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Current Trends in Product Development during COVID-19

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Abstract: *This paper will summarize the authors´ experience over the last decades, from new methods developed and used within Product Development, as well as current trends. Hence, a general and broad overview is presented, rather than recent research results. Driving forces in PD are: Technology, Market and Society. Ecological, economic and social sustainability require recycling, reuse, energy conservation and new business concepts. Customization is carried out by modular architecture, combining customer specific products with volume production of components and sub-systems. PD integrates "hard" properties (engineering), with "soft" properties (industrial design). Fundamental PD characteristics are: Iteration, Integration (technical and organizational), and Innovation. Globally distributed industrial partners co-operate using Internet. Iteration: modeling/simulation, virtual prototyping and additive manufacturing speed up process loops. Structured PD: Initial specification of "what" – functional requirements, then "how" - generation of design solutions. Interdependencies analysis is important to simplify the product´s structure. The V-model for specification and verification is commonly used. A 3-stage industrial process separates strategy, core technology development, and product design for market introduction..*

Keywords - *Product Development, Covid-19, Machine Design, Engineering design*

I. INTRODUCTION

Some of the most important characteristics concerning current PD methodology and procedures in industrial product development have been summarized. This paper is focused on the development of mechanical products, but today's complex products usually combine many fields of technology, not the least IT in form of embedded systems and networks for control of mechanical devices. The market situation is changing rapidly; industries have to respond and have to consider many new issues, as sustainability and environmental effects of their activities and products. The fourth industrial revolution means decentralized "smart" factories, with a high degree of automation and information/data exchange in networks, as well as monitoring of services

Nomenclature

B2B	Business to business
CAD	Computer Aided Design
CAE	Computer Aided Engineering
DFA	Design for Assembly
DOE	Design of Experiments - orthogonal arrays
DSM	Design Structure Matrix
FMEA	Failure Mode and Effect Analysis
FTA	Fault Tree Analysis
IPD	Integrated Product Development
LCA	Life Cycle Assessment
LCC	Life Cycle Costing
PD	Product development
PDM	Product Data Management
PLM	Product Life Management

PSS	Product/Service Systems
QFD	Quality Function Deployment
RE	Reverse Engineering
RP	Rapid Prototyping
SW	Software
VP	Virtual Prototyping

As a background, applied research within product development and engineering design is a relatively new academic discipline. It differs in many ways from the traditional academic disciplines, as the PD process is cross disciplinary and comprises both synthesis and analysis. Engineering science at the technical universities has traditionally been focused on analysis, often with narrow and deep specialization, e.g. in rigid body mechanics, strength of materials, fluid mechanics, thermodynamics etc. As opposed, design problems are "open", many quite different solutions can be found, that meet the specified targets and constraints. Architecture is the research field within a technical faculty that is since long directed to synthesis and hence related to PD and design.
Engineering design research evolved gradually during the 1960-ies and 1970-ies in Germany. Initially empiric prescriptive methods were formulated, prescribing the stages and activities to be carried out during the various phases of a design project [1]. From fundamental research the theory for technical systems, the domain theory, and function analysis were developed [2]. International research within PD and design and its industrial implementation has had a rapid growth from the 1990-ies and forward [3, 4]. One important issue is methods for analysis of, and guidelines to minimize, couplings and interdependencies by Axiomatics [3] and DSM [4].
Originally, two main areas of design research could be seen. One direction was the PD and design process with support methods and organization/management of PD; the other direction was the more technology oriented development of IT-support, analysis, simulations, optimization and model based PD [5]. Within the latter - technology and IT support oriented - field, the research methodology is the traditional from natural sciences: A theoretical model is formulated, based on known theory and/or empirical results. Models and theories are usually validated and verified by physical experiments, as a basis for more or less generic conclusions. These models are usually formulated mathematically and the variables are usually physically/technically measurable. Within the process directed PD research, instead the industrial PD process is studied, e.g. industrial implementation of new PD-process models, design support methods, work procedures and PD management. This research methodology is different, action research is often carried out, to change and further develop an industrial activity and to gather knowledge of this change process. One or more real cases are studied in detail, to formulate and test models. Methods from behavioral sciences are then often used, as questionnaires, interviews and semi structured deep interviews. One significant problem with this type of case studies is of course that there is no controlled test situation – the "test" cannot be repeated. The generalization of results and validation/verification are then central issues.
With the introduction of industrial design as an essential part of PD, an additional new and non-conventional research field was introduced. One future challenge in academy would certainly be enhanced collaboration between and integration of these different fields.

