industrial cost estimation is fundamental for those companies to determine the "right" selling price for their machines. The final price of course must be definitely higher than the unit production cost since it is necessary to cover up even the overheads, but when a new machine is designed, the main hidden part is represented by the production costs. In particular, the correct identification of the direct cost of the finished machine is crucial for companies operating in a saturated and competitive market such as packaging industry. Traditional estimation systems and rough cost approximation could be sufficient when the margins also allowed committing blunders, but nowadays have become highly risky. For this reason, the analysis of the direct production cost and the operating margin has become essential to drive also the design activity. As a consequence, cost optimization is a fundamental issue to face for machine builders in the packaging sector worldwide.

2. The research approach for structured cost-oriented re-engineering

The proposed approach is based on DTC approach, which starts from the definition of a clear target cost at the beginning of the design activity, to be respected along the process by properly managing the knowledge related to the production process [5]. According to DTC approach, cost analyses are fallen back to the early design stage so that the conceptual models continually interact with cost considerations. DTC is hard to implement in practice due to the management of the product complexity and the variety of the production processes to be estimated and refined along the design process. Furthermore, the relationships between performances, geometries, manufacturing process, aesthetics, and costs and the reciprocal effects of such factors make cost estimation a critical job in the conceptual stages. Moreover, costs are highly variable according to market demands, production volume, cost amortization, and other logistics costs. In order to be successful, DTC needs robust analytical cost estimation models able to estimate the production costs according to consistent assumptions, when specific data are not available [6].

A good review of the existing cost estimation methods has been recently provided by [7] as quantitative and qualitative. Qualitative estimating techniques, also called intuitive, rely on experience and knowledge of product cost estimators, being cheap and fast in implementation. Differently, quantitative estimating techniques use mathematical algorithms and statistical tools, and set the value of product cost with respect to the manufacturing process specifications [8]. In this context, the Design for Assembly and Manufacturing (DFMA) theory allows to assess efforts and costs related to fabrication and assembly processes [9]. In particular, DFA aims at reducing the number of components providing a list of criteria through which the effective need of each part can be evaluated, and DFM allows the manufacturing process optimization and provides elements of cost for each component (e.g., raw materials, set-up costs, processing costs, additional costs) [10]. In addition, the FBC approach suggests to identify the product features as geometric information and collect all functional and technological information (e.g. tolerances, surface finishing, manufacturing cycle, etc.) and to use knowledge-based systems to apply the most proper cost models [11].

Furthermore, product cost must be related also to the market. Indeed, a product is generically able to satisfy certain user needs and fulfil certain functions [12]. Value Analysis (VA) considers the product "value" and verifies if the industrial cost for each offered functions is coherent with the cost expected by the market [13]. The "value" means the ration between functions and costs as well as the ratio between offered performance and market price. As a consequence, a mismatching between functions and performance brings to customer dissatisfaction for inadequate performance or money wasting for unneeded capabilities.

2.1. The design methodology for cost-oriented re-engineering

The methodology used for cost analysis and cost-oriented re-engineering combines the above-mentioned approaches to carry out a synthetic product cost estimation. It uses the product 3D CAD model and, according a FBC approach, the main manufacturing processes are defined. After that, it combines DFMA and VA to improve the general design quality and identify the main areas of improvement. Such a methodology has been conceived for cost-oriented re-engineering of existing machines, which is one of the more complex activities in the packaging sector. Indeed, re-engineering of existing products is usually very hard due to the need of a critical analysis and the resilience to change decisions taken in the past. Furthermore, usually production processes and available technologies can greatly vary in ten of twenty years, and new solutions could be identified over the years for product optimization. New machines and materials can be available to replace old processes, and can achieve higher performances, not possible in the past years. However, such re-engineering is complex and time-consuming if not properly structured. Furthermore, a critical analysis of the product features' perception and the added value perceived by the customers can support the machine functions' redefinition to reduce machine costs and reach a good saving.

The proposed method starts with the analysis of the product Bill Of Material (BOM), the critical analysis of the BOM according to the Pareto's principles (80-20), a structured cost analysis by detailing the different contribution for each part (i.e., raw material, manufacturing, treatments, etc.), the selection of the most appropriate technique for cost reduction among DFM, DFA, DTC and VA (Fig.1).

