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Engineering Design and Development

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Subject review

Combining Industrial and Functional Design methodologies for the development of new products and systems requires a broad understanding of human behaviour and industrial activities. The requirements of international standards, protection of the environment and the ability to make a profit on sales requires a sound attitude and approach to succeed, especially in current economic conditions. This highlights the importance of good business and management strategy that must be dynamic to meet the changing needs of the market. Competitiveness depends largely upon advances in the fields of design and Innovation, cutting edge research and new advances over a broad range of topics dealing with innovative design and manufacturing technologies.

This paper encompasses traditional and new areas of design methodologies including Reverse Engineering, Value Analysis (VA) and Value Engineering (VE), Concurrent engineering Value Added, R&D. Modelling and attitude to the environment and customer. Linking marketing, manufacturing and innovation to maximise the design process work is discussed and solutions for SME's to explore methods of expanding their product portfolio are proposed.

Inženjerski dizajn i razvoj

Pregledni rad

Kombiniranje metodologija industrijskog i funkcionalnog dizajna pri razvoju novih proizvoda i sustava zahtijeva široko razumijevanje ljudskog ponašanja i proizvodnih procesa. Udovoljavanje međunarodnim standardima zaštite okoliša, te istovremeno mogućnost ostvarenja dobiti traži poseban pristup i pažnju da bi se ostvario uspjeh, posebno u današnjim gospodarskim uvjetima. To ističe važnost dobre poslovne strategije koja mora biti prilagodljiva kako bi udovoljila promjenjivim potrebama tržišta. Konkurentnost uvelike ovisi o napretku u području dizajna i inovacija, naprednih istraživanja i novih dostignuća na širokom polju tema koje se bave inovativnim dizajnom i proizvodnim tehnologijama.

Ovaj članak obuhvaća tradicionalna i nova područja metodologije oblikovanja uključujući prilagodljivo inženjerstvo, analizu vrijednosti i timsko inženjerstvo. Modeliranje u odnosu prema okolišu i zahtjevu kupca. Obraden je umreženi marketing, proizvodnja i inovacije kako bi se povećala učinkovitost procesa dizajna. Ponudena su i rješenja za malo i srednje poduzetništvo sa svrhom povećanja profitabilnosti proizvodnje.

1. Introduction

In the past, design in a manufacturing organisation was undertaken by personnel who produced drawings for new components and products. These were then given to production that happened to be located in a different part of the organisation. These people ironed out any problems to assist the manufacturing process and as a result, a product that began with certain vital functional and Industrial design attributes ended up as a totally different design. This resulted in long lead times and high numbers of engineering changes, resulting in manufacturing complexity and high costs if customer requirements were to be met. The initial challenge was to combine manufacturing with design so that design now involved

the experts from both disciplines working as teams to develop better products and reduce introduction times. The success of future designs and product introduction to the market requires effective integration of personnel, resulting in almost zero distinction between researchers, designers, marketing and engineers, forming a multi-disciplinary team. The multi-disciplinary team can solve conflict early in a design process and quality can be designed into the product. A combination of disciplines in an organisation should expand to all departments to improve a company's overall ability: to be competitive and generate profits.

A product must be designed and be value engineered. This calls for cost effective industrial design. When a new product is introduced or an existing product

improved, the most important factors influencing the development are costs, quality, customer satisfaction and the duration of the development programme. The reasons a product may not be designed to the optimum can be due to lack of ideas, lack of information, lack of time, wrong beliefs, habits and attitudes, poor resources and lack of communication. Design changes can be costly, time consuming, and have repercussions for marketing and sales. Problems that arise in modifications include change of suppliers and a need to reduce manufacturing costs. On the other hand, if a product is well received by the market, it will be capable of making an industry profitable. Early to market with the correct product results in increased benefits and profits to an organisation. Many companies however still focus their cost management effort on building products when we already know that costs are built into the product at the design stage.

2. Human requirements and design

2.1. Human requirements for products

From a design point of view, human hierarchy of needs usually arise in the following ascending order: Functionality, Usability, and Pleasure. A product will be useless if it does not contain the functions needed to perform the tasks for which it is intended. Also users want products that are easy to use (ergonomic aspects). From a pleasure point of view, these provide emotional and hedonic benefits (values, tastes, hopes and fears) along with physiological, social, psychological, and ideological pleasures.