II. DRIVING FORCES

Traditionally the PD driving forces have been Technology represented by revolutionary quantum leaps, introducing new technology commercialized in new innovative types of products, and Market represented by evolutionary product modifications in smaller steps. During the last decades a third driving force – Society - has been more pronounced. Society as driver concerns issues as environmental impact, sustainability, health and safety. PD could currently be characterized as complex multidomain system design. Other dimensions to be integrated are Hard product properties related to engineering design and measurable design parameters, and Soft product properties related to industrial design and properties that are not usually easily measurable. However, in many cases, in particular for consumer products (e.g. cars), fulfillment of Hard requirements based on engineering could be seen as necessary constrains, while the customer purchase decision would be based on the product´s Soft properties, i.e. user interface, ergonomics and aesthetics. The general aim of PD is to improve the performance/cost ratio for new products. Performance should then be interpreted as a combination of technical - Hard - performance and Soft performance as described above. Cost should then be seen as a measure of utilized resources; costs for both producer and user in monetary terms, as well as environmental impact over the products life cycle.

A products life can be interpreted in two ways. From a market perspective, the life history of a product generation on the market can be illustrated as in Fig. 2.1, the so-called S-curve. Investment in revolutionary development of a new innovation will be followed by volume and profit growth until the market is saturated and competition increases. Finally, defensive investments for cost reductions will not be sufficient and the product family has to be withdrawn from the market and be replaced.

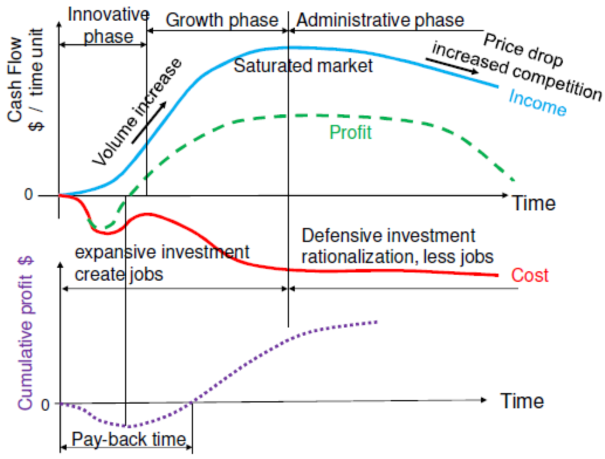

Fig. 2.1 Product life cycle on the market, "S-curve"

Another interpretation of a product´s life cycle is the various life phases of an individual product unit, according to Fig. 2.2. All life phases of the product have to be considered during design. The life cycle should preferably be closed, i.e. raw material extraction as well as landfill of scrapped material should be avoided or at least minimized by implementing component reuse and material recycling.

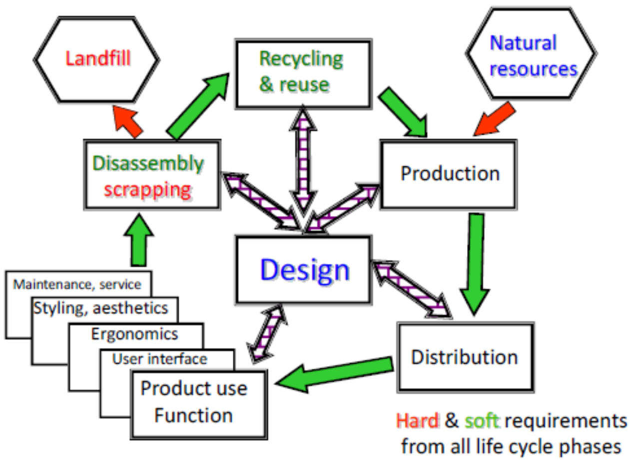

Fig. 2.2 Product Life phases for a product unit

Environmentally-wise, a product can be *active* having its major environmental impact in the use phase, during operation. A *passive* product, on the other hand, has its major environmental impact during the production and scrapping life phases. Examples of active products are vehicles, load carriers in motion, refrigerators, etc. Examples of passive products are (non-heated) building constructions, bridges, stationary vessels and containers etc.