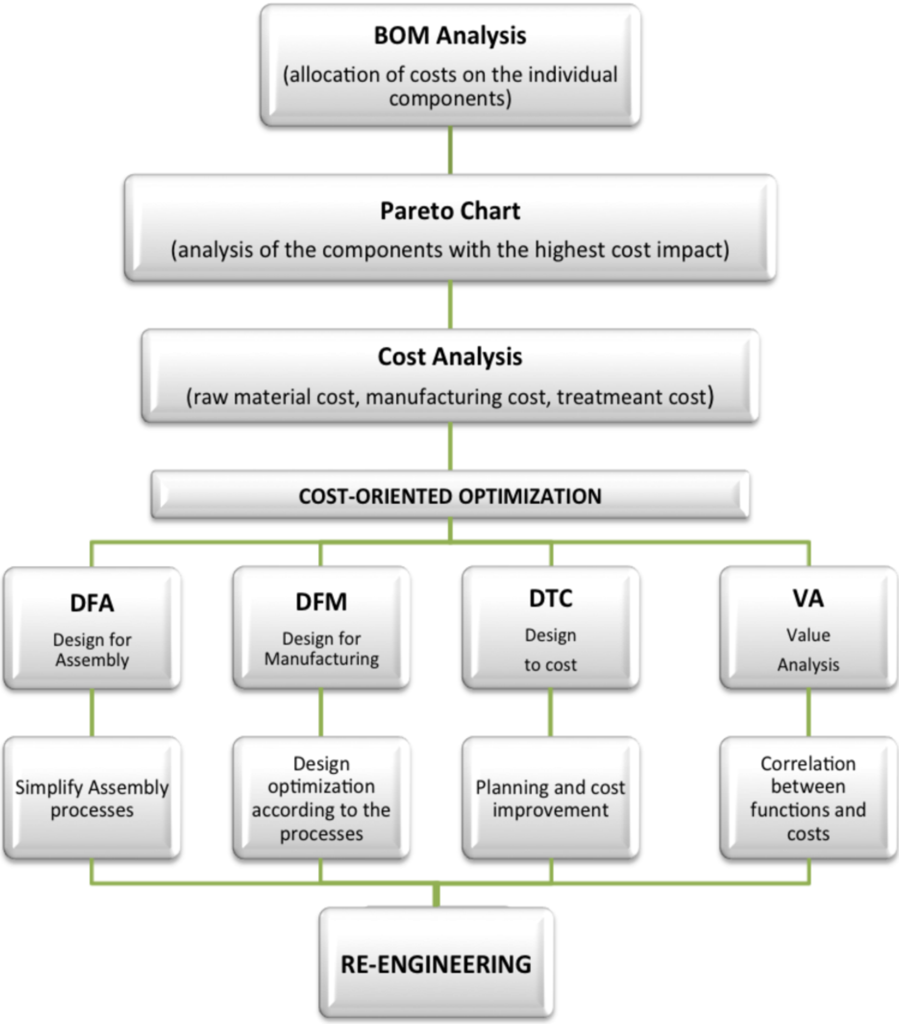

Figure 1. The proposed methodology for cost-oriented re-engineering.

3. The industrial case study

3.1. The company

The case study was developed in collaboration with a leading company in the field of tissue converting and packaging machines, which realizes complete lines for the production and packaging of industrial rolls, toilet rolls and kitchen towels, with 6 production sites in different countries. The company has recently implemented a very detailed system analysis and cost management process according to its need to analyse and manage production costs to compete with competitors and react to environmental changes that have occurred over the years. In the actual demand for more competitive products that led to global and unstable markets, the company is prepared to offer new products with shorter time to market and ensure a wider market share. The machine design is today characterised by the following aspects:

- Highly customizing products according to customer requirements;
- Need to define the cost perceived by the customer and how much is willing to pay for the goods produced;
- Adoption of methods to achieve the level of profitability for the company;
- Adoption of design to cost method to define precise target cost and verify the design at the different stages, according to a formal “step and gate” process.

