DEPARTMENT OF
MECHANICAL AND
AEROSPACE ENGINEERING
(DIMEAS)

MASTER OF SCIENCE IN AUTOMOTIVE ENGINEERING

MASTER THESIS

Analysis of Product and Process Design According to Industrial V 4.0 Perspective.

Supervisor:

Prof. Paolo Chiabert

Candidate:

Ram Kumar Vengatesan

Academic Year – 2019 – 2020

April 2020

Turin, Italy.

Abstract

Title: Analysis of Product and Process Design according to Industrial V 4.0 Perspective.

As we are living in the era of the Industrial 4.0, which is characterized by the digitization of manufacturing, the engineers need to think forward for using digital tools and technology for the future growth and incremental increase in this Industrial Evolution. In this Industrial Evolution 4.0, the need for New Product Development is drastically increasing to make high-quality products more prolific. The companies are reverting swiftly to satisfy the customers' demands and try to understand customers' expectation and their mental framework about the new products. The manufacturers' loyalty towards the customer also improves the market share.

So, the Analysis of Product and Process Design plays a vital role in New Product Development. In the analysis of a product, the role of the designer is to create new products following a systematic approach starting from conceptualization and evaluation of ideas to execution of new products with digital tools. Thus, the designers must be able to communicate, visualize, analyse, 3D modelling products and produce tangible, and viable products suitable for the era of 4.0 Industrial world.

Moreover, the digital thread is not only beneficial for analysis of the product and process design but also accommodating or permissive for managing the full product lifecycle starting from idea generation through product and process design, product development and finally to Disposal, wherein the Product lifecycle management (PLM) comes in.

In this Industrial Revolution 4.0, all the data, processes, decisions and results at each stage of the product lifecycle need to be feed into the PLM Platform for obtaining better operational performance. PLM platform helps in accessing, tracking, and storing all the relevant and required data. Recording the changes and the services provided all to be maintained as the support for maintaining, connecting and exchanging of information in between departments by various Bill of Material's (BOM's), Engineering Bill of Materials (EBOM'S), Manufacturing Bill of Materials (MBOM's).

Furthermore, the rapid- advancement in technologies allows the engineers to design and manufacture products that often cannot be made by using traditional manufacturing methods, whereas Additive manufacturing which includes 3D printing technologies can be implemented. In addition to that, the product and process designers have more challenges in designing. To have won over a position, Designers can use 3D printing technologies by shortening the prototyping process. It enables the designers in stimulating new design and able to experiment with new product development processes before releasing the product into the production phase.

To throw a better insight and understanding, this project gives an overall idea of Product Lifecycle Management and how the Industrial 4.0 impact on NPD process. The Project also explains how to design and analyse the products and processes for increasingly smart manufacturing facilities.

Key words: New product Development, NPD process, Product and Process Design, PLM Platform,3D printing technology.

Acknowledgement

Firstly, I am grateful to my creator for the opportunity and other amenities that he has given me to do this project. It is because of my venerable and loving Academic Advisor, Prof. Paolo Chiabert Department of Management and Production Engineering (DIGEP). In my Master Thesis Project, I perform **"Analysis of Product and Process Design According to Industrial V 4.0 perspective".** In acknowledging his valuable suggestions, ideas, expertise, guidance and motivation. I would like to express my profound gratitude to him. I think I am fortunate to have a wonderful Academic advisor who has shaped and groomed my academic performance. I ever cherish this wonderful time in my carrier in future.

I would like to express my sincere appreciation and gratitude to all those who supported me in various ways to finish this project.

Contents

Chapter 5

List of Figures

List of Tables

Abbreviations

PLM - Product Lifecycle Management.

NPD - New product development.

PDM - Product data management.

EDM - Engineering data management.

CDM - Collaborative data management.

ERP - Enterprise resources planning.

BCG - Boston Consulting Group.

VOC - Voice of customer.

QFD - Quality function deployment.

HOQ - House of quality.

FR - Functional requirements.

CA - Customer attributes.

DP - Design parameters.

PV - Process variables.

BOM - Bill of Materials.

EBOM - Engineering bill of materials.

MBOM - Manufacturing bill of materials.

Chapter 1

Introduction

As of today, we crossed three Industrial revolutions starting from First Industrial Revolution which was introduced in Europe & US, the transition of new manufacturing process from Handmade manufacturing process into Machines which was divided into different types of manufacturing process named as: Chemical manufacturing process and Iron Manufacturing process. In addition, to that Manufacturing process has done with help of Steam and Waterpower which causes the major changes in various countries mainly in Europe, US and UK both in economic and social life.

The Second Industrial Revolution gradually grew with help of chemical Industries and petroleum products. It's not an end of the second industrial revolution, because there was a rapid growth in Industrialization since the introduction of Hydroelectric power generation in later 1880's.These things that are made possible by means of structured models implemented in large factories and also the organizational model of mass production as envisioned by Taylor and Ford.

Nearly the century later, the third revolution grew rapidly due to rise of electronics, information technology, and telecommunications and computers. These technologies were integrated to develop a high-level automation in production supported by two inventions of Programmable Logical Control (PLC) and robots.

"***The industrial revolution allowed us, for the first time, to start replacing human labor with machines". by Vitalik Buterin.***

Finally, it shows that the last three industrial revolutions, companies are producing the product using the traditional manufacturing process and methods. With changes of time and development in technology by using different structured organizational approaches, principles, models, techniques, tools and technologies that gone for lean manufacturing.

The three Industrial revolutions form a fundamental base for the fourth industrial revolution in all fields of technology mainly in the production and manufacturing fields.

"The Industrial Revolution was another of those extraordinary jumps forward in the story of civilization". by Stephen Gardiner.

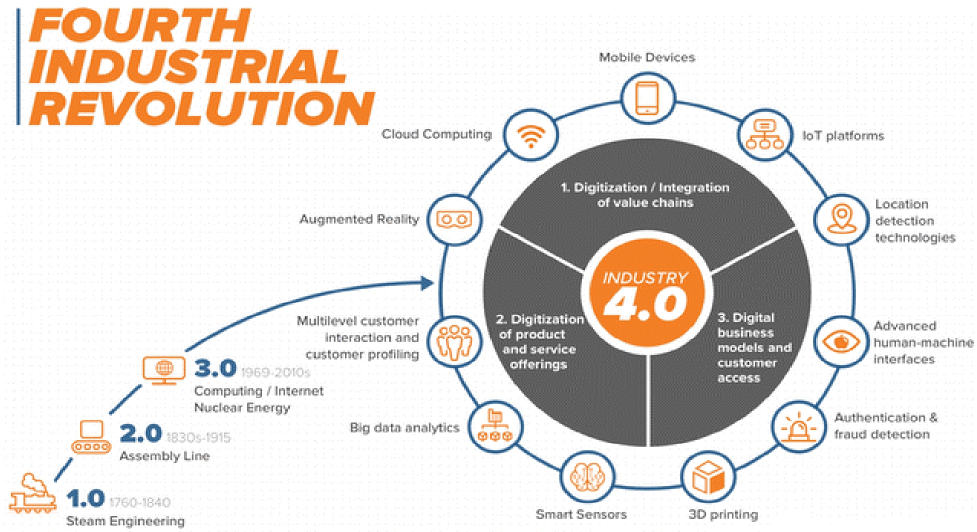


Fig 1: Transformation cycle from Industry 1.0 to Industry 4.0

Now we are in the Fourth Industrial Revolution 4.0, the term Industry 4.0 was originated in 2011 from a project in the high-tech strategy of the German government, which promotes the computerization of manufacturing. Because of the changes that made in the third industrial revolution named digital revolution there was change from analog and mechanical system to digital ones and its forms a fundamental base for fourth Industrial revolution. In addition to it, it has rapid development in computers, and in ICT.

In the opinion of "Boston Consulting Group" (BCG), a global management consulting group, express that Industry 4.0 is the building blocks formed by nine technologies: which are called as Big data analytics, Autonomous Robots, Simulation, Horizontal and Vertical integration, the Industrial Internet of Things, Cyber security, Additive manufacturing, the Cloud, Augmented Reality.

In the field of Manufacturing and Production companies uses Additive_Manufacturing, such as 3D printing to build Prototypes. 3D printing widely used to produce small batch of customized products which are light weight and more complex in shapes and designs.

New Product Development (NPD)

Why we need of new product?

- The companies need to grow for survival and growth.
- To be in business for a long time.
- The company existing product lines becomes outdated & the sale is on the decline.
- To satisfy the customer needs.
- The new product must be available in the market more quickly.

New Product Development

Recent trends in the global market is that product must be new, innovative, and must have a new brand image, in terms of quality and it should be competitive enough to attract the customer in terms of low cost. Companies must grow to retain the business continuously in the market for the existing products & new products. New technology and tools of best practices are required for creating & modifying new products with high quality to meet the new trends in the market & satisfy the customer requirements in terms of standards, quality in the changing future. The other requirements are the products should be eco - friendly and must subject to any analysis and give good result in testing. The product should meet the engineering requirements, and provide components details and information etc.

The main goal is to offer a wide range of value-added services to the customers for the whole product life cycle. Nowadays, the product manufacturers try to find new ways to attract the already existing customers by providing extra added value services.

One of the challenges commonly occur during Product development process is to track the changes of a product. For this reason, Companies adopted Product lifecycle management (PLM). PLM is one of the core IT tools in a company which offers management and control of the product process and the order-delivery process, the control of the product related data throughout the product life cycle, from the initial idea to the scarp yard. One of the functionalities of Product lifecycle management (PLM) is to track the New product development Process. PLM is an integrated and information driven approach used by industries having various departments such as engineering, marketing, purchasing and manufacturing and others department also. Here some definitions of PLM most common seen in books

- ✓ PLM drives the next generation of LEAN thinking.
- ✓ PLM is all about product data, information and knowledge.
- ✓ PLM concerns itself with the entire lifecycle of the product, from inception to end of life.
- ✓ PLM is an approach that is more than software or processes.
- ✓ PLM combines the elements of people in action (practices or methods), processes.
- ✓ PLM crosses boundaries: functional, geographical and organizational.

"Product Lifecycle Management: Is concerned with processes, methods, and tools used from a product's inception through the end of its service life".

"Is the science of bringing these three disciplines together to create an environment that enables creation, update, access, and, ultimately, deletion of product data".by Ford motor company.

General Overview of Product Lifecycle Management (PLM)

In Late 1980's there was a need for manufacturing industries especially for engineers to control, track, store and maintain BOM's, and to establish relationships between parts and assemblies in that case EDM (Engineering Data Management) & PDM (Product Data Management) plays a vital role in terms of controlling, reusing, documenting at revision levels and see the immediate relationships between parts and assemblies. PLM is a subset of EDM & PDM.

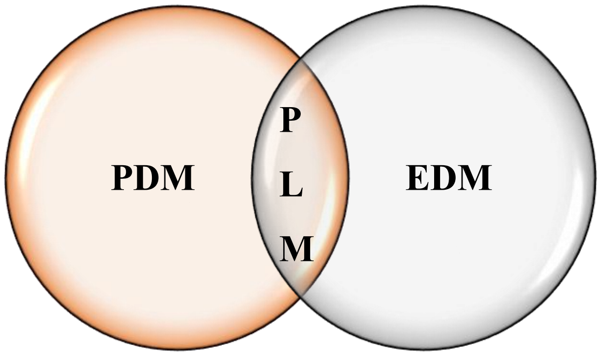


Fig 2: Subset of PLM

PLM is mainly focusing on storing, refining, searching and sharing of product information. PLM plays a vital role in managing and analysing the product results, quality and standard. It gives importance to the engineering requirements, product performance, product information, manufacturing procedures and so on.

