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Product Design and Development: Phases and Approach

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***Abstract*- Product design and development together are essential to drive commercialization and growth in the manufacturing sector. To capitalize on current and future market opportunities manufacturers should keep on focusing their product design and development strategies by evolving customers' requirements. This paper defines product design and development processes together, along with the process of transformation of market opportunity into product available for sale. Paper highlights phases of product design and development process, and gives the systematic approach of product development. Based on the phases defined paper tries to give inter-relationship and differences between product design and development. Depending on the type of firms and their products, their product design and development strategies may differ. It is necessary to combine all methods with the understanding of common problems and needs. The paper tries to frame product design and development process in all type of firms and gives a common generalised approach of product design and development that can be used irrespective of type of firm. Paper should be taken as wider discussion which broadens the view of product design and development.**

Keywords: Product Design; Product Development; Product Design Specifications; Design for Manufacturing; Product Launch Strategies.

I. INTRODUCTION

The basis of production begins with a need of product, which is identified by customer and market demands. The end product goes through two major processes from the concept generation to the finished product. These processes are the design process and the product development process. These two functions are very important areas in any production and, therefore, the interrelationship between them always is of principal importance. Companies now a days are facing tremendous pressure to innovate and develop new products at an accelerated pace with declining price. In order to meet these business imperatives companies must take care of several key challenges to manage product conceptualization, design and development programs. New products or services, which are developed on a regular basis, are one of the main factors for sustainable success of companies. Product design and development together are essential to drive commercialization and growth in the manufacturing sector. To capitalize on current and future market opportunities manufacturers should keep on focusing their product design and development strategies by evolving customers' requirements.

The term product design and development together has more of a business approach, as it also incorporates issues like market studies, market introduction, product review activities, knowledge management, collaboration and others too. This paper brings product design process and product development process together. Study represents different phases of product design and development process in detail and proposes a systematic approach of product design and development process. Based on the phases defined paper tries to give inter-relationship and differences between product design and development.

Product design and development process is a cycle of continues improvement over time with iterative feedback and recurring inputs from development team members, executives, sales and marketing departments and production teams. Recent trends in product design and developments are shorter innovation processes, emerging customer integration into product development, as well as increasing degrees of multidisciplinary in the design of new products. However, different companies can follow different strategies to transform the market need into the product for sale. These strategies depend on the type of company, type of product, location of company, etc. This paper tries to bring all strategies under one roof by giving a common generalised approach of product design and development that can be used irrespective of type of firm.

II. PRODUCT DESIGN AND DEVELOPMENT

A. *PRODUCT DESIGN*

Design is the very core of innovation. Product design is not about making products to look aesthetically pleasing or stylish. Product design is a multi-disciplinary process. Product design includes design related activities that occur during physical production. Product can be called as well designed only if it is well appropriate to its market. Basic elements of design are formulation of the design strategy, the

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design task, the way of designing, the use of an organization as well as the actual context and the designer's reaction upon it. In product design ideas and needs are given initially as solution concepts. When a new product is to be formed several different solutions that can be embodied in concepts are often possible.

Product design may involve adopting totally new products or may entail the refinement or upgrading of existing designs, to improve functionality, performance or appeal. However, product design not necessarily tends to adopt use of new technologies to create novel products. Design mainly deals with introduction of changes to functions and concepts.

B. Product Development

Product development is conceptualised as the set of activities needed for the conception and design to build the product, from the identification of a market opportunity to its delivery to the client. In short product development is transformation of a market opportunity and set of assumptions about product technology into a product available for sale (Krishnan and Ulrich, 2001). A product concept is generally brought to life through decisions about the physical form and appearance of the product. Product development process is mainly driven by rapid assimilation of technology, increasing consumer demands and increasing competition. Evolving product platforms which can form basis for multiple products and developing solutions concurrently with products can manage cost and complexities during product development.

The product development can be taken in two ways first is to grow or change something into a more advanced form, something that has been adopted from an existing product or service and second is to invent something new or to bring into existence, something radically new (Marxt and Hacklin, 2005) (Wenwen and Zhibin, 2012).

The process of product development, as much as the features of the product itself, ultimately determines success. Thus product development is a deliberate business process involving hundreds of decisions, many of which can be usefully supported by knowledge and tools. These decisions are part of an activity generally called industrial design. Decisions are made about the relative priority of development objectives, the planned timing and sequence of development activities, the major project milestones and prototypes, mechanisms for coordination among team members, and means of monitoring and controlling the project. Product strategy and planning involve decisions about the firm's target market, project prioritization, resource allocation, and technology selection. Decision making process is often an iterative process, in which the basic sciences and mathematics and engineering sciences are applied to convert resources optimally to meet stated objectives.