Characteristic features of PD are: Iteration, Integration,and Innovation. Iteration means that there normally are analysis-synthesis loops in the process. As opposed to trial-and-error often applied longer time ago, the loops are now carried out systematically and speeded up by means of powerful IT tools, CAE and VP. Iteration will be carried out at different level of detail. There are different aspects of Integration, technical and organizational. Various technologies are integrated in multi-domain system products; engineering design and industrial design have to be combined to fulfill all requirements (hard and soft) for a product. Organization of the PD process should be integrated with concurrent participation of various disciplines (engineering, industrial design, production, purchase, market, etc.) in the IPD team. Product realization is an often used expression for the integrated process PD - production. *Innovation* can be seen as parallel to a systematic guided PD process. Innovation is usually based on an invention – a new technical solution - but innovation also comprises the application and implementation of the invention in a product that is introduced on the market. Real needs should be investigated, not just customer opinions. Visionary persons and management support are essential prerequisites. Creativity is however needed both in free innovation and within the frame of a guided PD process.

PD in larger corporations is often carried out at three levels: *strategy* at management level; *core technology* development within fields of strategic importance, and *product development projects* scheduled for market introduction, Fig. 3.1,

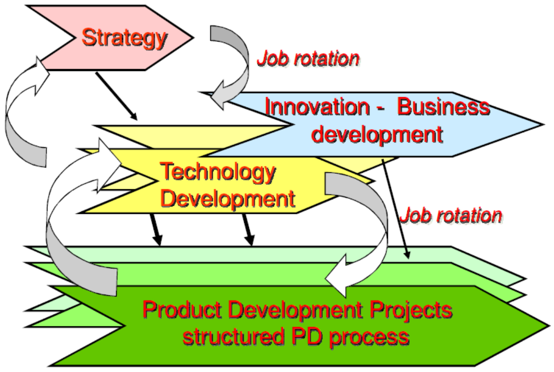

Fig. 3.1 Three-stage industrial PD process

Basic technology development means a certain degree of uncertainty and should be avoided in product development projects. Core technology should be developed separately with results put "on the shelf" for later use in products. Job rotation with responsible persons following their projects between the different levels could be one way to avoid the NIH (Not Invented Here) syndrome.

The well-known V-model for specification and verification/validation is often used, Fig. 3.2

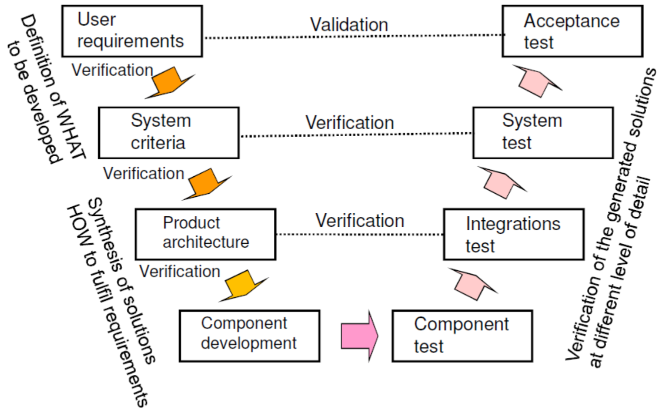

Fig. 3.2 The V-model

Companies usually have their own PD manual with internal variants of the analysis-synthesis process of academic origin. In addition design support methods are used, such as QFD ("translation" from customer requirements to design parameters), FMEA and FTA (safety, reliability), DFA (assemblability) and LCC (life cycle cost). These methods support cross-disciplinary cooperation in IPD teams. In a test situation where parameter influence cannot be captured in mathematical models, DOE is used to get maximum information out of a minimum number of tests [7].