In addition to that, the modern PLM is equipped with operational efficiencies and capabilities which include workflow, program management and project control features to accelerate product management operations**.** In order to foster the sharing of information about the products value chain, the electronic information, data reuse with traceability and with greater security.

Product Lifecycle Management In 21st Century

In 21st century Product lifecycle management (PLM) is not only focusing on managing their products across their lifecycle starting from idea generation to way through its disposal, but also defining the resource i.e. wealth of its products to enhance the activity of product development by means of advance innovation in technology, to decrease the Time to Market (TTM) and to promote new services, to give support for the already existing products.

To the manufacturing companies the PLM helps in reducing the cost related to products i.e. Materials, Energy, in reducing the Waste etc. which are fixed during the early stage of product development process. And, the PLM helps in solving the overwhelming problems of the new product development by the use and support of already existing products.

Furthermore, for the new product development, the companies are especially focusing on attracting the new opportunities in local and global market by creating product portfolios mainly in international market to get more revenues. PLM also provides a framework to manage products, including products data, processes, applications.

Product Lifecycle Management About Products:

PLM is all about the Product lifecycle management, i.e. the control of product related information throughout the product lifecycle. Since, it is a systematic and controlled concept, PLM forms a backbone of managing, developing and controlling of new products. By using PDM and PLM the companies can develop and manage product lifecycle. PLM product data is classified into three types:

1) **Definition of data of the Product:** It helps to determine the technical data of the product in terms of physical and functional properties of the product from different point of view such as customers' expectation and satisfaction, manufacturers' profile etc. By using the products' data information one can get the overview of the complete product definition to solve various technical problems related to it.
2) **Lifecycle data of the Product**: these data is helpful in understanding the various lifecycle stages of the product in its lifecycle and also to understand the information about the interconnectedness between the stages of the product starting from research, designing, sketching, prototyping and production. It evolves certain important stages of use, reuse, maintenance, recycling and disposal of the product. All these stages of lifecycle of the product must be well connected with possible regulations and with product.
3) **Meta Data:** Metadata is also called as "Information about Information", by Anselmi Immonen. The main purposes of Meta Data are about the product data to provide information and answer all queries by means of **5W's** i.e. Where, Why, Which, Who and in identifying the location, accessing the product, recording the details of the products, and maintaining a data bank.

The product data, Product Structure and Bill of Materials (BOM) are inter-connected. BOM is more related to Manufacturing and list of the parts, it also contains all the details about manufacturing and assembling and all the details of the necessary components that are required for the product.

1.1 Thesis Outline

The thesis is organized as follows.

- Chapter 2: New product development, Product lifecycle management and Integration of NPD and PLM literature reviews.
- Chapter 3: New product development of product sliding door trolley implementing via various models and results obtained in various phases of NPD phase cycle.
- Chapter 4: Implementation of New product development in PLM platforms by using ARAS Innovator software.
- Chapter 5: Conclusion of my thesis.

Chapter 2

New product development and Integration of NPD in PLM Platform

In this chapter, different strategies and the process that are implemented for new product development in various industries for their growth and development of their business in market will be dealt in the light of available literature**.**

New Product Development

New product development is more commonly referred as NPD - is a set of activities starting with the customer needs and/or customer demand, designing the product and ending in the production, sales and delivery of a product.

2.1 New product development in 1980's

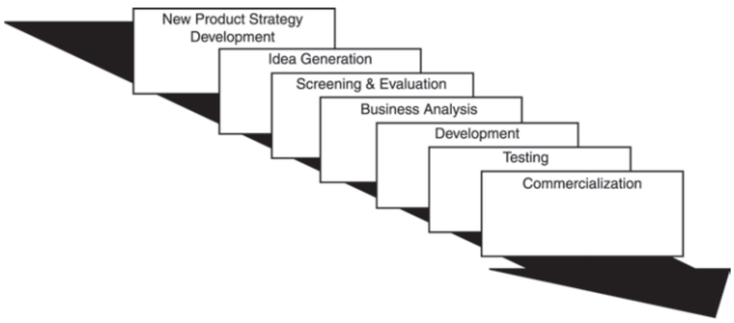
In the last few decades, as companies become smarter and more conscious about the introduction of new product in the market, it drastically increased their long-time success in business. Parallelly companies are trying to find out the best way to manage the new product developments and their process. NPD requires time, financial investment in the product and human resources by the firms involving in NPD. The deciding factors about the rate of success or the failure are the knowledge about taking the new products into the market and sustaining in the market by satisfying the customers' expectations.

> "***A new product evolves over a sequence of stages, with an initial product concept idea that is evaluated, developed, tested and launched on the market.".***

Introduction of new product in the market also involves great risk. By adopting the one such of systematic framework for managing new product activities which was developed by the management consulting firm of Booz, Allen and Hamilton (currently known as Booz & Company).) The risks related to new product development can be minimized even evaded by adopting the following seven sequential stages:

1. New product strategy development.
2. Idea generation

3. Screening and evaluation
4. Business analysis
5. Development
6. Testing and commercialization.



From New Products Management for the 1980s by Booz & Company. Copyright © 1982 by Booz & Company. Reprinted by permission of Booz & Company.

FIGURE 2-1 Booz, Allen, and Hamilton's New Product Process

Fig 3: NPD Model

Stage 1: New product strategy Development

It starts with the development and implementing of new products. The important strategic developments are aiming at achieving their company's objectives, goals and mission, and identifying specific roles to focus on generating ideas and concepts which may help as a guideline for establishing selection criteria.

Stage 2: Idea Generation

The main purpose in this stage of idea generation is to do lot of brainstorming to generate several wealthy ideas and alternative ideas. In this stage, companies generate a pool of ideas; each idea must be considered and tested for its validity, reliability and suitability and to determine the most suitable idea for product objectives that are defined in the new product strategy development. The below fig 4 shows the number of Ideas generated vs Cumulative time.

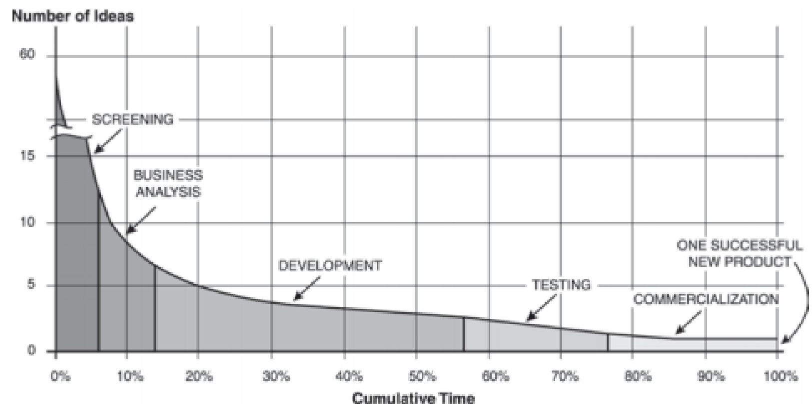


Fig 4: Number of Ideas Vs Cumulative Time

Stage 3: Screening and Evaluation

In this stage, the pool of ideas that are created in the stage of idea generation are subjected to screening and evaluation. This helps in avoiding the pitfalls in deciding the alternative ideas and for the process of further investigation of things related to the ideas chosen.

The below fig 5: shows percentage of total cumulative expenditure vs Cumulative time. At last, the most promising ideas proceed to the next stages of business analysis and other remaining ideas are eliminated.

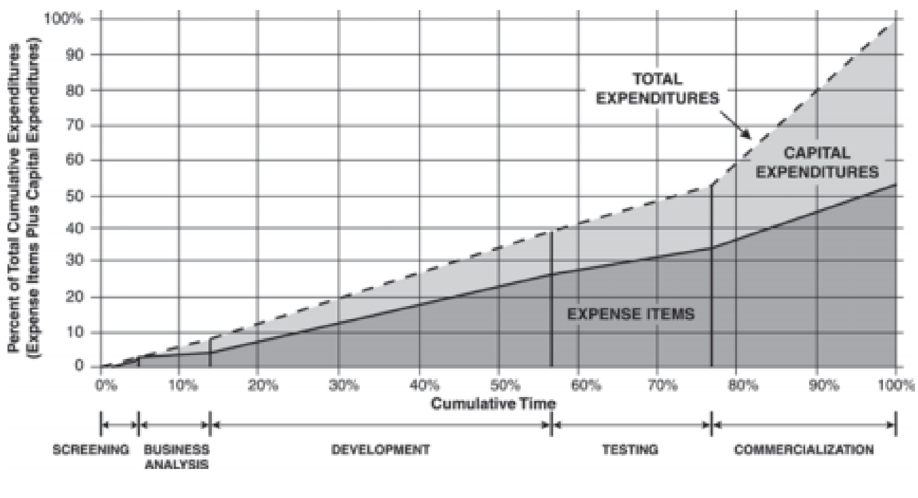


Fig 5: Percent of total cumulative expenditure Vs various stages of NPD process

Stage 4: Business Analysis

In the stage of business analysis, all the attributes of the products are identified. The barriers to have an entry into the international or domestic markets are analysed. The current and potential competitors are identified. Information on market targets, market growth, information of already existing products or new products, and the methods of promoting of different kinds of products are gathered and predicted. This analysis is helpful in getting a clear picture of promoting the product in the market and to proceed further with great confidence.

Stage 5: Development

This is the stage of implementation, in this stage; the ideas that are chosen to be the most suitable for product development are executed in order to transform the ideas into actual product. For example, if the idea is meant for product development, then it involves the actual physical assembly of the product, and if the product idea is about service based product then the development involves the assembly of all the components required for services to be offered. Apart from that, lots of alterations must be done, because at this point the ideas are realized and try to transform into actual product.

Stage 6: Testing

Before the new products entering the market, they need to be tested; testing seeks to validate earlier projections associated with new offerings through experimentation. Experiments are done by conducting trials to know the suitability of marketplace. If the products are tangible, they need to be tested and well suited for laboratory testing and the results of testing will be required for marketing strategy also.

Finally, the test conducted for both goods and services connected by means of feedback loop, which helps company for another opportunity to make ready of their products to entry into the marketplace.

Stage 7: Commercialization

It is the last stage in the process of new product development; this stage involves commercialization, which is the introduction of new product into the market in a full-scale for sales. After the new product released into the market, the companies need to collect feedback from the customers to know how far the product is satisfying to the customer needs and expectations. In case if there are any “bugs” that are identified, such things need to be remedied immediately. In addition to that the companies need to understand the reactions of competitors about the new product offerings and require to take some necessary steps to counteract with competitors' response.

2.2 General Introduction to Innovation management and New product development (NPD)

New product development has various disciplines such as marketing, production, design, engineering and economics and are interconnected with each other. Each discipline has different perspective and a way of approaching is different to each other. For example: from the marketing point of perspective they are concerned to understand the needs of customers and how the business will be successful and meet the best needs. The production department evaluates the development of products from a manufacturing perspective.

Matrix for product development strategies

The matrix for product development strategies which was created by Ansoff's directional policy matrix by Johnson and Jone's (1957) which is replacing the Ansoff's product variable techonolgy. By using this matrix, the companies can take decisiosn confidentally, since the matrix is distinguish between improving existing techonlogy and acquiring new technology and also there is also higher degree of risk when probability to use more intensive resources.