2.2. Design Investment

Product design and development begins with research in the market place and with meeting customer requirements. On completion the product is assessed not just by the company but also by the customer on the basis of Quality of design and Quality of conformance. Ireland, along with other European Countries still produce some low-value added products, attempting to compete with low wage economies and therefore exposing ones business to severe competition. This arises in food Production, clothing, metal components, foot ware and packaging. In some areas of the economy, low investment in equipment and limited research is a major contribution to this. In recent times, government support has been very encouraging for innovation and design and recovery may be built around the following factors as outlined in a recent article [1]. Competing with low cost economies is fine if we can do it better and effectively. Ones interpretation of a low cost-low technology product

may differ and some products that we class as high-technology based may not be accurate.

The solution to successful collaborations on a national basis may take the following format:

1. Extended co-operation between funding agencies, academia, IP agents and industry in a productive way.
2. Innovation from 1. above.
3. Integrate and accelerate design and manufacturing processes.
4. Achieve and maintain an adequate level of basic research.

A high investment in design at the start cannot be replaced by introducing design at the end of a process. Funding agencies, Industry, IP experts and Education collaboration can successfully develop the fundamental and basic research structure needed to develop new products, leading to successful patent applications and greater revenues for organisations through royalties and tax incentives. However this also requires the most important variable; the market place and those that will use and operate the products under being developed. Almost all added value in products is determined by the design process [2].

Therefore would an extra hour or euro spent on design or reliability analysis have added more to a companies profits? This question is addressed by the headlines each year regarding product withdrawal and part modifications of vehicles such as Toyota (2009/2010), and child buggy's (2009). Doubling the design effort may mean doubling a products quality, increasing revenue, reducing costs or increasing sales. There should be a move towards increasing the rate of early spending on design.

A company's approach to design and development is dictated largely by the nature of the product and the customer it serves and the objective of any company is to make products which will be sold at a profit. However many companies still concentrate their efforts on selling what they produce rather than producing what the market requires.

2.3. Design Control

Design control allows companies to achieve design objectives such as reliability, safety, functionality industrial and aesthetics while developing a trouble-free product. It optimises the design elements and ensures the designed product can perform. It ensures the product is easy to manufacture and insensitive to variability on the factory floor, enhancing quality, decreasing costs and improving productivity. This is done by controlling quality in product design before the product goes into full production. A three step approach is normally used which

includes System design, Parameter design and Tolerance design. System design includes basic design and testing of parts. Parameter design is the determination of the level of each component that will infuse the least variation into product performance. Tolerance design determines how much we can deviate from the target specification.

3. Production and design

3.1. Product Design

Early practices emphasised the following general steps for a design process;

- **Feasibility study:** This validates the need, defines the problem and appraises possible solutions which culminate in design concepts and profitability estimates.
- **Preliminary design:** Resulting in model making, prototypes etc to allow analysis of the technical economic and financial feasibility of a number of possible solutions.
- **Detailed design:** This stage takes the best possible solutions and brings it to production and utilisation.
- **Review and revision:** This might be desirable to redesign to meet the changing needs of customers.

3.2. Case study for design process for a mechanical component

A typical design development process may take the following routes;

1. Material selection: Based on strength analysis
2. Component design: (able to fill the functions requested)

These merge to produce a basic design acceptable to the market. If the material can carry the loads, then the design can proceed, otherwise the first iteration takes place (either a new material is chosen or the design is modified with customer approval). Detailed specifications are produced to meet ergonomic, environment (Health and Safety and legal aspects) and stress requirements. Considerations of the appearance and feel (aesthetics) should take place concurrently. The design is viable if it can be produced economically and competitively. The choice of manufacturing can be determined by the materials chosen. The production routes will be influenced by the size of production runs, and how the component will be finished, and joined to other parts or packaged. If the production process determined by the materials chosen show that costs are too high, then a new material or component design resulting in an alternative production path may have to be chosen. Prototype development and market performance can be assessed concurrently throughout the project. Full scale production can then follow. This process is now integrated as a concurrent engineering approach, where all the activities take place together, with the use of a multi-disciplinary team.