III. PHASES OF PRODUCT DESIGN AND DEVELOPMENT

The product model is a simplified representation of the product. The product data model contains all data which describe the technical system and which are produced by using of process model. The process model is the central component of the product model (Pelt and Hey, 2006). All aspects of the life cycle need to be included in the development, by providing detailed knowledge collected from former projects, experiences, literature, and other internal and external sources (Ulonska and Welo, 2013). Objective of earlier stages of product design and development is to make study of primary market, business and technical assessment. Objective of later stages is to actually design and develop the product (Ebrahim et al., 2009). The process of the product design and development is mapped below.

The process of product design and development together, mainly includes following phases:

- Analysing market and customers' needs
- Product concept generation
- Product design specifications
- Design for manufacturing
- Development of concept and prototype
- Detailed design
- Design evaluation and review
- Product launch

A. Analysing Market and Customers' Needs

The journey of achieving customer satisfaction starts with effective capturing, analyzing and understanding customer's genuine requirements (Jiao and Chen, 2006). The role played by customer is changed from the receivers of the product to the main factor that determines the success of an industry. They became the sole purpose for the existence of competition and the evolution of various trends (Rambabu et al., 2013). Customers' needs can be complex and multiple or sometimes very specific too. Normally customer's requirements are qualitative and tend to be imprecise and ambiguous due to their linguistic origins. In most cases, requirements are negotiable and may conflict with one another, and thus trade off become necessary. It is very important to be very clear about customers' needs and market trends. Differences in semantics and terminologies always lead to transfer requirement information less effectively from customers to designers (Jiao and Chen, 2006). Specification of requirements results in consideration of many engineering concerns at very initial stage of product design and development. Market led design process is the process of transforming customers needs into such a product which can be sold out in market. These needs of customers of different markets for the same sort of product may change depending on environmental conditions, geographical conditions, financial capabilities and life style of people, cultural trends, and availability of other supporting resources. Hence analysis of customers' needs and market is important to produce product which is suited to the needs of its targeted customers and to avoid the costly mistake of designing a product for which there is less demand or no demand. Thus at this stage marketing department analyses and collects information about existing products and markets, and the need or problem which the product will be aimed at satisfying. Prioritizing customer preference with respect to set of customer requirements is also an essential thing, which can guide designer in compiling, organizing and analyzing product design issues. To figure out customer's need marketing department may carry out observation, survey, ethnographic approaches, self report and interviews. This can be achieved by assigning different importance weights for customer requirements.

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Individual customer can be put in a direct contact with organisation via a channel of information technology.

B. *Product Concept Generation*

To start with Product design and development it is necessary to generate product idea or concept to evaluate whether it is going to be commercially saleable or not. This step involves analysing customers' needs first, followed by conducting extensive market research, scouting new technologies, and mapping potential emerging markets to assess customer needs. A concept is an early representation of a product, incorporating only minimum details; just enough to show the main characteristics of the product. Concept describes and defines the principles and engineering features of a system or component which are feasible and which have potential to fulfil all essential design requirements. Concept development also involves the embodiment of various attributes into some kind of technological approach. When more than one concept are developed, the concepts which fulfils maximum requirements in a best manner, is to be selected. Importance of concept generation and selection resides mainly in two facts, concept is faster and cheaper to develop and to change than final developed product and second, for a large project returning to the concept stage after detail design stage has been completed is not desired at all.

C. *Product Design Specifications*

The product design specification document is created during the Planning Phase of the project or during the problem definition activity very early in the design process. Much of the product design specification is driven by customer needs. It is intended to show what the product should be and what it should do. The product design specification document documents and tracks the necessary information in order to give the development team guidance on development of the product to be developed. In product design specifications marketing and technical parameters of the product are defined.

Marketing parameters involve issues like- potential customer base, market constraints on product, expected product competition, target cost of the product, target production volume and market share, expected product distribution environment. Technical parameters involve issues like- expected product quality standards and requirements, product size and weight, product aesthetics and ergonomics requirements, product performance requirements (product life, service life, power requirements),material requirements, expected product reliability, product safety requirements, product service environment requirements, manufacturing process requirements and limitations , maintenance requirements, product recycling potential and expected disposal.