Increasing technology newness →

Increasing market newness ↓

Products objectives	No technological change	Improved technology	New technology To acquire scientific knowledge and production skills new to the company
No market change	Sustain	Reformulation To maintain an optimum balance of cost, quality and availability in the formulae of present products	Replacement To seek new and better ingredients of formulation for present company products in technology not now employed
Strengthened market To exploit more fully the existing markets for the present company's products	Remerchandising To increase sales to consumers of types now served by the company	Improved product To improve present products for greater utility and merchandisability to consumers	Product line extension To broaden the line of products offered to present consumers through new technology
New market To increase the number of types of consumer served by the company	New use To find new classes of consumer that can utilise present company products	Market extension To reach new classes of consumer by modifying present products	Diversification To add to the classes of consumer served by developing new technology knowledge

Fig 6: Market Vs Technology Newness Matrix

New products Classification

Generally, the new products are classified according to certain categories. Defining the new product categories may vary depends on subjects to judgement and distinction between one category and another is one of the degree. It is worthy to note , however the, that only 10 percent of all new products are truly innnovative. These products involve the greatest risk because they are new to both the company and market place. Most new product activity is devoted to improving existing products.For example: Sony company, 80 percent of new product activity is undertaken to modify and improve the company's existing products. The following classification (Booz, Allen and Hamilton, 1982) identifies the commonly accpeted categories of new product developmements.

1) New to the world products.
2) New product lines (new to the firm).
3) Additions to existing lines.
4) Improvements and revisions to existing lines.
5) Cost reductions.
6) Repositionings.

General overview of NPD theories:

Given that all products possess limited life spans, non-profit executives must continually seek to develop new product offerings that will ensure long-term growth and prosperity (Booz, Allen & Hamilton, 1982). For a new product it evolves over a sequence of stages, with an initial product concept idea that is evaluated, developed, tested and launched on the market. [1].

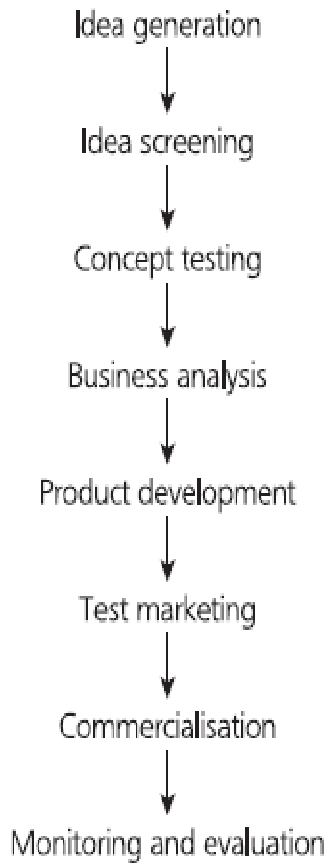


Fig 7: Linear NPD model

It is a simple linear NPD model composed of 8 sequential stages and which more common in many books. But some research suggests that the process needs to be viewed as a simultaneous and concurrent process with cross-functional interaction (Hart, 1983).

As a result, many researchers suggest that on new product development will be varied and fragmented, making it extremely difficult to organize for analysis. Finally, the most important thing needs to consider that if anyone is developing a new product development process must have to organize and manage the NPD process.

New product development models:

Several models that are commonly presented and these models which are suggested by different authors to identify some of the activities and that need to be managed. There are many possible ways to classify the various models into 7 distinct categories (Saren,1984).

1) Departmental – stage models.
2) Activity – stage models and concurrent engineering.
3) Cross- functional models (teams).
4) Decision – stage models.
5) Conversion – process models.
6) Response models and
7) Network models.

Departmental – Stage model:

It is one of the earliest NPD models, based on the linear model of innovation, since each department are responsible for tasks and responsibilities. This model is represented by the following ways for better and easy understanding and for sharing information between departments. This model named as "over-the-wall" model. Because in these models, these departments would carry out their tasks before throwing the project over the wall to the next department.

- ✓ R&D department provides the technical ideas.
- ✓ The engineering department will then take the ideas and develop possible prototypes.
- ✓ The manufacturing department will explore possible ways to produce a viable product capable of mass manufacture.
- ✓ The marketing department will then be brought in to plan and conduct the launch.

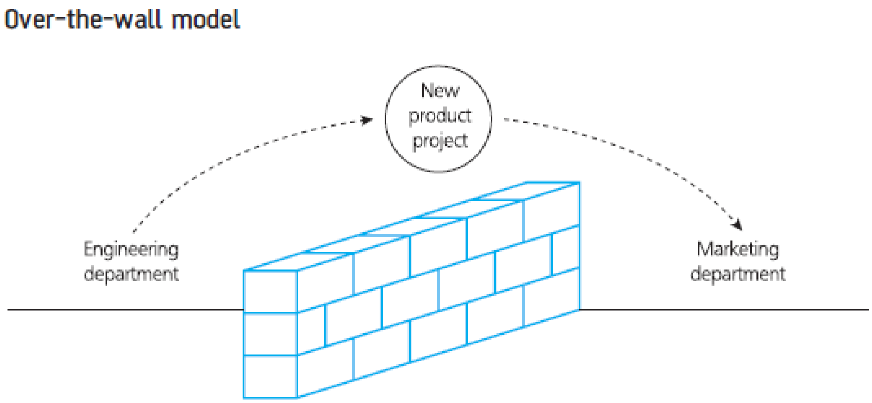


Fig 8: Over -the-wall NPD model

Nowadays, this approach which is suggested and captured by Mike Smith's (1981) humorous tale of "How not to design a swing, or the perils of poor co-ordination", also named as insular departmental view of the process hinders in the development of new products.

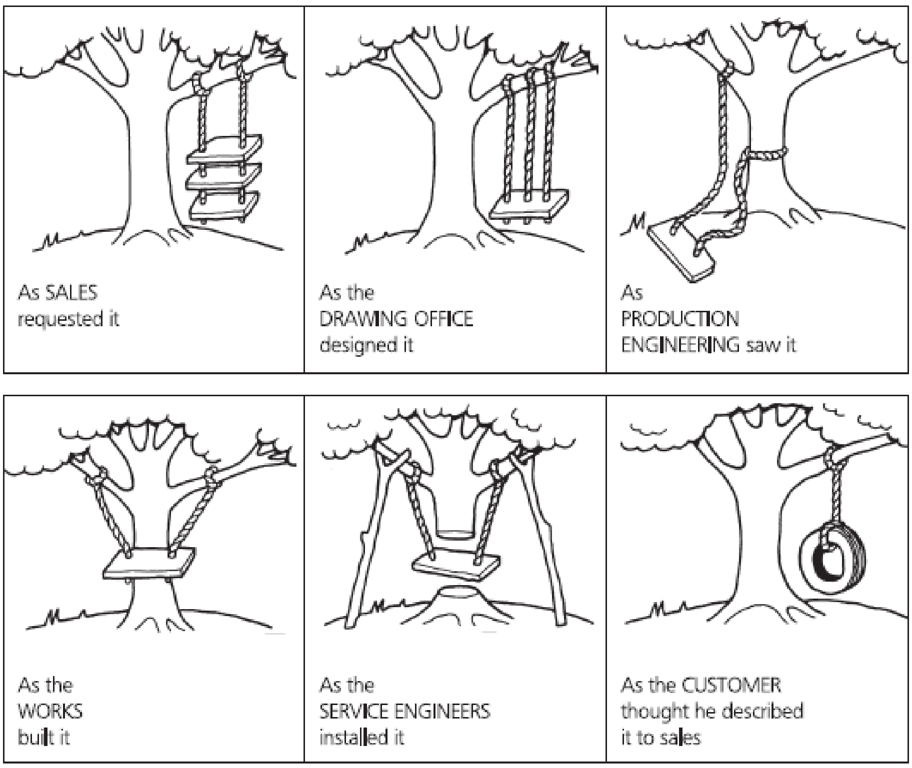


Fig 9: Departmental Model

the main work is done by the market research, who provides continual input to the process. The process is usually characterized by a great deal of reworking and consultants between functions. Moreover, the project control will vary from while it goes from department to department, and which current department is currently engaged is in the charge for the project control.

Activity – stage model

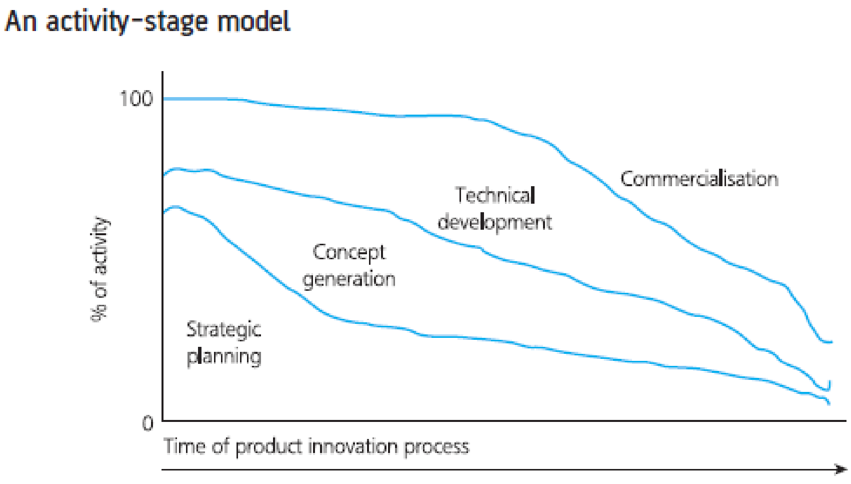


Fig 10: Activity stage model

The activity stage model is very similar to departmental model, but in activity stage model have number of iterations with feedback loop. The main difference is that all the activities such as strategic planning, concept generation, technical development, and commercialization are started at same time but in magnitude of each activities are varying.

2.3 PLM for New Product Development

Nowadays the companies are trying to renew the products from the early period of manufacturing, i.e., the percentage of renewing the products for the past fifty years is drastically increasing in the environmental world of the products. With increasing complexity of the products and their components, there is a real confusion which one is the feasible solution in this complex environment. During this period of changes, there are several associated risks possible either to create problems or to create some opportunities and sometimes it may resultant in unexpected events to occur. [2].

About the Product Lifecycle Management (PLM) is the ***activity of managing the products throughout its lifecycle," From cradle to grave"," from sunrise to sunset". By Author J. Stark.***

It is a known fact that the product lifecycle stages are not a constant one and the variation depends upon the views of the manufacturer and user. For example, from the marketing point of view, there is a market-oriented lifecycle for products. Accordingly, the products have four stages of lifecycle starting from product introduction, growth, maturity and decline. Form the user point of view the products have five stages of market lifecycle that are product development, market introduction, market growth, market maturity and sales decline. Apart from that, there are environmental product from global resource viewpoint.

Since the emergence of PLM in 2001, the companies are trying to manage the product across their lifecycle, the product management is done by separate departments such as marketing, R&D, Manufacturing, Support Department and other departments such as quality control, IS, etc and they take care of the Quality and Product related decisions etc. but one cannot guarantee that the final results can satisfy the companies. To interconnect and to manage the various departments related to the product lifecycle across, the PLM plays a vital role in an integrated way, for the parts, products and portfolio of the product. So that PLM forms a new way of thinking about the product and manufacturing industry.

Generally, once the product is created, lot of people need to work with many activities included in the lifecycle of the products. In order to differentiate and understand the product structures easily, creating a list of products, parts and their structure could be helpful. For example, if the product has ten parts, by creating the list of all ten parts, one can decide which part need to be manufactured and which parts need to be assembled by means of structured list, an array of hierarchical structure. Apart from several BOM's, EBOM's and MBOM's are also made in graphical view or tabular view.