3.3. Concurrent Engineering

Concurrent engineering is applied to the solving of problems through the use of multi-disciplinary teams. This relates to merging the expertise of designers, engineers, assemblers, marketing, metallurgists, finance, quality,

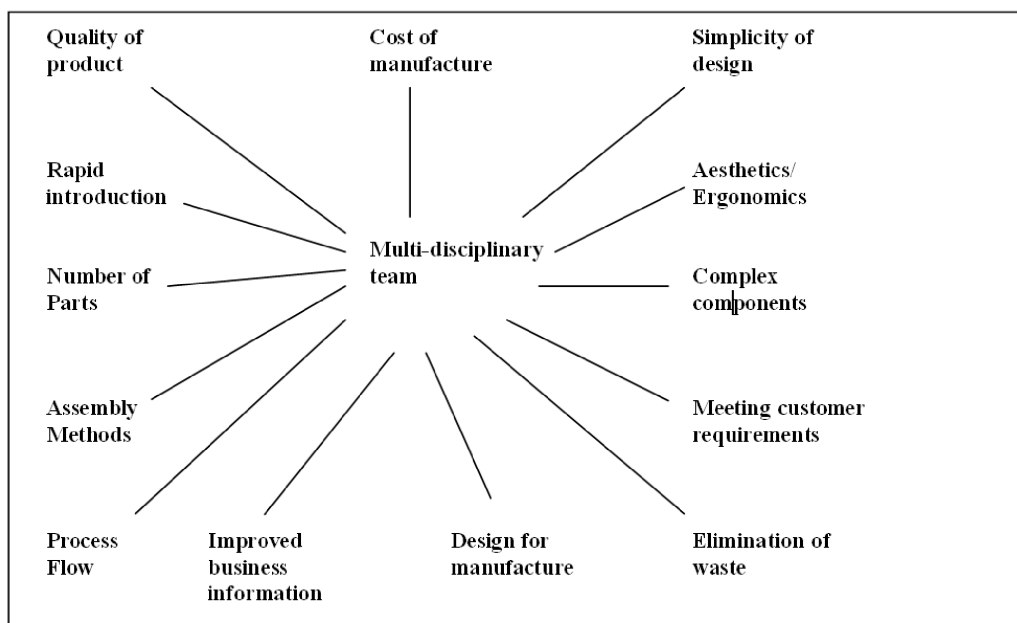


Figure 1. Example of Multi Disciplinary structure
Slika 1. Primjer višedisciplinarne strukture

and purchasing personnel etc. as an integrated team to minimise design errors at an early stage and avoid serious problems in terms of manufacturing, quality and costs at a later stage. A typical structure is shown in Figure 1. Some of the main problems that can be solved efficiently with this process include:

- Manufacturing process restrictions are considered and overcome.
- Product development cycles are reduced
- Quality can be improved
- Optimum materials are selected for the product
- Ease for assembly and manufacture are built in to the design
- Minimum waste at manufacturing and assembly stages
- High chances of success by addressing Marketing needs.
- Satisfying needs of the customer as well as resources of the organisation
- Better and faster design solutions in the future with a dynamic team approach.
- Designing products for automation/ assembly
- Design for manufacture, quality, Health and Safety and hygiene

3.4. Multi disciplinary teams

The multi-disciplinary team can solve conflict early in a design process where quality is not inspected but designed into the product. Ideally, staff who have relevant knowledge and who are part of the supply chain process should be consulted and their views considered when decisions are made. As a result all the main departments associated with the organisation and value chain make a positive input at an early stage ensuring:

As each department will play a role in the development of a product, they must also be involved in the generation of the product design specification. This provides a focused goal for the organisation and consist of a written document, formally agreed, dated and with an issue number to avoid confusion later on. It is important at the start of this process to properly consider the problem, as problem definition leading to product design specification is more important than problem solving. Table 1 shows the main elements of a product design specification.

3.5. Marketing and design

Marketing skills are involved in design in terms of market research, opportunity identification and downstream activities such as packaging, pricing, distribution, advertising and promotion [3]. The co-ordinated interface between marketing and design are therefore necessary for product success through market penetration. Understanding of each others role is essential and in some cases marketing and design people get the opportunity to use and maintain their own equipment and products in real situations. This provides good market research, can help improve product design and hopefully generate superior products in the future [4]. Direct communication with the consumer can cut down on interpretations and the number of iterations a design may have to undertake. Closeness to retailers and distributors can also provide practical knowledge on what sells and in what quantities.

3.6. Design for manufacture and assembly

Proper manufacture, assembly, material and process design to improve product quality, reduce costs and time to market. Almost 80 % of the product quality and cost are determined at the design stage yet only 5 % or less of a project cost are invested in design. Resources given to manufacturing, automation and productivity

Table 1. Product design specification

Tablica 1. Specifikacija oblikovanja proizvoda

Functional and environmental requirements				
Operation	Life	Society	Customer	Producer
Performance Environment Corrosion Size Weight Ergonomics Aesthetics	Product life Service life Shelf life Reliability Testing Maintenance Operating costs	Codes of practice Regulations Safety Liability Environmental effects	Needs Perception Competition Pleasure Ergonomics Aesthetics	Quality Costs Company limitations Investment Facilities Process Marketing

improvements will have less effect on quality, customer satisfaction, and costs than design.

