

# Benchmark Pre-Production Practice in Manufacturing Engineering

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**Abstract.** Prototyping stage is a very important phase of new product development, where many decisions need to be taken to get high quality, zero defect products at the right time with minimum cost. Therefore, any value added improvements or best practices in the prototyping stage will support competitiveness of manufacturing companies. This research aims to benchmark the best practices in prototype part manufacture to support early stages of product introduction. A set of best practices in the prototype component manufacture, along with validated four step prototyping strategy model and best practice prototype journey path model were developed. Research findings provide insight about prototyping trends, best practices and optimum ways of doing prototyping in the manufacturing companies around the globe. Manufacturing companies can use the developed models and best practices to make better prototype strategy in their new product introduction system to achieve their business objectives.

**Keywords.** New product introduction, prototype, pre-production, benchmark

## Introduction

Due to the presence of international competition and market globalisation, manufacturing companies have to compete effectively by reducing product development cost and time, while assuring zero defect products. Therefore new products must be more quickly and cheaply developed, manufactured and introduced to the market [1]. This can be achieved by improving prototyping stage which is most important phase in the new product development (NPD) process. Prototyping (pre-production) phase is a very important stage where many decisions need to be taken to manufacture high quality product at the right time [2]. Therefore, any value added improvements or best practices in the prototyping phase at early stage of product introduction (PI) will support the company in the long range. This research has been carried out with an industrial partner, with aim of finding best practices in prototype part manufacture in the manufacturing companies.

The most important process for many companies will be the New Product Development (NPD). NPD aims in finding an opportunity in the market, converting that opportunity into product and finally launching it successfully in the market [3]. NPD is a huge field dealing with the design, prototyping, actual production and marketing of new products. Fang and Ou stated that the continuous development and

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market introduction of new products can be an important determinant of sustained company performance [4].

Manufacturing companies' success mainly depends upon its ability to introduce new products successfully into the marketplace. According to Sethi et al. [5]; Wang [6]; Buganza and Verganti [7]; Huang et al. [8] and Arastehfar et al. [9], many companies face more and more uncertain environment as changes in technology accelerate, customer expectations and global competition. To overcome these challenges, Ali et al. [10] stated that evolution of the market has necessitated the reduction of time-to-market. This is mainly because the product life cycle is shorter and also very important to proceed more rapidly from an initial conception to a mass production. Leading companies worldwide are discovering that Rapid Product Development (RPD) is a huge and relatively untapped source of competitive gain, especially for new products that have not appeared previously. If a particular product can be introduced early, it gains more customers and is able to maintain their loyalty due to the cost of switching to another product.

Camburn et al. describes that the prototyping is an important tool to identify challenges, reduce risk or prove a hypothesis and should be used wisely [11]. If prototyping is not handled properly, whole PD cycle will face the problem. With prototypes and feedbacks, design teams can effectively explore the ideas versus functional requirements [12]. Prototype in the NPD is the reference point from which the value of future improvements can be assessed as PD progresses. Therefore, a major tool for detecting all the problems is the prototype.

Physical prototypes are information channels carrying information richness, and enable one to cope with uncertainty. Marion and Simpson argues that for successful release of a new product physical prototype iteration is the key driver [13]. Bennett and Gibson et al. believes that both physical and virtual prototype techniques should be used simultaneously in the NPD process to develop complex products [14][15]. Both these techniques have similar goals, which is reduction of time and cost and to get more flexibility in the PD.

Zhang and Liu states that Rapid Prototyping (RP) is a new kind of manufacturing technology and it provides an effective measure for rapid manufacturing (RM) of products and dies to meet the demands for market competition and attracts more attention from corporations day by day [16]. Xiong et al. shows that direct metal prototyping methods like 3D welding Selective Laser Sintering (SLS), Shape Deposition Manufacturing (SDM), shaping welding, Electron Beam Melting (EBM), Laser Engineering Net Shaping (LENS) etc developed to fulfil the requirements for metallic prototypes and tools [17].

The literature explains the different prototyping methods. Most of the works mainly concentrate on either prototypes for software development or rapid product development. There is little information available about proper guidelines for building better physical prototype in PD. It is always not possible to improve reduction in development time by procuring new rapid prototyping machines or using digital prototype method. Instead, proper guideline should be evaluated for better physical prototyping in a PD cycle. To fulfill this gap in the research, benchmarking approach to find out best practice in physical prototype part manufacture, in the manufacturing companies around the world was planned to carry out.