In order to make the links between the physical structures of the product to other characteristics of the product and to understand deeply about the relationship throughout the product lifecycle creating a product architecture which is linked to the design is very important. This product architecture should be created by means of graphical form and array form also. In addition to that, the companies can also create product portfolio and catalogues for each product line when the company has more than one product. The product assemblies are made by top down viewpoint or bottom down viewpoint. Another type of product model give a better understanding by providing the details about the physical properties of the product such as its appearance, electrical and electronic behaviour and for a car aerodynamic that the products have many different models and each type of models helps in understanding and increasing knowledge about the product and its parts. Thus, one can understand how these models and types can play a key role in managing the products across its lifecycle.

2.4 PLM for Product Data Management

There are two main acronyms used in the area of product development process that are PDM and PLM both are interrelated with each other, but their scope and significance are difference with each other. PDM is also called Product data management and it is a kind of tools and methods mainly focusing on managing the product data more efficiently. In addition to that, PLM is named as product lifecycle management aimed to control the lifecycle of the product. Apart from that, PLM provides an approach and it has wide range of different concepts, technologies and tools for managing the product lifecycle. [3].

The PLM fundamentals explain all the core functions of Information processing systems adapted to get more insight about the practical reality of product lifecycle management starting with product data and defines in detail about product related information by classifying them into three types

1. Definition data of the product.
2. Life cycle data of the product.
3. Metadata that describes the product and lifecycle data.

In Product lifecycle management systems, the product has been described by means of its items, because the product may be an element or a component, or a material or a service. An item is the systematic and standard way to identify, encode and name a product in a best possible way. There are many advantages, if the product is defined by means of an item, main things is to identify the documents. If the things are described in terms of items, it makes it easier for classification, and to obtain different viewpoint based on different classes, and sub classes for different types of industries and also for manufacturing business.

Generally, the Product Lifecycle Management system is the integration of all IT concepts and systems. This integration is done with product data by means of connecting, integrating, updating and controlling the product processes. Moreover, the PLM also integrated with various systems such as Computer Aided Design (CAD) and Computer Integrated Manufacturing (CIM) depends on the business and manufacturing industries requirements. Furthermore, the PLM system functions as a central hub in providing a wide range of functions to support different processes to acquire product related information by creating, updating, recording, distributing, utilizing and retrieving the information.

The PLM system is unique in its form, the overall idea about this system being helpful to the companies in bringing the product to the market within shorten period of time with good quality. In addition to that, the companies need to bring changes in the product for proper and efficient ways of functioning, and also to find the product related information very quickly by means of reliable and effective way of communication.

2.5 Introduction to New Product Development and PLM Integration

For the new product development and PLM integration there are different examples in which different industries implemented these NPD and PLM process. Here the researcher explained some of the examples of new product development process which are integrated with PLM, and how the industries achieved their business growth by using PLM platform. The Section 2.6 explains about new product development and Integration of PLM which was implemented by one of the famous chemical industries in Serbia, followed by that, the section 2.7 explains about NPD process which is adopted as a “Family Business” by using IDE0 approach and also by implementing various management architectures such as PLM, CDM, PDM and ERP systems.

2.6 New Product Development and PLM Integration in Chemical Industries

The PLM is a strategic business concept that is used for achieving business integration with the key goal: “Product development”. The product development must gather all the information from the overall product lifecycle (Anisic, 2011).

There are examples to understand and have a deep knowledge about how new product are implemented in industries. One such example is the new product developed by “Beohemija” chemical industry in Serbia, which introduced plastic bottle production system in the company, and they have done this through the integration of PLM (Siemens,2011). [4]. They managed by using new product development process through various phases such as

1. Opportunity identification and selection.
2. Concept generation.
3. Concept evaluation.
4. Development and
5. Product launching.

In order to obtain an efficient final outcome at the end of launching the product in the market, the companies started focusing on problems to understand the market needs and demands rather than to hear the voice of customers, and also they try to solve the problems of the already existing products within the company and in supermarkets where the product are kept for sale. The main issue they faced while placing the plastic bottles named as ***“Spin Surface Cleaner”,*** was that they could not be fit in the shelves. They solved the problem by changing its dimensions: the average mass of the plastic bottle is 70gms and by reducing the height to some mm, and by increasing the average mass by 2gms and also by reducing the quantity of chemical filling inside the bottle to 50ml, they succeeded in their efforts. Finally, they produced a modified product with creative packaging to attract the diverse requirements of customers in the market.

“Innovation is our lifeblood - new ideas and new products that make consumers' lives better, build customers' sales and profits, and build P&G's market share, sales, profits, and Total Shareholder Return” (Siemens, 2011).

The companies initially faced some difficulties and were not at comfort zone while starting the integration, the reasons were the work was partially carried out manually by humans and the remaining was done by IT systems to support some processes of the lifecycle. The companies used the PLM system for collecting information from the PLM database i.e. CAD, ERP, CRM etc. To begin the project, the companies designed a table for project tasks and formed a responsible organisational unit through at different phases to identify and to have a clear insight of the project. But the companies still had a lot of problem in accessing all the data in real time in terms of document flow among the organization units, at each stage for getting the approval of documents and for changing the tracking of data.

	Tasks	Responsible organizational units
I	Opportunity identification and selection	
	Opportunity identification	Marketing, Sales, Development
	Opportunity selection	Marketing
II	Concept generation	
	Project definition	Project management, Sales, Development, Marketing, Production
III	Concept evaluation	
	Project analysis	Technical development, Project-development management, Marketing, Brand management
	Project approval	Top management
IV	Development	
	Project schedule	Project management
	Project schedule analysis	Project management, Sales, Marketing, Supply management, Development, Production, Quality control, Technical preparation
	Project schedule approval	Project-development management
	Realization of defined tasks of the approved project schedule	Project management
	Industrial testing	Project management, Development, Supply management, Production, Quality control
	Project verification	Project management, Development, Institutes, Accredited laboratories
	Project validation	Marketing, Project-development management, Technical development
	Validation approval	Top management
	Project realization	Project-development management, Production, Quality control
V	Product launching	
	Presenting the product to the market	Marketing
	Distribution	Sales

Table 1:Project tasks and Responsibility of Spin Surface Cleaner Project

Need of workflow for the project task which is drive by the PLM workflow or change in process events. And also need and allocation of resources which is provided by PLM IT solutions to managing, allocating resources for planned activities and needed for future also.

Moreover, the company is much more focused only on packaging the plastic bottle for Spin Surface cleaner, PLM platforms offers a wide range of integration specially in design tools such as AutoCAD, NX CAD and various design tools helps for the company in package design of the product. The company also created around 12 users in PLM systems for various organizational unit within the company to keep in interconnect with each other with single source of project and easily accessible for all the users locally and globally in real time to manage and approval data, managing the product configuration, in case of change in design in both process and product.

2.7 New product development and PLM integration in Family Business

Most of the luxury apparel brands at world level are run by a family named as family business. For example: large size companies such as Louis Vuitton, Gucci, Hermes, Prada and Ralph etc., these luxury industries termed as a family business phenomenon. 'Family Business' phenomenon is considered a dominant source of growth, development, and social and economic stability within the luxury industry, representing the most widespread business model in the world. Since the Family business is run by patrimony of history, and trust, reputation, values and prestige handed down through the generations, giving the brand long-term authenticity. [5].

Luxury industry decided that need to expand the market, because nowadays the buying behaviour of customer is changed. In addition to that, markets, products, services, marketing distribution are also changing in environment for innovation. So, the luxury industries planned and adopted "Collaborative Product Development/Definition and Management" (CPDM) solutions. CPDM is a set of collaboration solutions in NPD process, comprising of different architectures for sharing, archiving and managing product information and sharing the management of development processes.

Collaborative Demand Management (CDM), Customer Requirements Management (CRM), Product Data Management, Enterprise Requirement Planning (ERP) or Product Lifecycle Management (PLM), some kinds of solutions are generally employed to manage data needs at certain point of the manufacturing process (Chan & Wu, 2002; Colquhoun, Baines, & Crossley, 1993).

In order to overcome and need of NPD process to develop the luxury industry, and needs to be positioning in the innovative market, they adopted "User-Centred Approach" with detailed study about their user's viewpoints.

Finally, they proposed to start with IDEF0 based approach it includes functional analysis, shows data flow, system control and functional flow of lifecycle processes. Starting by the use of this methodology, luxury industry used various methodology to support the IDEF0 based approach. Some of them are Quality function deployment (QFD) approach to correlate with luxury NPD process with CPDM features.

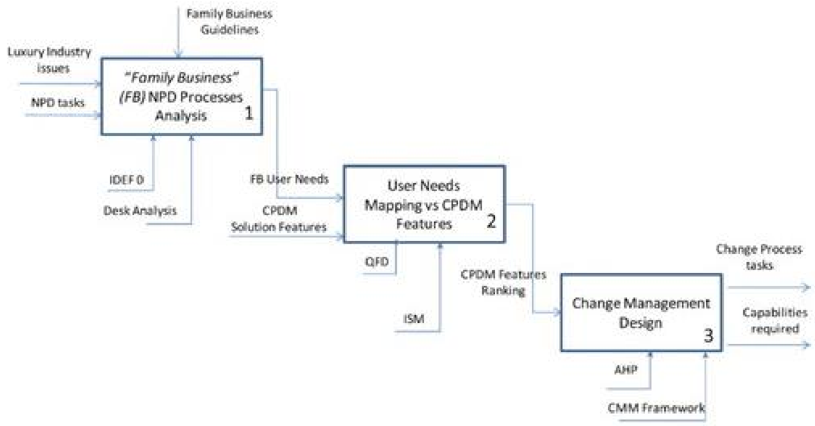


Fig 11: General structure of proposed methodology

By using of "User- Centered Approach", the luxury industry started constructing FB NPD process for both planning & merchandising process description, and supplier auditing description in a family business.

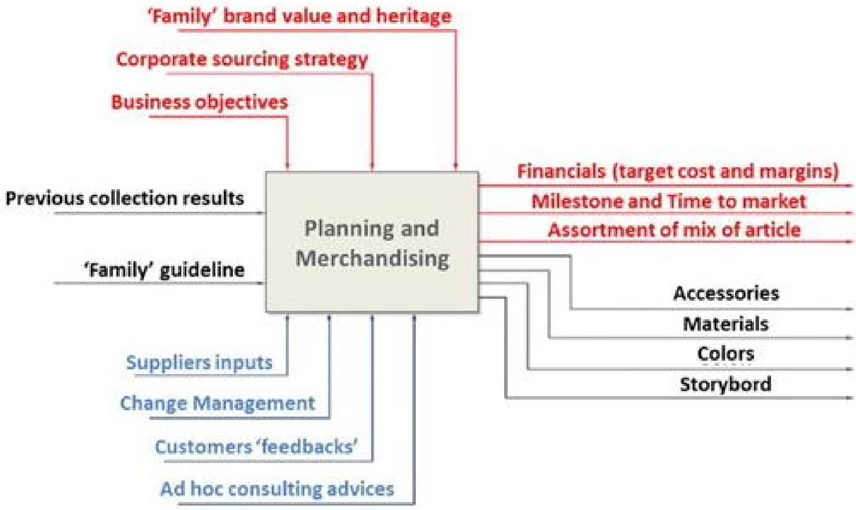


Fig 12: Planning & Merchandising process description in a family business.

By the use of planning & merchandising process description in a family business, luxury industry taken many strategic decisions in terms of style of collection, the timing of development and related financial aspects. By obtaining several outputs by means of images and idea of the collection from this structure. These things they are used by designers during design and development stages.