The concept of lean product design is based on lean production, with methods and tools to eliminate all activities that do not contribute to the products' value. Hence this is another formulation to maximize the [created value/used resources] ratio. Standards have now been harmonized on European and international level, to get away from a wide spectrum of national regulations. Many general standards are applied, e.g. management systems as ISO 9001 (quality), ISO 14001 (environment), ISO 26000 (social responsibility), STEP – ISO 10303 (exchange of product model data), and ISO/IEC 27000 (information security). On detailed level various specific standards and codes are used, e.g. for structural design.

Producer responsibility is gradually increasing, from scheduled preventive maintenance to PSS - Service systems and new business concepts combining physical products and service [8]. This can be seen as adaptation for sustainability and improved utilization of physical resources. Other significant changes are distributed PD, with many partners and sub-suppliers from different geographical regions co-operating in PD projects, utilizing IT technology and networks [9, 10]. In addition to subcontract manufacturing in regions with lower production cost, outsourcing also of subsystem and component design is now common. It is however important for the system integrator to maintain the competence needed for procurement.

Flexibility and preparation to meet rapid changes in the society is also essential. Market analysis and forecasts for equipment used in industrial processes could as an example be carried out based on statistics for the industry sectors of interest, combined with knowledge of the own equipments share of the process. Expected process technology changes affecting future use of the equipment should also be considered. The total potential volume of equipment can then be estimated. Combined with knowledge on process growth rate and average life time of the equipment, an estimation of potential annual market can be obtained. Potential annual market χ for the product, in % of the total "fleet" of products can then be estimated from business growth rate p % and the equipment's life time n years, Eq. (1), Fig. 3.3, and Table 3.1.

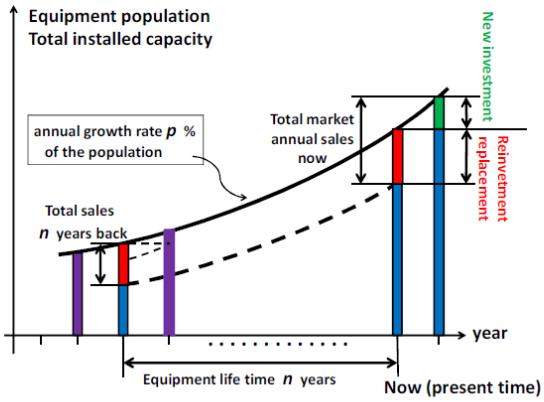

Fig. 3.3 Market estimation: Annual sales vs´ business growth rate and equipment lifetime

$$\chi = \frac{p}{1-(1+p/100)^{-n}} \qquad (1)$$

TABLE 1. Annual market χ in percent of the total population of products.

Growth rate p %	0	2	5	10
χ for life time n = 3 years	33	35	37	40
χ for life time n = 10 years	10	11	13	16
χ for life time n = 20 years	5	6	8	12

To summarize, in industry both a controlled systematic PD process, as well as some slack time to allow for free innovative development will be needed [11]. Several innovations during the years are results of informal "skunk" works.

Market requirements for increased functionality have lead to more complex and smarter products based on integration of different technologies. Mechatronics is one representative such field. Embedded processors, electronic hardware and software with distributed "intelligence" are used to improve the functionality of mechanical systems. Industrial robots are typical examples of mechatronic systems. Electromechanical actuators are controlled by an advanced control system. Haptic robots with "sense", feedback of contact forces, are being developed [12] as well as more intelligent robots that can replace humans. Autonomous robots have sensing, information processing and action planning abilities. Internet of things means physical products with embedded control systems that can be communicating in networks, enabling remote control.

III. INDUSTRIAL DESIGN

Despite still some cultural differences between industrial design and engineering, industrial design has become an integrated part of PD. This is valid both in development of consumer products as well as B2B. Industrial design is far more than just styling, aesthetics, form and color. Industrial designers also care for the product´s surface structure (tactile, haptic perception), semiotics (the product´s expression and communication with the user), sound, smell, and properties related to all senses [13, 14]. Ergonomics and user interface are other important issues within industrial design. Ergonomics comprise biomechanics (human´s ability to exert force and power), anthropometrics (human geometry), and perception (human´s interpretation of signals). During the last decades, educational programs in industrial design engineering have been introduced at technical universities. This kind of engineer means one way to bridge the engineering and industrial design disciplines. Having a more generalist approach, these industrial design engineers have been well received in industry.