## **1. Prototype Part Production Requirements**

However, industrial partner are already having a New Product Introduction (NPI) roadmap for their new product. They are looking to incorporate latest best practices in prototype part manufacture from successful engineering organisation around the globe. By improving prototype part production phase in NPI system and using this improved system company looks forward to deliver high quality, zero defect new products to its customer with shortest lead time so that it can form a strong platform in the global market.

Some of the key issues like speed of making prototyping, technical integrity of the part and dimension stability, accuracy and finish of the parts are very important to be considered while benchmarking outside companies. When considering all these requirements individually, even small improvements in these requirements will make the organisation grow exponentially.

## **2. Benchmarking: Data Collection and Analysis**

One of the best ways to compare the practices in prototype part production in a company is to compare their process, strategies and requirements with external companies' best practices. To achieve this objective a benchmark study is carried out to get the exact trends in prototype part manufacture in different companies around the world. This approach is allowed comparing the best practices from external companies of different manufacturing sectors with the industrial partners' requirements. This activity enables in getting better idea of what was happening in prototype part production activity around the world.

The main tool used in benchmarking process is on-line survey questionnaire. Survey questions were developed based on the knowledge from the literature review on the chosen research topic and converting industrial partner requirements. Apart from the on-line survey, five different sector companies interviewed face-to-face to get more information about best practice in their prototype part manufacture. These company names were mentioned by letter A, B, C etc.

For the benchmarking purpose, companies from different manufacturing sectors around the world were identified. These sectors belongs to aerospace, automotive, consumer goods, medical and electronic equipments, software, process industries etc.

## **3. Benchmarking: Data Analysis**

To check the quality of data received from the survey an analysis on the experience of the respondent in the field of prototyping was done. It was found that 80 % of respondent have 5-25 years of experience in the prototyping field. This shows that the valuable data used for benchmarking purpose coming from the most experience people of the respective company and these data can be considered as the most authentic.

### 3.1. Factors for physical prototyping

For building better physical prototype for any new product in the NPD phase, number of factors should be considered. The factors mentioned in the Figure 1 were either from the literature review or from the requirements and same is used for benchmarking purpose. Based on these factors companies designer can think of selecting suitable type of prototyping method for their company new product.

Companies were asked to rate these factors from values 1 to 5 (1= never important and 5= extremely important). It is interesting to see that on an average all the factors are between important to extremely important as shown in the Figure 1 even though these scoring changes when analysing each sector separately.

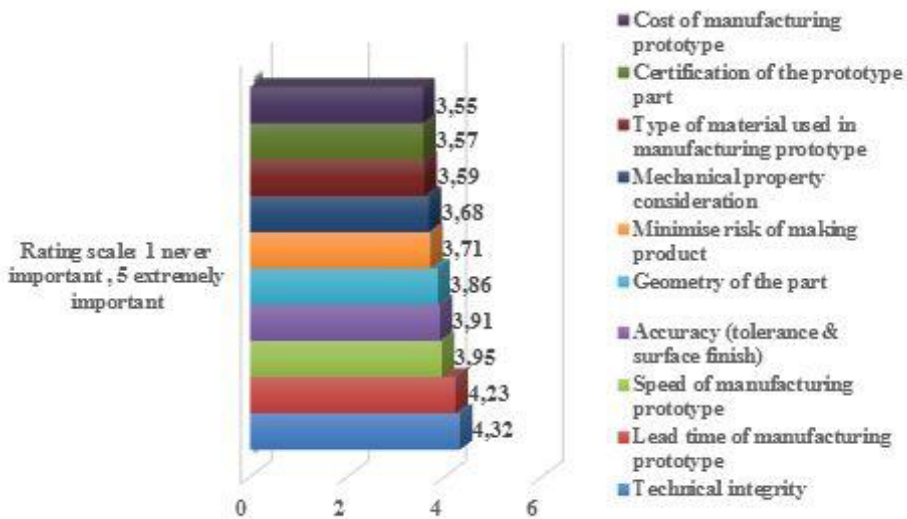


Figure 1. Important factors for building physical prototype.