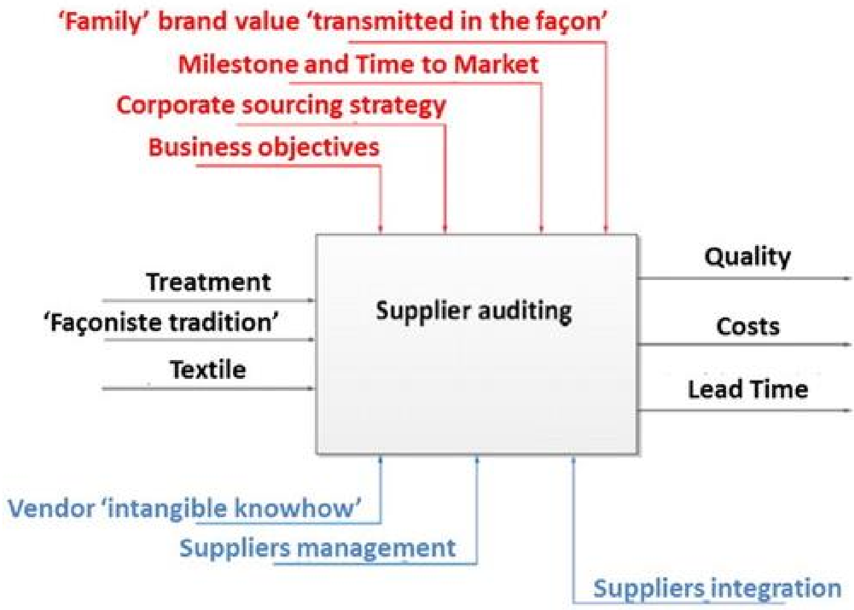


Fig 13: Supplier auditing description in a family business.

In this model of supplier auditing description in a family business luxury industry given more important to the customer what they are looking for and understand more deeply about the buying behavior and given more importance to family identity and brand. By giving inputs to the process that are more relevant to offer customers. Apart from that, they used some of key enablers of this process, change management, supplier's inputs and customer's feedbacks etc., are some of the key enablers that are used by Family business (FB).

At last, the luxury industry by using IDEF0 center-based approach they obtained several results from the analysis and they ranked the score based on Likert scale from 1 to 5, 5 is the highest importance and 1 is the least importance score. Then the importance score is transferred to Focus group table to split the scores into two values Absolute importance (A) that contains the Likert scale value of 1 to 5 and relative importance (R) contains the percentage value (%) to know the value of user needs. After obtaining all results from analysis, the organization decided that to place relative scale value to idea level for each of the five dimensions. So that FB takes a decision regarding of product lifecycle of a business product to upgrade management control and process management related to product.

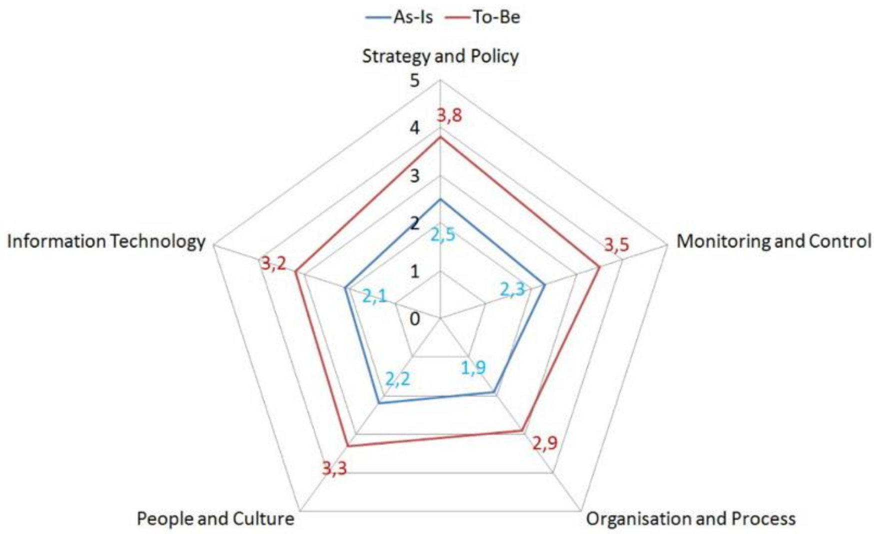


Fig 14: FB NPD processes: as-is Vs to-be.

As the final result, the Family Business (FB) learn that the need of NPD process by using IDEF0 approach with the use of various management such as CRM, PLM, CDM & ERP systems helpful to find to give more prior importance at the starting stage of NPD process to make the brand very successful in the market in long term by reducing risk of failures.

Chapter 3

In this section explaining about New product development (NPD) process and methods need to do starting from Eppinger model, how to define the new product, analysis of new product and processes design to manufacturing the new product. In addition to that, how to develop the project in sequential of stages to get over all idea, knowledge and more insight for developing both product and processes design. Moreover, it is also one of the acceptable methods for development of new products or already existing products.

In additional to that, introduction of "Product lifecycle management" for managing the products in each stage of the product lifecycle. Moreover, implementation of NPD process in PLM platform for analysing the product data in more effective manner.

3.1 About Product and New Product Development

Product: A **product** is something sold by an enterprise to its customers. In my thesis the product that I am dealing is **"Sliding Door Trolley"**.

In order to deal with development of new product or already existing products, first need to know the fundamental reasons for developing products and also to know the best way is to handle in new product development.

Need of a New Product

- Companies are need to grow & survival for growth.
- To be in business for a long time.
- To satisfy the customer needs.
- The company's existing product line becomes saturated and the sale is on the decline.

New Product development (NPD) is a set of activities starting with the customer needs and/or customer demand, designing the product and ending in the production, sales and delivery of a product. Majorly, three departments within the company are responsible/active participants in the product development:

- **Marketing** -Marketing acts as a mediator between the customer and the company. Marketing department often gives a report on customer desires and needs, defining the market segments and identification of product opportunities.
- **Design** - The design team plays a major role in the product development by defining the physical form of the product which have to meet customer desires, Technical feasibility (i.e., available resources, Machines etc. in Manufacturing field) and Business viability (i.e., Profits, Product share in the Market etc.). This design department includes **"Engineering design + Industrial design, Product Design + Process Design".**
- **Manufacturing**. – Manufacturing team is responsible for operating and /or managing the production system in order to produce the product in time.

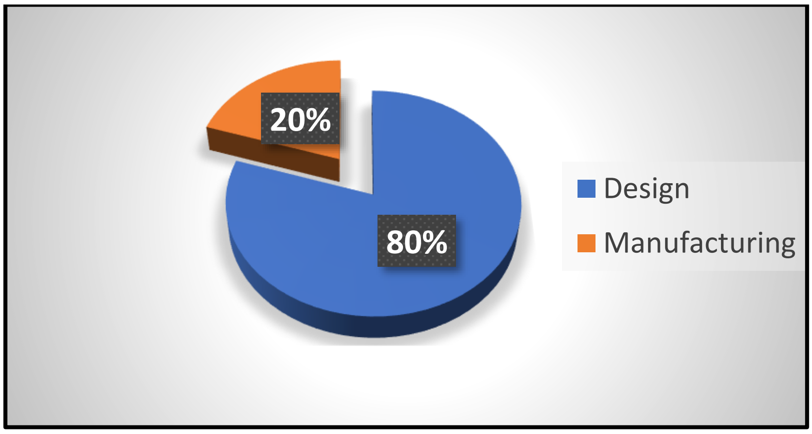


Fig 15: Contribution of Design and Manufacturing

3.2 New Product

Due to changes in consumer preferences, increasing competition and advances in technology or to capitalise on a new opportunity. "New product" must be in the Form**:**

1) Products that has never been made or sold before but have been taken to market by others.

2) Product innovations created and brought to the market for the first time. They may be completely original products, or existing products that you have modified and improved.

3) Product has labelled in "New" form by altering any one of the dimensions of packaging.

3.3 New Product Development (NPD) Process:

In New product development process, there are7 different phases in NPD process. But all these phases vary depends on how we are developing the projects, mandatory phases are needed in order to develop the process of the projects.

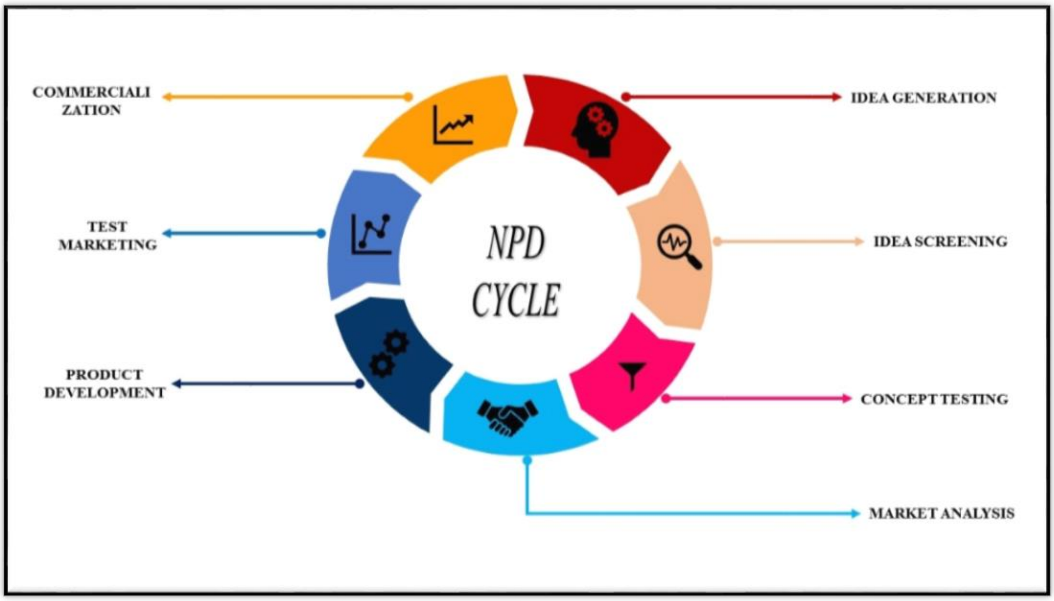


Fig 16: General New Product Development Cycle

3.4 Types of Product Development Project

Generally, there are 4 types of product development project that are mentioned below:

- **New product platforms**: This type of project involves a major development effort to create a new family of products based on new common platform.
- **Derivates of existing product platforms:** These projects extended an existing product platform to better address familiar market with one or more new products.
- **Incremental improvements to existing products:** these projects may only involve adding or modifying some features of existing products to keep the product line current and competitive.

- **Fundamentally new products:** these projects involve radically different product or production technologies and may help to address new and unfamiliar markets. These types of projects may have high risk also.

3.5 Reason to Develop Product Development Process

According to **"Eppinger model",** [6]the product development process is the sequences of steps or activities that transform a set inputs into a set of outputs. There are 4 major reasons for the developing the product development process:

- **Quality Assurance:** A product development process, is the set of phases and sub phases. At each phase it goes through the checkpoints for assuring the quality of product is at good results.
- **Coordination:** For each phase and sub phase there is need of contribution and exchange of information between the departments.
- **Planning:** In a product and development process, mainly setting of milestones and time for each sub phase to get over all phase to get over all development of project.
- **Management:** It's about the managing of project by comparing the actual results and performance of the project.
- **Improvement:** By identifying the better opportunities for improvement, need to do some documentation and regularly doing reviews of the project top get over all improvements in the project.