IV. MODEL DRIVEN PD

There has been a pronounced development towards VP, with the ambition to carry out most of the design work computerized, with CAD models and related CAE, i.e. SW tools for analysis, simulation and (optional) optimization [5, 12]. Methods as multi-objective optimization, genetic algorithms and neural networks are often used [12]. By applying VP, cost and time consuming physical tests can then be minimized, but will anyhow usually be needed for final verifying and validation. Models also play an important role for communication and information exchange e.g. between partners in a distributed PD project [9]. Efficient and smooth exchange of information is then necessary for a distributed PD process. STEP (Standard for the Exchange of Product model data) is the international standard for representation and exchange of information related to product information. The data format is neutral, independent of specific IT systems. Concepts and relations are modeled in Express, a language for information modeling. Product data comprise information related to all life phases, PLM (previously PDM-Product Data Management). With these systems the previous situation with many isolated, independent, “IT islands” should be eliminated. A number of techniques for RP have been introduced, to produce physical models in polymer materials or metal. RP models are used for full scale demonstration, for production of spare parts, and also as tools for injection moulding in small series. RE means the process of creating CAD models from physical products or parts. RE is used e,g. for spare parts and redesign when original design info is missing. RE is sometimes used also for copying. For geometrically simple ”2D” designs, measurement of a limited number of critical dimensions is sufficient. For complex double curved ”3D” designs a more complex RE process is needed: 3D scanning by coordinate measuring machine, optical methods (e.g. laser scanning), or X-ray – computed tomography. Data reduction of the measured ”point cloud” is needed before CAD modeling from the reduced point cloud. Tolerances and material properties are however then not directly obtained.

V. ENVIRONMENTALLY DRIVEN PD

Since the 1990-ies eco-design, i.e. environmentally adapted PD has gradually been established in industry. Products should be prepared for closed lifecycles [15]. With the increased consciousness of global climate change, pollution and depletion of limited natural resources, the scope has now been widened from eco-design to environmentally driven PD. The aim is to reduce the total environmental load over the products life cycle, while satisfying the society’s demand for products and services. PSS business concepts are increasing, i.e. an extended producer responsibility for a product over its entire life cycle. PSS also means increased utilization of products, having a direct positive environmental effect [8]. Service systems are however related to user behavior and life style, issues where implementation of changes usually takes longer time.

Technical and industrial systems have to be radically environmentally sounder. Eco-effectivness means that from alternative technical solutions find how to produce functions with minimized environmental impact, that meet the society’s requirements. New concepts could be e.g. small scale local energy production from renewable sources; effective transport systems (vehicles, infrastructure, traffic planning); zero energy buildings, etc. Future transition from the fossil and nuclear based society to utilizing the solar inflow in various forms will be a huge challenge for the next generations of engineers. Marginal improvements will not be sufficient. Eco-efficiency means that by product improvements concerning materials selection, energy efficiency, disassemblability etc. reduce a products environmental impact over its life time. There is an intensive development of methods, tools and standards within this field. LCA comprises a number of methods for systematic compilation and analysis of in/out streams of material and energy, with related environmental impact over the entire life cycle. Definition of system boundaries is often difficult, expert competence is needed for LCA. A number of simplified methods have then been developed and are developed and are used in industry. used in industry.

VI. CONCLUSIONS AND FUTURE SCOPE

The recent decades have experienced a fast development of PD theory and methods. Industry corporations are forced to be effective in their PD, to respond to rapid changes on the market and in the society. Much of the current industrial practice is based on academic research. Future PD research should be directed to further integration of various research fields within PD, as: PD processes and methods; IT tools and PLM systems; networking and distributed PD; industrial design; PSS; and sustainable technology.

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