Companies face several risks during new design. The company should be able to categorise most risks as technical, market, schedule, or budget (Unger and Eppinger, 2011). Technical risk stems from uncertainty about whether a new product will be able meet its own functional and design specifications. Market risk stems from whether product design specifications meet customer needs; if not, a technically successful product could fail in the market (Unger and Eppinger, 2011). The product design specification document sets out the parameters within which the product is to be designed. However it does not limit the design solution. This is a constantly evolving document. It is subjected to change as the project progresses and as more information is learned further details can be added as the design grows.

D. *Design for Manufacturing*

Since the improvement of CAD/CAM technologies, the term design for manufacturing has been drawing more interest. Even though design takes into account of the manufacturing process, often design for manufacturing practices are not followed. In common, the interaction between design and production functions has been very less. Design for manufacturing involves the consideration of how parts and components will be produced and assembled. In plants where assembly is the main activity and there are many such facilities, design for manufacturing mostly makes considerations well beyond the ease with which components will fit to involve assembling processes and other downstream functions (Wankhede et al., 2014).

Clear documentation of product knowledge in a hierarchical product model can replace the confusing variety of documentation between projects largely (Ulonska and Welo, 2013). Now days almost everything evolved from their initial state the method of organizing too took a leap forward by opting new techniques to manage the vast design, manufacturing and production processes. The new techniques required the computer hardware and software such as SAP, CIM etc. These became the modern trends and the most recent trends being combining the different techniques together to obtain a multipurpose tool that serves every possible purpose by leveraging the functionalities (e.g. SAP PLM) the core business process will be integrated with Design and Development process (Rambabu et al., 2013). Designers are expected to have significant knowledge of manufacturing processes and of the service department's requirements. Designers should give closer attention to their ideas and drawings from the manufacturability point of view. They are expected to design what the available tools and personnel are capable of producing. It is essential to be fully aware of the production techniques and their limitations and materials to be used. Designs, therefore, are customized according to the production and assembly facilities in which the products will be manufactured. Design for manufacturing is an integration of product design and process planning into one common activity. To address challenges of modern, competitive product engineering, a combination of these disciplines is necessary to develop advanced high-technology products, including creativity, lean practices, and systematic risk mitigation on component and system level. Thus, all of them need to be considered for providing an effective approach for knowledge-based product development (Ulonska and Welo., 2013).

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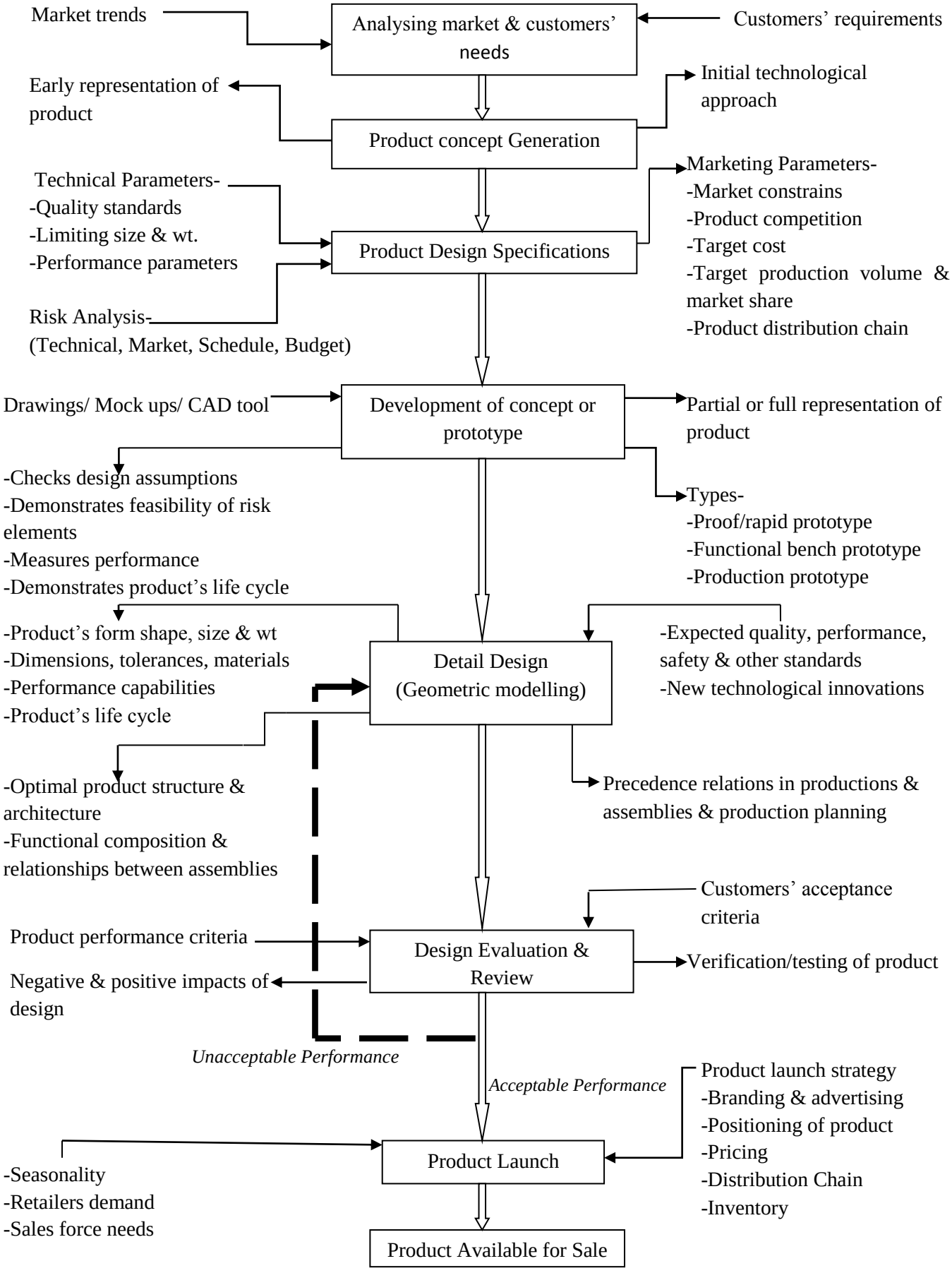