My thesis study is on **"Sliding Door Trolley"** which is already existing products in the market. So, I followed the Eppinger model, for developing product development project for sliding door trolley which comes under the **"Incremental improvements for existing product".**

Up to now I just created the general overview of the project idea for development of project and which product platform supposed to use for further development of my project. Since the project development is the step by step process, need to be clear in several stages to give more accurate results at the end of my project.

Next section explains about how to define the products, and which one is the best option for creating the idea to develop the new product or already existing products.

Furthermore, classification of product is necessary for further process in product development.

3.6 Opportunity

In the case of product development, Opportunity plays a key role in product development process (PDP), because opportunity is an idea for a new product. Its starts from possible solution concept which helps in identifying the opportunities for new products in a well-defined category. Moreover, the product can be classified into two types:

- Consumer based products.
- Material based products.
- Technology based products

Avoid Risk of Failure in Opportunities:

To reduce the risk of failure to avoid deviate the opportunities, opportunities further classified into categories in terms of ***uncertainty HORIZON***. Different types of Horizon are

- **Horizon 1:** Opportunities are largely improvements, extensions, variants and cost reduction of existing products for existing markets.
- **Horizon 2:** Opportunities push out into less known territory in one or both dimensions of the market or the technology.
- **Horizon 3:** Opportunities represent attempts to exploit opportunities, that in some way are new to the world, embodying the highest level of uncertainty.

"Sliding Door Trolley" which is a consumer-based product and falls under the **"Uncertainty Horizon 1".**

So, for I explained how to develop the general process for developing New product starting from idea generation and goes through intermediate stages such as business analysis and at the end is commercialization of product in the market. Instead of that, general NPD process I created the NPD process by using "Eppinger model", how to develop the project in terms of product platforms, opportunity of product in the market in terms of Horizons to distinguish products in in terms of knowledge of solutions Vs the knowledge of users/markets.

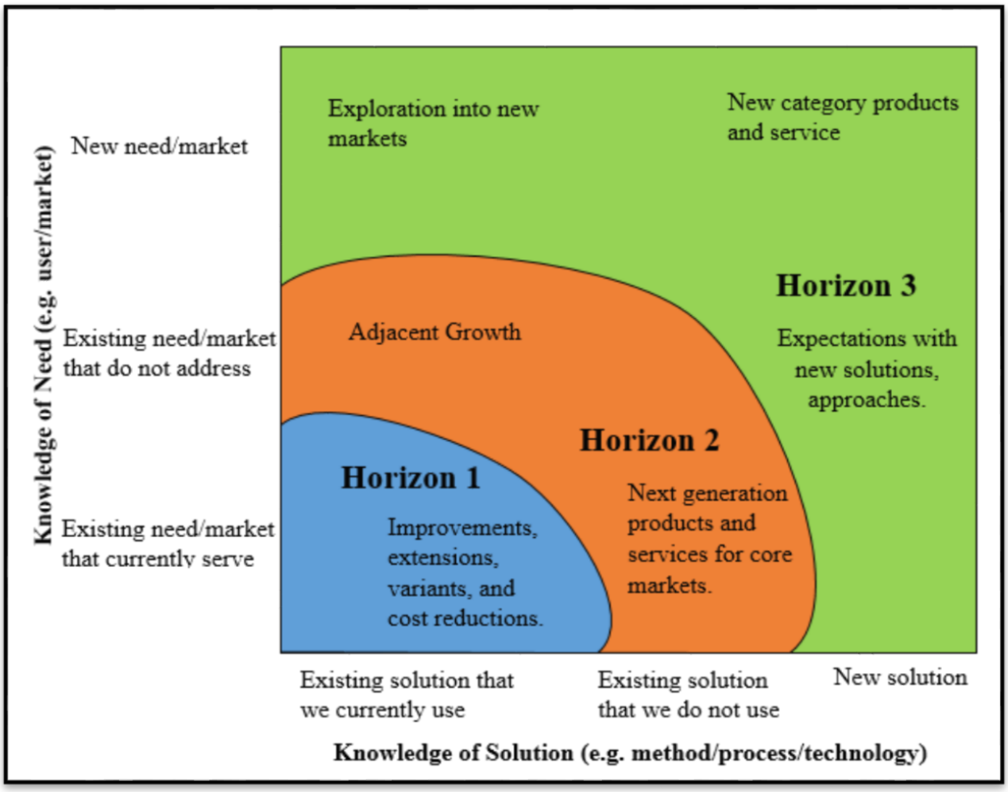


Fig 17: Types of Opportunity, Horizon 1, 2 & 3

After that, I started creating the **" New Product Development Process ",** for the product named as **" Sliding Door Trolley "**.first step is to create the **" Main phase of Product lifecycle Management " process** considering all the main factors for the new product development starting from **"Market analysis and evolves certain intermediate phase such as Product and Process Design and finally ends up with Decline and Disposal "**.

This thesis work is more focus on ***first 4 phase of lifecycle of a product***. Starting from Market Analysis, Planning, Design which consists of ***two sub phases called Product and Process Design***, and finally prototyping which includes 3D printing technology for prototyping to get samples for testing before the actual production of the product begins in later stage.

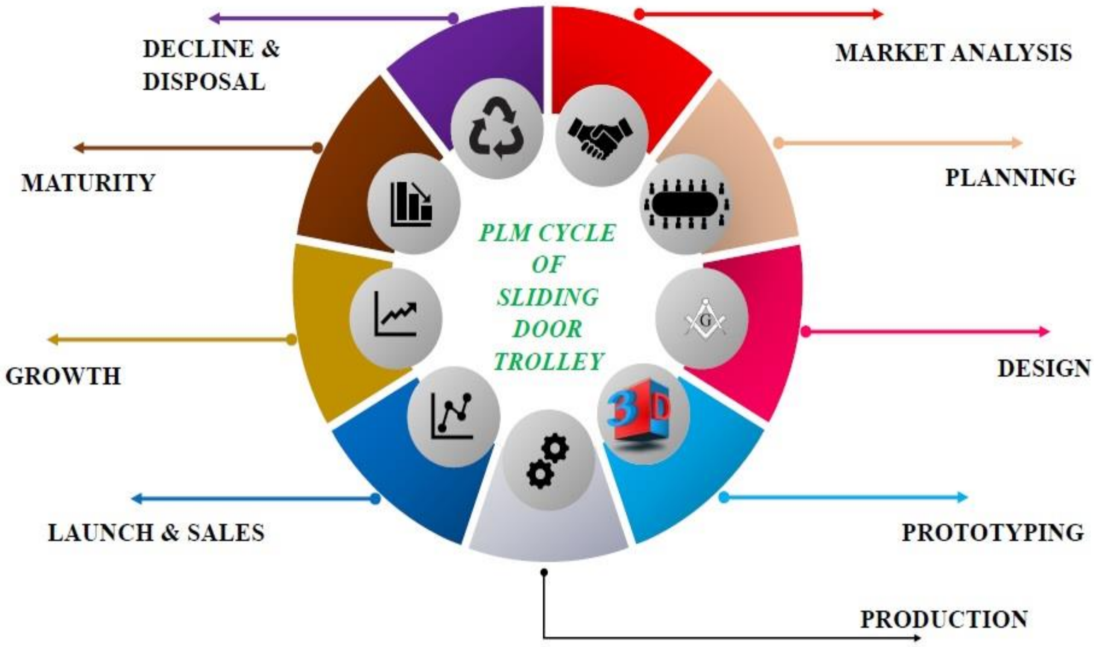


Fig 18: PLM cycle of Sliding Door Trolley

3.7 Overview Four Phases of PLM

Phase 0 Market Analysis

In market analysis, need to follow some strategy model of our product helps us a guide for development of a project to perform internally. Apart from that, need to know how we are performing against the competitor and which is best choice to stay in the market for long term growth.

In terms of New product development, the business strategy also helps to connect the customer with new products or improvements in already existing products. Therefore, the business strategy helps us to strengthen all key points, to keep focus on customer experience in each stage of NPD process.

Finally, by creating a business strategy, it's possibly to define the product, set goals for each phase of NPD process and take an account for the customer experience across and each stage of the process.

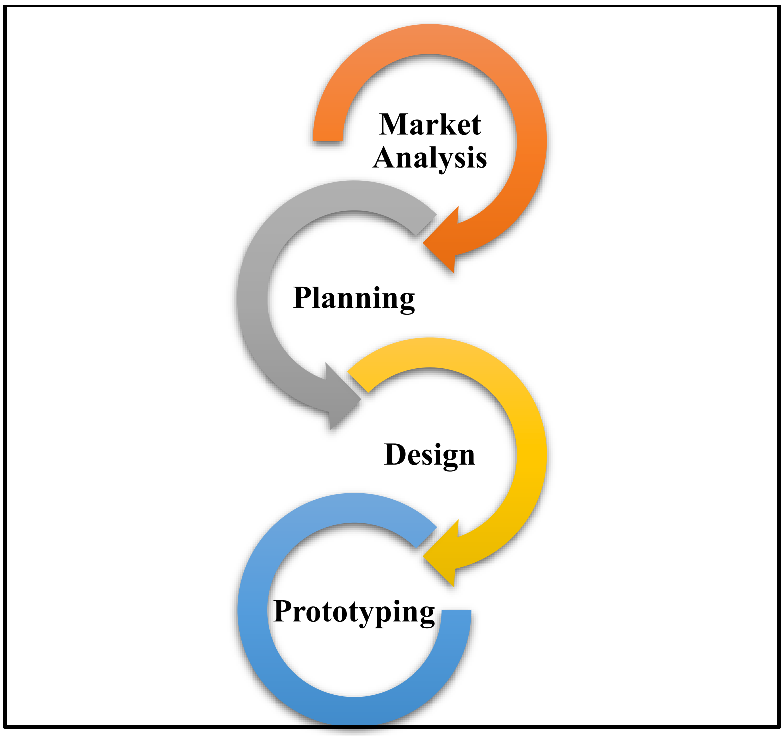


Fig 19: First 4 Phases of Sliding Door Trolley.

3.8 Types of Business Strategy

There are several hundred of business strategy out there, ranging from simple to extremely complicated one. But in today's business world, we need to adopt best business strategy that are needed to overcome all the weak points and to increase the in growth in sales volumes. Apart from that, in the era of industrial revolution V 4.0 perspective, there is a need to choose the best business strategy for New product development that are very helpful to get accurate results based on calculation when compared to theoretical one.

1) Porter's Five Forces Model.
2) Hambrick & Fredrickson's strategy Diamond.
3) Treacy & Wiersema's Value Disciplines.
4) Ansoff's Matrix.
5) BCG Growth -Share Matrix.

Ansoff Matrix:

In this thesis work on "Sliding Door Trolley", which is already existing product in the market. So, I selected the best business strategy tool and I assume myself as of start-up company. So "Ansoff Matrix" is best strategic tool for analyse the product in market.

Ansoff Matrix is also called as Product/Market expansion grid and it is a tool used by the firms to analyse and plan their strategies for growth. Moreover, it is a strategic planning tool that links an organization's marketing strategy with its general strategic direction. It presents four alternative growth strategies in the form of a 2x2 table or matrix.

"One dimension of the matrix considers 'products' (existing and new) and the other dimension considers 'markets' (existing and new)".

		Products: Existing	**Products: New**
Markets	**Existing**	**Market Penetration**	**Product Development**
	New	**Market Development**	**Diversification**

Fig 20: Ansoff's Matrix

By means of this Ansoff matrix I can possibly to classify the product "Sliding Door Trolley", which falls in the Products of Existing one in horizontal direction and markets of the existing one i.e., the Market penetration.

Market Penetration: focusing on selling your existing products or services to existing markets to achieve growth in market share.