Based on the result shown in the Figure 1, it is clearly visible that irrespective of the sector technical integrity factor (scores 4.32) is extremely important to consider while building prototype. However for one of the fast consumer goods company this factor is never important. Lead time, speed of manufacturing the prototype, geometry of the prototype and accuracy (tolerance and surface finish) of prototype parts these factors is also other more important factors. Therefore PD team of the company should consider these five important factors seriously before building any prototype to get success quickly.

### 3.2. Prototyping strategy

Survey results shows that nearly 90% of the company built their product physical prototype within six months depends upon the criticality of the product. Within that 35% of the respondent company confirms that their lead time for making physical prototype is about 6 months. Industrial partner average lead time for building prototype is one year. Survey gives hope that industrial partner still has the opportunity to reduce the lead time of building prototype from one year to six months by using novel methods.

Concerning the number of prototype build, 70% of the responded company built less than 15 numbers of prototypes for their new product in the PD phase. In which 30 % of the company built only 5 prototypes. Process industry will get the optimum benefit by building only one prototype to verify their design where as automotive industry will get the optimum benefit by building 50 prototypes before validating the design. Again these numbers depend upon company requirements and based on the level of benefit they need from these prototypes. It is interesting to see that considering overall results this number will not cross more than 50 numbers. The industrial partner on an average built nearly 20 prototypes before series production. When trend is like this it is better to make careful plan of building these low volume prototypes for success in the PD phase.

Even though selected companies are from various sectors, nearly 40% will manufacture the physical prototype in-house using separate prototype facility rather than making them with the existing production facility. Most of the aerospace companies are using this approach for manufacturing their prototype parts. By seeing this result it is hard to conclude that this approach is best practice, because nearly 30 % companies manufacture their product prototype in in-house using existing production facility. And nearly 20% make all their prototype parts from outside vendors. The industrial partner is using all these methods for manufacturing its product prototype parts depending on many criteria. Since each one is having its own pros and cons, each strategy should be analysed in depth before choosing the best one. Even then survey shows the trends of making prototype parts towards in-house using separate prototype cell.

Most of the companies around the world build prototype in their NPD for many reasons. Since prototype will be used during early pre-production stage of the PD, survey shows that nearly 72% of the company uses their prototype for validation purpose and nearly 67 % company uses for proof-of-concept purpose. Thus prototypes used mostly for three purposes i.e. for proof-of-concept, validation and test an idea quickly. Therefore these best practices should be used during building prototype stage in the PD.

### *3.3. Methods of prototype*

Survey results reveal that the most of the company always built physical comprehensive prototypes which is fully operational version of the product. This prototype will be given to customers in order to identify any remaining design flaws before committing to production. Survey also shows that most of the companies always use extensively an analytical-focused prototype i.e. 3D CAD model to solve most of the problems before building physical prototype. It is always better idea to use the combination of these two categories of prototype methods to solve many hidden problem in the product before ready for final production. Again any one type of prototype method is not suitable for all the manufacturing sectors.

## **4. Prototype Part Manufacture: Best Practice**

This research approach provides a set of best practice models within which company has to work out its own strategy to get the maximum benefit out of the models.

#### 4.1. Best practice solutions from benchmark study

Benchmarking study analysis and literature knowledge gives some of the best practice solutions. These solutions were already used by the successful companies. However, the following good practice solutions in NPI roadmap to reduce the lead time of making zero defect products have been reported by companies:

1. Use 3D CAD modelling, CAE and FEA techniques maximum before starting to build the physical model. Most of the cases full scale physical prototype can be eliminated.
2. Use reverse engineering techniques for developing new parts.
3. Use more non-destructive test rather than destructive tests.
4. Use concurrent engineered dedicated prototype shop and prototype quality department for prototype development.
5. Use real supply chain and the production vendor for developing prototype parts.
6. Use prototype as learning and communication tool. Capture these learnings in a better data base.
7. Use analytical prototype to narrow the range of feasible parameters and use physical prototype to fine tune the design.
8. Use rapid prototyping technology extensively in PD, but accuracy, build-time, strength and fabrication efficiency aspect should be considered carefully before choosing this method.
9. Addition of a short prototyping phase may allow a subsequent activity to be completed more quickly than if the prototype were not built.
10. Involving customer through out the PD stage. This is possible by building physical prototype in the PD process.