Fig. 1 Product Design & Development Process

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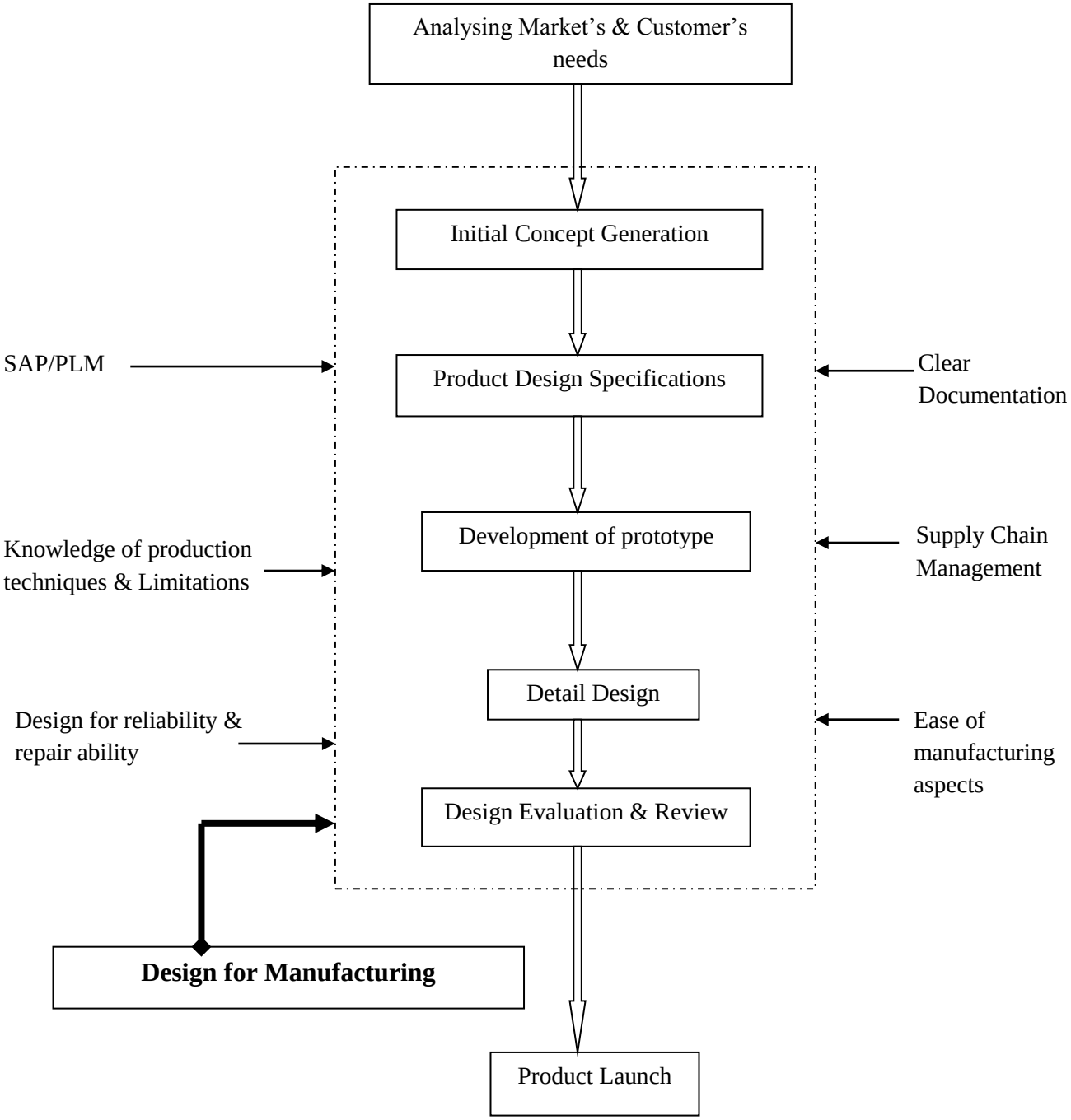