For each verification step (gate), functional and performance features are compared with the expected costs, by using appropriate checklist. The bottom line is to not incur costs but to build them in advance on the basis of the choices made in the early design phases, with reference to the customers’ needs and expectations. Thanks to the “step and gate” process (Fig. 2), the company passed from using traditional costing methodologies feedback (feed-back costing) to predictive methodologies (feed-forward costing) to push the company to optimize and reduce the production cost from the early stages of machines’ development.

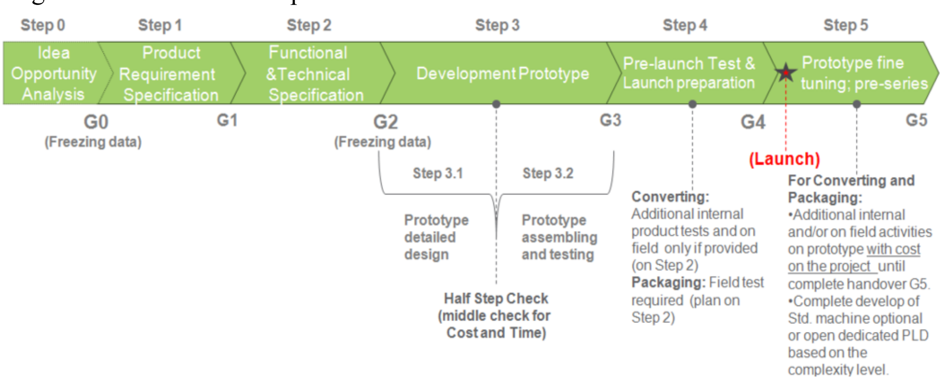

Figure 2. The actual “step and gate” process in the company.

Since 2015, the company has decided to carry out the cost estimation on 3D models by the adoption of a dedicated software tool (i.e., LeanCOST, www.hyperlean.eu). The use of 3D models and the possibility to estimate the cost of each single component, directly from the analysis of the 3D models according to a FBC approach, have opened new scenarios for cost-oriented re-engineering. Furthermore, the tool was integrated with the company enterprise resource system (i.e., SAP) for an automatic recovering of the necessary data. As a result, a more structured feature-based cost estimation allowed a great reduction of the time required for estimating complex parts and simplify the analysis.

3.2. The case study

The case study is represented by a roll/pack high-speed machine (Fig. 3) designed and produced the company. It is an automatic machine for high-speed bagging of toilet rolls or kitchen packs, by means of polyethylene that is automatically done by a single coil. The machine production rate is up to 30 bags per minute.

The proposed method has been adopted for its re-engineering. In particular, the machine BOM has been analyzed and, thanks to the Pareto analysis, 14 components were identified for cost optimization. Each case has been analysed carefully and the most appropriate technique for cost estimation has been adopted. Among them, 2 parts were re-designed according to DFA principles, 6 parts were re-designed according to ne processes by DFM principles, and 6 parts were re-designed by adopting DTC and VA in a combined way. Figure 4 shows a synthesis of the main re-design actions. 60 different design alternatives were analysed among all cases and, finally, a 59% of the cost saving was obtained with respect to the original cost (limited to this 14 parts). The DTC actions were implemented considering the value for the machine functions and alternative designs, and VA allowed to validate the different alternatives. The DFA actions were oriented to simply the product structure and reducing the number of parts. Finally, DFM allowed to change the technological process and coherently the design.

Figure 3. The roll/pack high-speed machine (CMB 202 EVO).