At the design stage, changes are easier to make and therefore quality and manufacturing costs can be optimised at this stage. If a product needs to be re-designed due to problems later on in the process, waste will be excessive. Simplicity of design and reduced parts will in most cases simplify manufacturing and enhance quality as well as reducing costs. The aim is to minimise the number of variants and use standard parts and features which incorporates common technology, common assembly, and common parts and modules. Ease of assembly can normally be facilitated by reducing the number of parts. The following simple analysis can be made to decide if a part can be made in one or more pieces [6]:

1. Does it have to move relative to the other parts present.
2. Does it have to be made of a different material to other parts.
3. Does it have to be separate to allow for assembly of other parts.

3.7. Value Analysis/Value Engineering

Value Analysis is a functional approach which has for its purpose the efficient identification and elimination of unnecessary costs. That is cost which provides neither quality, nor use, nor life, nor appearance, nor customer features. Waste can be as simple as reducing the number of bolts in a component to radically introducing different technology such as electronics to replace mechanical components. If you consider a part for a product, you may identify 3 suppliers of materials, 5 different materials, 6 manufacturing methods, 5 ways of machining it, and 3 ways of assembling it. This gives a maximum of 1,350 possible combinations of solutions to completing a part. The first solution picked may not be the most suitable. Value Analysis is aimed at investigating the functions of each product, part by part, in order to produce a product at the lowest cost without effecting quality, performance, safety, reliability, and maintainability requirements. Value Engineering is applied at the design stage. Requirements of the customer can be provided by a set of functions which when combined will satisfy needs. Needs analysis consists of identifying, clarifying and naming the function design has to accomplish [5]. The process, normally undertaken by a team, involves an examination of each component, purchased parts, design, materials, manufacturing, purchasing, quality, packaging and servicing. Following a step by step analysis of all component parts, the process seeks ways of performing the same function at a reduced cost. A badly designed product can be totally overhauled by Value Analysis techniques in terms of cost and function. Group brainstorming sessions are ideal for producing a

list of alternatives where individuals generate ideas from each other without criticism or logic analysis. The 7 basic elements of Value Engineering consist of:

- Product selection (What are we going to analyse)
- Definition of function (Specific functions that must be performed by a product)
- Information phase (Gathering of facts such as costs, quantities, requirements)
- Researching alternatives (How functions can be performed by other means)
- Evaluation of alternatives (Cost and feasibility of alternatives)
- Verification of alternatives (proof that alternatives will meet the needs)
- Presentation of alternatives (formal change proposals)

The types of value in a product are use, esteem, exchange and cost and methods of analysing the need for parts can be considered under the following headings:

- Does its use add value
- Is its cost proportional to its usefulness
- Are all features necessary
- Can a standard part be used
- Can a supplier provide it for less
- Are competitors buying it cheaper
- Is there something better
- Can a part be obtained at a lower cost
- Can it be manufactured cheaper, or in larger quantities

Typical questions requiring answers at the design stage using VA/VE are;

- Can the specification be changed to effect a cost reduction
- Can unnecessary functions and costs be eliminated
- Are there any special material requirements and why
- Has similar problems been solved before
- Can cost targets be met for the quantities and production rates
- Are there new materials or components (family of components) as well as manufacturing tools which will offer cost advantage over other types.
- Can the design be changed to simplify parts or use standard parts
- Can the number of specified parts be reduced or combined
- Can parts be eliminated
- Can parts be assembled easily in a fool proof way and simply

- Can standard inspection equipment be used with ease
- Will the design ensure easy maintenance
- Will all parts result in reliability
- Can the product be packaged easily, and transported safely
- Can a less expensive material be used
- Is material available with the relevant tolerances and surface finish
- Does the design permit the use of standard machine tools

The above approach specifically highlights the importance of knowledge management within an organisation. Based on this analysis, the outcome of a design process should identify the method of manufacture, the number of parts, method of assembly, materials employed, functionality of the product, aesthetics and ergonomics, skills and equipment required to produce the product. These inputs should dictate the quality of the product, the final costs and how the product is packaged and transported to the customer.