Fig. 2 Design for Manufacturing

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The goal is to design a product that is easily and economically manufactured. The primary goal is to reduce costs but design for manufacture may also be targeted at improving quality or minimising environmental impact during the production process.

Design for manufacture is closely related to design for reliability and repair ability. Designing for reliability involves the determination of the mode failures of a product - how the product is likely to break down. Reliability and durability can be improved by simplifying complex systems (which are usually less reliable) or by changing the design or specification of parts which are likely to fail. Some parts are actually designed to fail or be expendable, but are easily replaceable. This is to avoid having to replace a more expensive component. Designing for maintenance and repair requires that the designer take into account how the product will be serviced.

Design for manufacturing involves following aspects- reduction of total number of parts in an assembly, use of standard components instead of customised components, designing multifunctional parts, design for ease of fabrication (selecting the optimum combination between the material and fabrication process to minimize the overall manufacturing cost), avoiding separate fasteners, minimizing assembly directions and handling. Design for manufacturing should be implemented or it should be taken into account at concept generation, while developing product design specifications, at the time of development of prototype along with detailed design phase.

The term supply chain management deals with both inward and outward flow of materials. The capability of company to design product has to be complemented by the capability to manage a complex supply chain that delivers the product to the market. Hence for ease of manufacture supply chain design also plays an important role (Gan and Grunow., 2013). Issues like supplier selection, design of production and distribution systems can address sub-components designed specifically for product outside of the company, development and supply of process equipments. Thus supply chain management can be considered under design for manufacture as all these issues can affect performance of manufacturing system (Krishnan and Ulrich, 2001) (Gan and Grunow., 2013).

E. Development of Concept and Prototype

The prototype development stage of product design is when design concepts and solutions are developed through drawings and mock-ups or on Computer Aided Design tool. The solutions should meet the requirements of the product design specification (Wankhede et al., 2014). It can be defined as concrete representation of part or all of an interactive system. Along with product specifications and the product's basic physical configuration, the extended product offerings such as life-cycle services and after-sale supplies can also be defined by prototypes (Krishnan and Ulrich, 2001). Prototype developed has an ability to explore a key idea quickly, it can give an assessment of design adequacy; it can assess quality and completeness of intended production methods and design assurance. Prototype can be a partial or full representative of design intents and functions. Primary goal behind prototype development is to check how true it will be in terms of performance and development. Prototype may demonstrate product's life cycle and it may also show its compliance with standards or legislations. Prototype development is mainly carried out to check design assumptions; measure performance; to develop platform; prepare manufacturing; complete design tests; confirm integrations. One of the most important reasons behind prototype development is to demonstrate feasibility of a critical or high risk element. More complicated risks are assigned to specific planned iteration cycles and reviews. For example, high customer uncertainty and the resulting market risk may be assigned to planned, cross-stage iterations that incorporate one prototype or customer test per cycle. Iteration provides feedback that reduces risk in the next round (Unger and Eppinger, 2011). Parameters listed evolve throughout the product development cycle, reflecting changes in priority and decisions being taken.