Code	Component	Quantity	Estimate ZVALN	Current Cost	Best Alternative	Method Used	%	Scanned Versions	Raw material cost	Processing cost	Treatment Cost
K075L0004	SHEET	5	943,45	1.050,00	295,15	DFM	69%	2	34,33	30,13	138,99
K075L0003	SHEET	4	758,48	840,00	180,66	DFM	76%	2	31	27,21	145,24
K000L3122	PLATE	2	530,24	630,00	204,66	DFM	61%	4	35,96	272,29	6,74
K030J9947	PLATE	2	734,58	800,00	529,66	DFM	28%	4	178,4	109,22	15,56
K031F9675	SIDE FRAME	2	767,74	920,00	317,9	DFM	59%	4	170,29	132,07	26,25
K030L3862	SHOULDER	2	270,9	238,00	191,4	DFM	29%	4	41,33	64,91	12,76
K031G2937	SHOULDER SX T/S	1	617,65	765,00	357	DFA	42%	2	244,01	320,99	135
K031G2938	SHOULDER DX T/S	1	612,4	765,00	368,42	DFA	40%	2	242	295,4	75
K030F6820	SHOULDER	2	150,54	90,00	80	DTC + VA	47%	6	27,5	60,63	0
K063E5549	FEED TABLE	1	83,65	120,00	55	DTC + VA	34%	6	58,43	25,22	0
K075H0336	SIDE GUIDE PLATE SX	1	71,2	80,00	35,5	DTC + VA	50%	6	13,33	45,87	12
K075H0337	SIDE GUIDE PLATE SDX	1	71,2	80,00	35,5	DTC + VA	50%	6	13,33	45,87	12
K060F8572	CARTER	1	48,74	40,50	10	DFC + VA	79%	6	11	12,09	14,25
K031E5548	FINAL BEAM	1	22,89	27,00	0	DTC + VA	100%	6	5,1	17,79	0
	Tot		5.683,66	6.445,50	2.660,85		59%	60			

Figure 4. Main re-design action taken in the case study.

3.3. Savings obtained by the re-design actions

Figure 5 shows the main outcome of the implemented re-design actions and the obatined savings, while Figure 6 compares the cost savings between AS-IS configuration of the machine, the analyzed solutions, and the potential savings obtained if such an analysis was extended to 100% of the machine parts (not only 14).

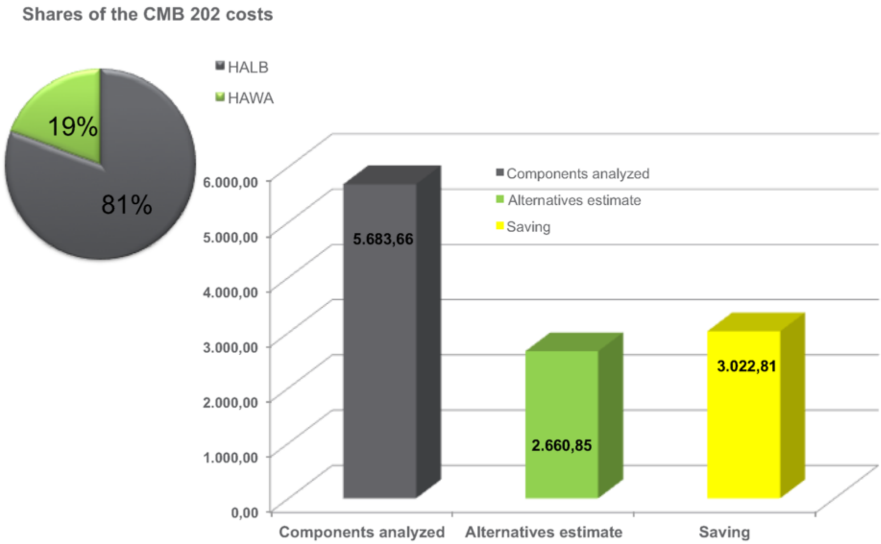

Figure 5. Main re-design action taken in the case study.