Material selection is an integral part of design as new materials appear regularly resulting in innovation in design. Materials offer new opportunities to the designer who can frequently redesign an established product, making use of the properties of new materials, to reduce its costs or its size and improve its performance and appearance.

4. Technology improvements

4.1. Non Value added activities and their elimination

Non value added activity seeks to eliminate waste and includes the principle of continually attacking and eliminating wasteful activities and unnecessary complexity of processes. Non value added is any activity costing money that is not a direct requirement of the customer and is usually a consequence of poor process and system design, typically transport, storage, unnecessary features in a product or excessive quality checking. Non value added can be as high as 50 % in some organisations. To become more competitive, costs must be reduced and some areas of attack consist of overhead labour costs,

manufacturing, re-design and quality inspection. The four-step approach to the elimination of Non-Value-Added are as follows in Figure 2.

4.1.1. Eliminate waste

Data collection and analysis stage. The following techniques are used at this stage;

- Process flow charts.
- Input/output analysis to find unnecessary outputs from each department.
- From/to analysis department to department.
- Cascade I/O for complete business to ensure an integrated design

Based on this analysis, priority areas for attack can be determined along with a detailed plan to reduce Non-Value-Added by say 50 % and eliminate it in design work.

4.1.2. Simplify what is left

Only simplify what cannot be eliminated.

4.1.3. Re-organise into natural groups

A group of people arranged around a significant information flow process to give:

- Total ownership and clear responsibilities for complete flows and business processes.
- Practically no Non-Value-Added activities.
- Communications based on people talking directly to each other, not complex paperwork.

Natural groups should only be formed after Non-Value-Added elimination and simplification has occurred.

4.1.4. Technology improvements

After waste elimination, simplification of what is left and re-organisation into Natural Groups, is it then appropriate to apply simple cost effective technology improvements similar to cell control systems, making effective use of less technology.

5. Customer Focus

In respect to customer focus, we instantly think of quality. However a successful quality system requires a culture that understands and accepts quality as an

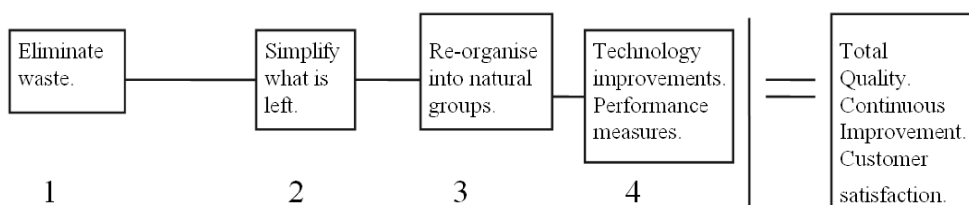


Figure 2. Four-step approach to the elimination of Non-Value-Added
Slika 2. Pristup eliminacijiji neučinkovitih aktivnosti

integrated part of the manufacturing process, which involves design as its main building block. Everyone in a quality organisation recognises the need to satisfy the customer. For most consumers, good design is probably taken for granted and we are more inclined to complain about bad product design. Defining quality as 'conformance to specification in order to achieve customer satisfaction' indicates precisely what a company has to do.

6. Conclusions

Identifying and solving potential problems must not be left to the designer alone. New product design will create some uncertain conditions which a multi-skilled team is better able to cope with. Meeting and including the market is essential for successful product acceptance. Providing rapid feedback at minimum cost is central to planning for the economical development of new products. A combination of good design practices, correctly specified materials coupled with an optimised controllable manufacturing process can reduce or eliminate waste and contribute to achieving higher levels of quality. Design can be used to create a unique identity that will help establish market niches and positioning, leading to exploitation of other markets by displaying the message that your products deliver the attributes that customers require. Design is one of the few areas where there can be real competition and usability is becoming recognised by manufacturers and consumers alike as a prerequisite of good design. Any successful product is likely to be 'copied' and development must be continuous. Design holds the key for attaining significant reductions in manufacturing costs and increasing productivity for

the manufacturer and quality for the customer. Ploughing funds into the design stage is a recipe for success and good design holds the key to improving the value added. Like quality and marketing, design is a strategy capable of giving a leading edge to organisations that take it seriously. A company needs to be organised for parallel activities by redesigning the product development process through performing activities simultaneously rather than sequentially, reducing the number of stages in the development process and by performing individual activities as fast as possible. Redesigning using tools such as value analysis have their place but the pace of new product introduction means companies have to get it right first time.

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