The process of coming up with design concepts will vary between designers and product types. More than one prototype should be produced and evaluation of all solutions should be carried out and the best possible should be selected. Solutions in the form of prototypes can be developed with reference to information from sources like existing products (produced by the company or competitors), existing or new technologies (which are applied or combined in new ways), from current ideas and trends within design (exhibitions, journals and interaction with other designers and engineers) and through creative problem solving and application of analytical theories.

Depending on priority and purpose prototypes can be classified into three types. 1) Proof/rapid/concept prototype 2) Functional bench/iterative prototype 3) Production prototype

Priority behind development of proof or concept prototype is to explore key idea quickly i.e. only major points are represented and actual product may vary highly than prototype. Rapid prototypes are created for specific purpose and are especially important in the early stages of design.

Functional bench prototypes give better assessment of design adequacy and can accelerate development. Small number of iterations may lead to final product.

Production prototypes assess quality and completeness of intended production methods. Iterative prototypes are developed to work out some details or to explore a wide various alternatives. This prototype may confirm and optimise production methods, handling, packing and testing. It may also confirm cost and can catch design faults.

F. Detail Design

This stage results in geometric models of assemblies and components, determination of precedence relations in the assembly, the detail design of the components including material and process selection, bill of materials, and control documentation for production (Krishnan and Ulrich, 2001). The goal of the design process is to reduce uncertainty until a detailed and solidified design is reached. During the process assumptions need to be made, introducing possible errors. Large errors may even lead to not reaching the target requirements and forces the design team to return to the conceptual stage (Jauregui-Becker and Wits, 2013).

During the detail design stage, product development and design team strives to ensure that the physical manifestation of the design will meet the required design specifications. The design phase is concerned with arriving at product characteristics that may provide the desired product attributes

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determined in earlier phases. Design phase sometimes can expose companies to market risk, especially if early specifications or assumptions are poor. When a company develops a product that meets design specifications perfectly only to find from early prototypes or market research that the design specifications missed evolving market demands. Learning about this design problem near the end of the process makes corrections difficult or impossible (Unger and Eppinger, 2011).

Detailed design stage is concerned to get optimum product structure and architecture. Functional composition of product and definitions of functional relationships between assemblies, sub-assemblies and, later, components are to be established in design stage. In this phase all properties of product are defined in details, for e.g. form, shapes, dimensions, tolerances, materials. This activity involves evolving the product design at an ever increasing level of detail, until all details have been laid down, and the product is ready for production. The rule which govern the sales of product is consumer tends to calculate the present value of all related expenses (including driving and maintenance of products) based on their cost at the time of purchase; this holds true for almost every type of product (Hwang, 2012). Detail design is done with respect to expected product reliability, maintainability, involvement of human factors, safety, supportability, availability of raw materials, life cycle of product and life cycle cost, flexibility, transportability, recyclability and disposability and environment effects. Along with all these factors many product characteristics have to be considered while running design activities. Continuous development and expansion of mechanical design of a product leads to establish – exact size and capability of a product, required chases and clearances, required space for a product, acoustical and vibration controls, visual impacts, energy conservation measures, product efficiency, perceived quality. Multiple design iterations are commonly carried out before a robust solution is accepted. Technical risk regarding the design of an isolated product component can be assigned to a detailed design stage with only minor iterations among design phase (Unger and Eppinger, 2011). Detail design should itself achieve refinement and co-ordination for a really good product.

G. Design Evaluation and Review

Design evaluation is a function which is carried out at various stages of the design process. Its purpose is to check that the design solution is in accordance with the original design objectives. Product evaluation begins at or before the start of product development with the formulation of customer acceptance criteria. Performance of product regards the information that determines the quality of the product being designed (Jauregui-Becker and Wits, 2013). The product must be verified against customer acceptance criteria and validated that it provides the customer with the operational capabilities actually needed; any divergences from expectations must be diagnosed and characterized as defects for disposition in a subsequent iteration of product development and product design should undergo necessary changes through detail design phase.

Critical design decisions are commonly made throughout the product development process assuming known material and process behaviour. However, variations during manufacturing can result in inferior or unacceptable product performance and reduced production yields. Thus it becomes necessary to evaluate design process and to take its constant review.