Since, the product which I analysed is already existing products in market. Hence, I selected "Market Penetration", which is existing in market and product is also existing thus 2x2 matrix criteria. Each one of these have risk associated of Ansoff matrix fig 21 risk related of each Ansoff's matrix types. For this thesis work, I choose market penetration which is associated with low risk matrix.

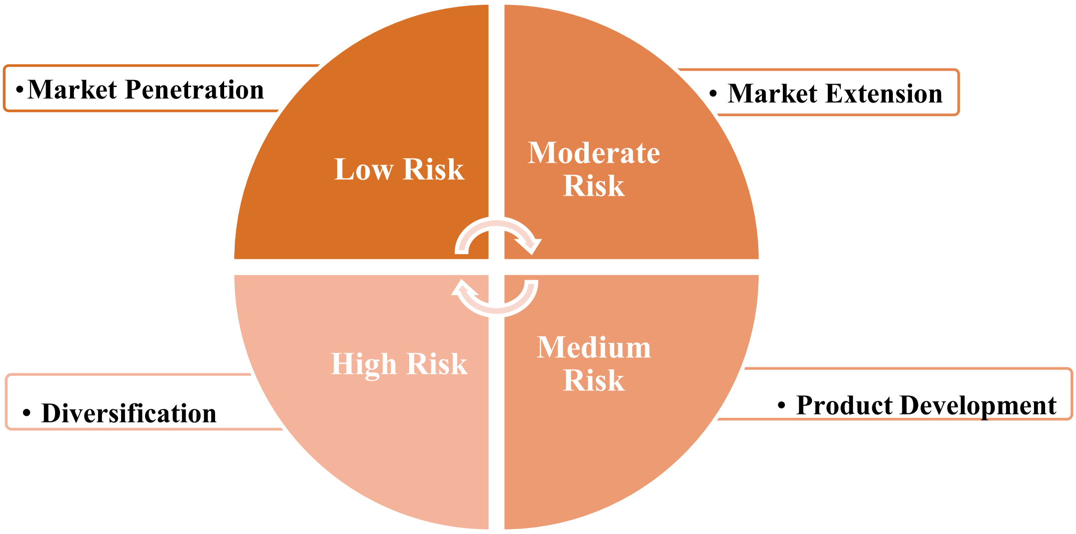


Fig 21: Risk Related of each Ansoff's Matrix types.

Market Analysis:

- Main goal for market analysis to find out the market volume to know about the amount of people willing to buy or actual requirement of the product sliding door trolley.

Market analysis-is done by **Market penetration**; it is the **percentage of identified potential customers** have acquired. It is a step by step method and it is done by using Mathematical formulas and calculations to get more accurate results to know about "***Target market to reach our product in that market.***

Market Penetration:

Market penetration refers to the successful selling of a product or service in a specific market, and it is a measure of the amount of sales volume of an existing good or service compared to the total target market for that product or service.

"Market penetration involves targeting on selling existing goods or services in the targeted markets to increase a better market share/value."

The penetration rate (also called penetration, brand penetration or market penetration as appropriate) is the percentage of the relevant population that has purchased a given brand or category at least once in the time period under study.
In my thesis I more concentrated in Market penetration in order to sell a product in a Piedmont region, Turin as my general consideration to get overall idea of the market analysis. And, I taken a total population of that region, in order to apply some mathematical calculation by using formulas by step by step methods.

Reason, behind the high penetration rate is about **90 % is most of the houses has approximation of 2 to 4 sliding doors trolley**. And, I considered the **90% of our target customer from the total population of piedmont region.**

Furthermore, I considered the maximum of ***2*** units of sliding doors trolley needed per house.

Step 1: Here I consider the Total population in a region as Piedmont Region with population of 4,356,406 people population as of 2019.

Before to know the ***"Size of the Market".*** We need to know our ***"Target Customer" in the market i.e., Quantify the market.***

Here I done the estimation about 90 % of population from the target customer of the total population in piedmont region. i.e., 9 out of 10 people can buy this product because it is a ***"Consumer based product",*** that what we defined in the ***"Opportunity of Eppinger Model".***

Step 1: Here I consider the Total population in a region as Piedmont Region with population of 4,356,406 people population as of 2019.

Step 2: To find out the ***"Size of the Market"*** is given by

> ***4,356,406 * 90% = 3,920,765 of population is the Target Customer of my product.***

Step 3: The Penetration Rate = ***3,920,765/ 4,356,406 *100 % = 90 % is the Penetration Rate.***

Step 4: Market Volume: is the overall market potential. i.e. Market potential Volume. To calculate the market volume of product is given by

Market Volume = Target Customer * Penetration Rate.

= 3,920,765 * 90% = 3,528,689 of people is our market volume.

Step 5: Find out number of houses from the Market volume

Total no. of houses = Market Volume / Household size & Composition.

By using statistical data which given by United Nation Department of Economic Affairs for Italy household size is about 2.4 % as of 2018.

Total No. of House = 3,528,689 / 2.4 = 1,470,288 houses.

Reason, behind the high penetration rate is about **90 % is most of the houses has approximation of 2 to 4 sliding doors trolley**. And I considered the **90% of our target customer from the total population of piedmont region.**

Furthermore, I considered the maximum of ***2*** units of sliding doors trolley needed per house.

Step 6*:* Here, I considered, **20% of market share of our company.**

Market share of our company is 14,70,288 * 20% = 2,94,058 houses is our Target Market Share.

Step 7: So, to find out the maximum units that are needed is ***294,058 * 2 units/house = 588,116 units/year that are required for the piedmont region.***

Step 8*:* Another important thing needs to do is the cost of the product, to find out the Annual Revenue of product (Sliding door trolley). Considering ***6 €*** per unit.

Total Revenue for the product = No. of units required * Cost of the product per unit.

= 588,116 * 6 € = 3,528,696 € is the total revenues of product.

As of market penetration calculation for product "Sliding Door Trolley" by applying mathematical calculation.

- ***Target market share = 2,94,058 houses is our target market share.***
- ***No. of units required = 588,116 units/ year.***
- ***Total revenues = 3,528,696 € is the total revenues of product.***

3.9 Results obtained from Phase 0 Market Analysis

From the market analysis, I got overall idea to do business of my product “Sliding Door Trolley”, considering the population of regions, finding the penetration rate which is rather high i.e. 90% indicating that my target market is too small, and I need to be expanded with new products, brands or distribution channels. From the market volume I get number of houses in that region by dividing the household composition which is given by statistical data of united nations.

Furthermore, I considered only 20 % of market share, since I considered as the start-up company cannot able to do maximum market share initially. Another point is about number of units that are needed for basic house which is in the range of 2 to 4 units. We need to find out number of units that are required to produce a product in a company. Finally, I need to know whether my product yields the maximum revenue for the company, multiplied by cost of the product per unit.

Next phase of my product lifecycle management is **Phase 1: Planning phase**. In this section, I created product policy of my product based on Eppinger model to define the product description, primary goals, rules and regulations, types of markets going to concentrated in etc.,

3.10 Phase 1: Planning

Once the Market analysis is done and verifying that, the projects make the profit in final. In order to know how to proceed with further steps in product development**,** the **“Opportunity statement can be rewritten as a Product policy”.** It gives the guidance for product development organization and more detailed about the definition of target market segmentation. This product policy gives an overall idea of the product that includes environmental goals, service objectives and specific technologies possible to identified for project development.

After defining the product policy of the product, need to move to next step in order to identify and satisfying the customer needs and expectations.

Product Description	*Sliding Door Trolley for residential use.*
Benefit Proposition	*Simple to use, less maintenance, load capacity in kg.*
Key Business Goals	• *Existing product platforms.* • *Product introduction in rapid prototyping.* • *Environmentally friendly.* • *Capturing more identified customers.*
Primary Market	*Residential consumer.*
Secondary Market	*Sliding movements for all doors and civil construction contractor for residential work.*
Assumptions & Constraints	• *Using PLM software.* • *Compatible with existing one.* • *Increase in life of the product.* • *Load capacity.*
Stakeholders	• *For users & purchasers.* • *Production.* • *Retailer.* • *Manufacturing operations.*

Table 2: Product Policy of Sliding Door Trolley

Consumers are more demanding than ever. So, we need to keep up with customer expectations and requirements voice of customer play a vital role in new product development to carry over all the customer expectations and requirements mainly in planning and design phase of product lifecycle management (PLM).

There are several ways to identify and rank the customer needs and requirements. I followed the traditional methods to fulfil all the customer requirement for the product “Sliding Door Trolley”.

3.11 Quality Function Deployment (QFD) & Voice of Customer (VOC)

Quality Function Deployment (QFD)

It is the structured method and mathematical tools for planning process of the product or services. Moreover, for identifying and Quantifying the customer requirement and translate into key critical parameter for Planning, Product and process design.

"QFD is the system for translating customer requirements into appropriate company requirements at every stage, from research, through production design and development, to manufacture, distribution, installation and marketing, sales and services". By American Supplier Institute (ASI)

Voice of Customer (VOC):

It is a term describes the customer's feedback about their personal experiences with and expectations of my product "Sliding Door Trolley". The focus of voice of customer is to satisfy the customer needs, expectations and helps in product improvement process.

Key things to reach our clear identification of our target goals in NPD Process:

- ➢ By ensuring proper conversion of customer needs into design technical characteristics.
- ➢ By prioritizing the characteristic of product from the customer of view.
- ➢ By carrying the VOC in all phases of product development.

Need of Quality Function Deployment (QFD)

There are many reasons for using Quality Function Deployment process. in New Product Development:

- ✓ It allows a better understanding of design relationships while plotting of customer wants and technical ***How's.***
- ✓ To identify and manage design trade-offs by using house of quality mainly used for consumer products.
- ✓ It carries the Voice of customer along the development of both Design and process development.
- ✓ It also evaluating the capabilities of both design and process to satisfy identified requirements.

In this thesis work, I perform Quality Function Deployment (QFD) for the product "Sliding Door Trolley" in order to design the product and process design for better product improvement and to satisfy the customer requirements in terms of Reliability, Price and Performances.

3.12 House of Quality (HOQ)

- House of Quality is more widely used technique mainly for **SIX SIGMA** black belt practitioners and it is a more advanced LEAN techniques.
- House of Quality is a Voice of Customer Analysis Tool since it starts with the Voice of Customer and its plays a major role Quality Function Deployment Process.
- House of Quality main key process by transposing that meets into what the customer prefers into products. Apart from that, in order to meet that customer preferences by plotting the Relationship matrix in terms of engineering design values.

How House of Quality (HOQ) is Performed?

To build the House of Quality (HOQ) need to follow 6 major steps

1. Identifying how the product will satisfy the customer.
2. Identifying relationships between HOW's.
3. Developing importance ratings.
4. Evaluating competing products or services.
5. Determining the desirable technical attributes.

Formulas for calculation in House of Quality:

1) In terms of Absolute weight:
   - ✓ Absolute weight = Importance rating * Relationship value.
   - ✓ Calculate the (%) percentage of absolute weight = Value of column in absolute weight / Total value of row in absolute weight.
- ✓ Finally, Absolute priorities rank has done based on % of Absolute weight.

2) In terms of Relative weight:
   - ✓ Relative weight = Sum of all column of What's Vs How's weight value of different customer requirements of each rows.

- ✓ Calculate the (%) percentage of Relative weight = Each value of Relative weight / total value of relationship Relative weight.
- ✓ Finally, Relative priorities has done by ranking based on % of Relative weight.