#### 4.2. Best practice model for prototype part production

There is a need to understand a set of models which will help companies to find the optimum solution for verifying engineering design. These models were developed based on the knowledge from the combination of benchmarking result analysis and the literature study as shown in the Figure 2 and Figure 3. Most of the literature says that, use of prototype whether it is analytical or physical will help the PD team to verify their design quickly and with less time and cost. Benchmarking analysis is also proved this theory. Four steps prototype strategy model has been developed as shown in Figure 2.

It is always better to start the prototype journey in virtual environment in the whole product level. By adopting this strategy most of the design unknowns can be identified and solved with lower cost and time. Better example for this case is use of simulation and mathematical model. Once the major problem solved, remaining problems should be solved by building focused prototype in virtual environment like CAD model and FEA analysis. Both these steps are time and cost saving.

To solve unanticipated problem which may occur during service of the product can be solved by building prototypes in physical environment. This prototype should be in detail level and should be focused to solve specific problem like strength test, rig test etc. Finally for integration and milestone purpose alpha, beta and pre-production

prototype should be built before starting series production. Which will be in whole product level and this prototype can be sell to the customer.

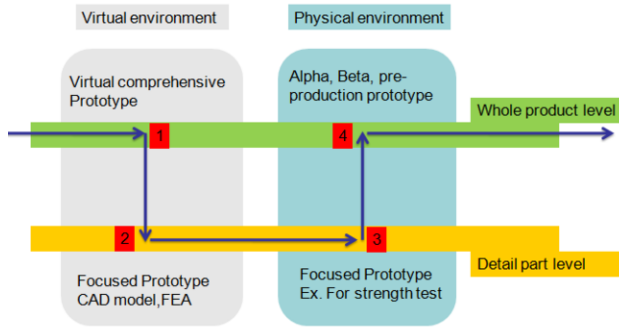


Figure 2. Four step prototype strategy model.

Best practice prototype journey path model developed as shown in Figure 3, using the knowledge from the literature reading and from the benchmark study analysis. This model is consist of 10 steps activity from concept stage to series production in any prototype part manufacture in a PD phase. These 10 steps should be carried out in sequence with eliminating one or two steps based on the company requirement.

Using this model company can able to improve its prototype part manufacture activity in better way and it can introduce its zero defect highly performed new product to the market with lowest possible time and with optimum cost.

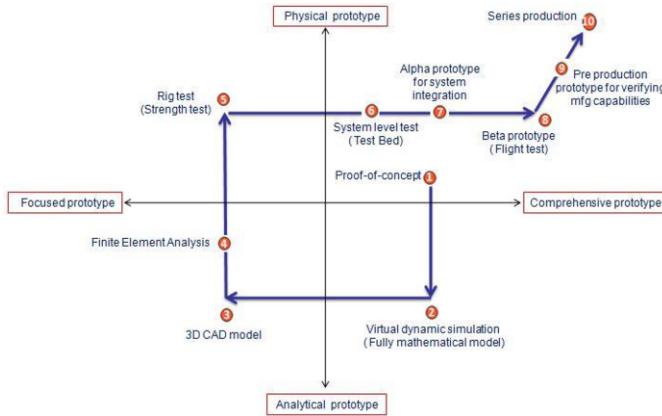


Figure 3. Best practice prototype journey path model.

#### 4.3. Validation of best practice model

Both the models have been generated from the literature review knowledge and from the benchmarking results. Therefore before implementing this concept in the company it should be validated by experts in the NPI area. These models were presented in front of both industrial and academic experts' and discussed about its advantages and area for improvements. Finally both the models were validated with minor modification. However these models can be used as guiding tool while making strategy in prototype part manufacturing in NPI and can be modified and customised according to the company requirements.

## 5. Conclusion

Benchmarking prototyping strategies in industrial organisations were carried out with the use of effective research tools such as survey and face-to-face interview. Best practices have been developed based on the analysis of benchmarking results. A 4 steps prototyping strategy model and best practice prototype journey path model have been created and validated through industrial and academic experts which can be used by different companies irrespective of their sector for better prototyping effort in NPD.

Prototype may reduce the risk of costly iterations but the anticipated benefits of a prototype in reducing risk must be weighted against the time and money required to build and evaluate the prototype. Therefore research efforts should be made on this issue.

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