Design evaluation is carried out to understand and account for not only the negative effects of design and manufacturing variations, but also the positive impacts of design and manufacturing flexibility wherein instantaneous corrections can frequently improve the product quality and eliminate flaws in the product design.

Design evaluation may be carried out after the initial concept stage and again after the detailed design stage and finally, before the design is launched on the market. The design review is a more general evaluation of the design process, to evaluate whether the design process has been successful and has kept within budget and time-scale.

Design evaluation mainly, occurs before production or testing, so the downstream production information is not known and cannot be used to influence the design. Some of the reasons of variations may be because of- inconsistencies in material properties, effect of un-modelled or unknown material properties, systematic errors in process conditions, inaccurate design or end-use assumptions. All of these factors may vary significantly across a product's development and life cycle. The evaluation methodology requires probabilistic ranges to be applied to each of the root cause variables.

For evaluation of design following things are mainly needed. - A set of product design specifications, a candidate design, an estimate of the sources and levels of variation within the design, an estimate of the sources and levels of variation within the manufacturing processes.

Conclusions drawn in design evaluation should be implemented and final product should be made accordingly. Again the product can be reviewed and process may have several iterations till product achieves desired qualities and till it performs at desired level. However, prior to launch, the product needs to be fully tested internally to ensure business can be delivered into market.

H. Product Launch

Companies need to launch new products earlier than their competitors before new technology emerges or the market changes. Increasing complexity and multi-disciplinarily of products, in combination with increasing need for effective, fast, and lean development, make it necessary to establish a broad knowledge-base for engineers (Ulonska and Welo., 2013). Developing a strategy for a product launch is the last stage in product design and development process. For successfully launching and sustaining the product in the market, the voice of customer on their requirements must be responded (Lee et al., 2012). Strategic launch decisions govern what to launch, where to launch, when to launch, and why to launch (Chiu et al., 2006). New products developed are associated with high risk of market uncertainty. Having a clear strategy is crucial to both a successful launch and managing the product in the early stages of its life-cycle. Even a superior product may fail due to poor product launch strategy. If products launch strategy matches with actual market conditions then product launch becomes successful.

There are a lot of elements to manage simultaneously to achieve a successful launch. Moreover, it may involve pulling together all the internal functions of the business and external marketing agency as well. It involves parameters such as

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branding, quality, positioning, packaging, pricing, advertising, supply chain and distribution, manufacturing elements, and inventory. Marketing task mainly involves promotion of the product at launch to make an awareness of product. Marketing task should have clearly defined goals such as to grow existing market share, to take market share from competitors and to grow new markets or opportunities (Chiu et al., 2006). Advertising is traditionally fastest and effective way to develop awareness to maximum number of people. However, since last few decade number of new ways and modes of advertising have been developed apart from T.V. and radio commercials. Company may need an external marketing agency for promotion.

Timing of product launch can have a significant bearing on success of product. Factors such as seasonality, retailer's demand, sales force needs, market trends, innovation of new technology and government regulations can affect timing of product launch. If the product launch is to be done in seasonal market then it should be done in its peak phase as most of the customers will be looking for their needs to satisfy.

Pricing of the product is the key factor for the success of product. Profit maximization requires a detailed knowledge of both customer requirements and market, and competitive pricing. It assumes an exact knowledge of product's cost to perform an accurate and meaningful profit margin analysis. The pricing of a product will dictate its success both externally and internally. Externally, pricing is a key indicator of positioning. Internally, pricing directly affects profitability. Premium market price is necessary for both positioning of product and in order to sustain an acceptable profit margin after absorbing the ingredient costs.

IV. CONCLUSION

Having new ideas for new products is not enough for companies, to successfully bring those products to market; companies also need to develop product design and development strategy, which can address their specific needs. The framework proposed in this paper follows phases of product design and development, and manage a parallel task of design for manufacture. Phases are characterised by few iterations and rigid reviews. Proposed framework for product design and development tends to fix design specifications early. These fixed specifications help companies to provide stability, creating sharp product definitions, avoiding scope creep, and reducing the need for midstream corrections. Proposed product design and development frame performs well when product cycles have stable product definitions, have high quality standards, and use well-understood technologies. The product architecture should be structured according to the steps of systematic engineering design processes, including the levels of requirements, functions, principal solution and detailed solution and their linkages, and including constant revitalisation of knowledge and expertise. However, paper gives a generalised frame to follow for product design and development processes together. The research in product development must be tightly motivated by the needs of industrial practice.

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