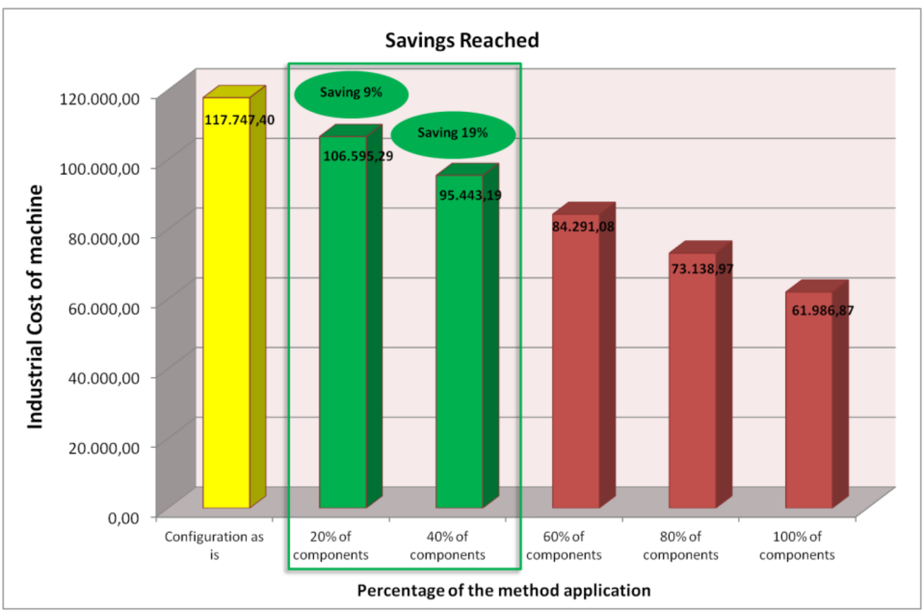

Figure 6. Reached cost savings by the implemented method and the potential savings for its adoption to the entire machine.

4. Conclusions

The paper presents a cost-oriented re-engineering methodology combining DTC, DFMA and VA techniques, and its application to a real industrial case study. Although these techniques have been implemented only to a limited number of parts, cost saving was impressive. Such result pushes to extend the method application to the entire machine. Future activities will be focused to a more accurate assembly costs analysis and optimization, and the application to other industrial cases, also to other sectors.

Acknowledgement

The authors wish to thank you Fabio Perini (www.fabioperini.com) for the precious collaboration and the industrial case studies.

References

[1] R. Rajkumar, Decision engineering report series in: *Cost engineering: Why, what and how?* Cranfield University, UK, 2003.

[2] D.M. Anderson, *Design for manufacturability & concurrent engineering*, CIM Press, California, 2004.

[3] K.T. Ulrich and S.D. Eppinger, *Product design and development*, McGraw-Hill, New York, 1995.

[4] F. D'Annunzio, *Packaging sector, facts, figures, trends for 2013*. Accessed: 15.03.2017. Available online at: http://www.nucerialab.com/en/il-settore-del-packaging-riflessioni-sulle-tendenze-per-il-2013/

[5] K. Ehrlenspiel, A. Kiewert and U. Lindemann, *Cost-Efficient Design*, ASME Press, 2007.

[6] P. Cicconi, M. Germani and M. Mandolini, How to Support Mechanical Product Cost Estimation in the Embodiment Design Phase, in: J. Pokojski et al. (eds.) *Advanced Concurrent Engineering, Proceedings of 17th ISPE International Conference on Concurrent Engineering, CE 2010*, Springer, London, 2010, pp. 419-430.

[7] O. Ievtushenko and G.L. Hodge, Review of Cost Estimation Techniques and Their Strategic Importance in the New Product Development Process of Textile Products, *Research Journal of Textile and Apparel*, Vol. 16 (1), 2012, pp. 103-124.

[8] A. Layer, E. Brinke, F. Houten and H. Kals, Recent and future trends in cost estimation, *International Journal of Computer Integrated Manufacturing*, vol. 15 (6), 2002, pp. 499-510.

[9] DRM Associates, *Product development toolkit*, 2006, Accessed: 15.02.2017. Available online at: http://www.npd-solutions.com/pdtoolkit.html

[10] G. Boothroyd, P. Dewhurst, W. Knight, *Product Design for Manufacture and Assembly*, Marcel Dekker, New York, 1994.

[11] A. Shehab and E. Abdalla, A Cost Effective Knowledge-Based Reasoning System for Design for Automation, *Journal of Engineering Manufacture*, Vol. 220 (5), 2006, pp. 729-743.

[12] N. Kano, N. Seraku, F. Takahashi, S. Tsjui, Attractive Quality And Must-Be Quality, *Hinshitsu*, Vol. 14 (2), 1984, pp. 147-156.

[13] M. Leber, M. Bastič, M. Mavrič, A. Ivanišević, *Value Analysis as an Integral Part of New Product Development*, Procedia Engineering, Vol. 69, 2014, pp. 90-98.