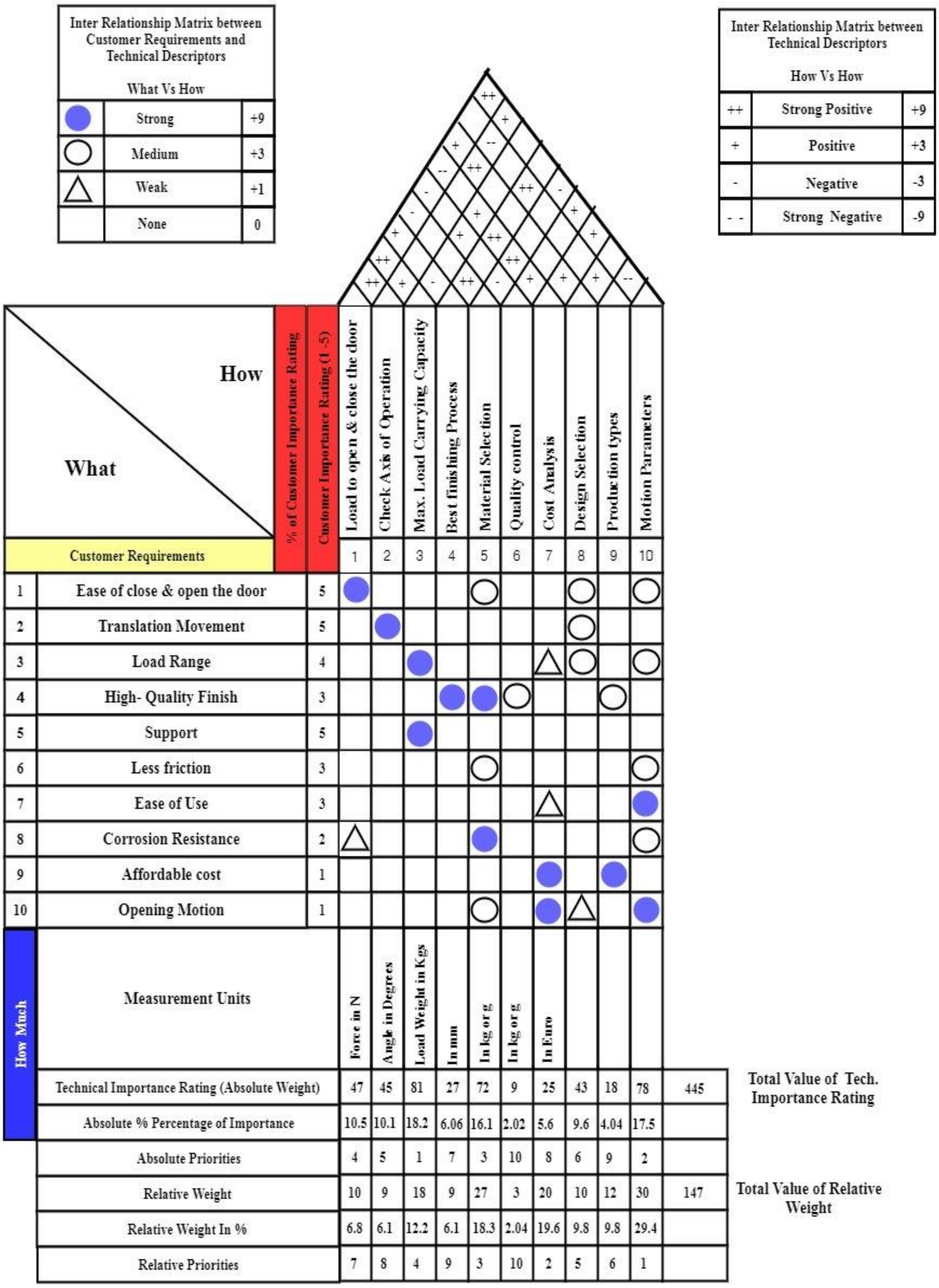


Fig 22: House of Quality of my product "Sliding Door Trolley"

3.13 Results Obtained from House of Quality

I constructed House of Quality of my product “Sliding Door Trolley” by above mentioning steps. I constructed house of quality by two algorithms absolute approach and relative approach to rank customer requirements. By using 1st algorithm absolute approach I obtained “Load carrying capacity” is in 1st rank and 2nd rank is the motion parameters. These 1st and 2nd rank need to be considered more while designing the product in design phase.

Finally, 1st algorithm is like an AND logic, because it tends to give high weight to all essential technical characteristics. But the 2nd algorithm is like an OR logic, in proportion to the weights through the sum of the weights of the row. i.e., importance of the customer requirement among all involved technical characteristics.

In my Thesis I used **1st algorithm i.e., AND Logic for the product “Sliding Door Trolley”** given importance to all essential technical characteristic of “How Much” for designing my product in next phase of **Design for Designing the product “Sliding Door Trolley”.**

3.14 Concept Screening

Customer needs and requirement, selecting one or more concept for further process testing and development. The concept selection is done by various methods. In my thesis I done one of the best methods for concept selection by means of concept screening matrix for the product “Sliding Door Trolley”

The goal of screening is simply to eliminate concepts/designs that are highly unlikely to result in the creation of value and to focus attention on the concepts worthy of further investigation. The concept screening is a quick and approximate evaluation. This screening is done by comparative systems are used. After several iterations are done to eliminate differ alternatives, and the selected one design goes through more detailed analysis.

The concept screening process is done by Six- step process for the concept selection activity. Steps to do Concept Screening are:

- **Step 1**: Prepare the Selection Matrix.
- **Step 2**: Rate the Concepts.
- **Step 3**: Rank the Concepts.
- **Step 4**: Combine and Improve the Concepts.
- **Step 5**: Select One or More Concepts.

		Concepts		
Selection Criteria	***A***	***B***	***C***	***D***
Ease of handling	*0*	*0*	*0*	-
Ease of use	*0*	-	*0*	+
Assembly settings	*0*	*0*	*0*	*0*
Positioning	*0*	*0*	*0*	*0*
Durability	*0*	*0*	*0*	+
Ease of manufacture	+	-	*0*	-
Portability	+	+	*0*	*0*
Sum +'s	*2*	*1*	*0*	*2*
Sum -'s	*0*	*2*	*0*	*2*
Sum 0's	*5*	*4*	*7*	*3*
Net Score	*2*	*-1*	*0*	*0*
Rank	*1*	*4*	*2*	*2*
Continue?	***Yes***	***No***	***Combine***	***Combine***

Table 3: Concept Selection Matrix between Various Concepts

3.15 Results Obtained from Phase 1 Planning

Results are obtained from Phase 1 of planning, by applying Eppinger model for product policy and concept screening selection matrix. In product policy defining the main objective and goals of the product "Sliding Door Trolley" with technologies supposed to implemented. Similarly, for concept selection matrix by Eppinger model, concept selection done by selection criteria considering all the factors that affect mainly ease of use, durability, ease to manufacture the product. Results, has done based on “Rank” by using the sum of 1’s and 0’s.

Next step is translating the customer needs and requirements, we need to translate the customer needs into technical characteristics. Parallelly, by prioritizing the needs of customers, I implemented “Quality Function Deployment” process and “House of Quality” in my thesis for the product “Sliding Door Trolley. House of quality calculation has done by “Relative and Absolute Approach” by giving importance to customer requirements.

Next phase of product development process is Phase 2 design product and process design. For product design, it is done by axiomatic design to transform the customer attributes (CAs) and functional requirements (FRs) by mapping process. Transforming functional requirements (FRs) into design parameters (DPs) by constructing design matrix. Similarly, designing all the parts, track types and design different alternatives. To obtain results of each section by comparing the results of each section to finalize the results.

Moreover, DFMA methods are applied to the product “Sliding Door Trolley” for assembly time by using MTM UAS analysis by DFA method. And Design for manufacture (DFM) by PRIMA’s strategies for designing manufacturing process. Additionally, to support the manufacturing process designing the manufacturing operation, process flow, Failure mode and effective analysis (FMEA), creating bill of materials (BOM), make or buy decisions for the product “Sliding Door Trolley”.

Phase 2 Design

3.16 Axiomatic Design of “Sliding Door Trolley”

From the output of House of quality there are two main important customer requirements for the product “Sliding Door Trolley”.

- Load range.
- Opening motion.

Product Design by Axiomatic Design Process

In order to do design, the product by using Axiomatic design principles which are governed by two fundamental axioms.

1st Axiom: Independence Axiom: “It states that the independence of the FRs must always be maintained, where FRs are defined as the “minimum sets of independent requirements that characterizes the design goals”.

2nd Axiom: Information Axiom: “It states that among those designs that satisfy the Independence Axiom, the design that has smallest information content is the best design”. [7]

First Axiom: Independence Axiom:

1) The FRs are defined as the minimum set of independent requirements that design must satisfy. A set of FRs is the description of design goals.
2) The independence Axiom states that when are two or more FRs, the design solution must be such that each one of the FRs can be satisfied without affecting the other FRs. i.e., need to choose the correct set of DPs able to able to satisfy the FRs and maintain their independence.
3) The independence Axiom requires that the “Functions” of the design be independent from each other, not the physical parts.

Second Axiom: Information Axiom:

1) Suggest that physical integration is desirable to reduce the information content if the functional independence can be maintained.

Domains Concept in Axiomatic Design:

During the Design stage the engineers play a vital role in Design phase of the New Product Development. The design stage involves an interplay between “What we want to achieve it” and “How we choose to satisfy the need”. For axiomatic design, the “Concepts of Domain” form a delineation between four kinds of design activities. These 4 four domains form an important foundation for Axiomatic Design.

Generally, the design is made up of 4 domains:

1) **Customer Domains**
2) **Functional Domains**
3) **Physical Domains**
4) **Process Domains**

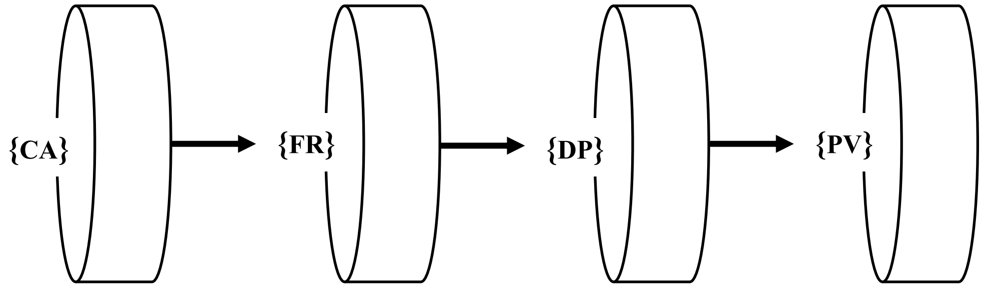


Fig 23: Mapping Process from One Domain to Other Domain.

From the fig 1.25 Four domains of the design world. The domain of the Left relative to the Domain on the Right represents "What we want to achieve", whereas the domain on the right represents the design solution," how we propose to satisfy the requirements specified in the Left Domain".

Customer Domain: is characterized by the needs (or attributes) that the customer is looking for in a product or process or systems or materials.

Functional Domain: the customer needs are specified in terms of ***Functional Requirements (FRs)*** and **Constraints (Cs).** To satisfy the specified (FRs), we conceive "Design Parameters" (DPs) in the ***Physical Domains.***

Process Domain: Finally, to produce the product specified in terms of ***Design Parameters (DPs),*** we develop a process that is characterized by ***"Process Variables (PVs),*** in the ***Process Domain.***

Customer Domain (CA)	***Functional Domain (FR)***	***Physical Domain (DP)***	***Process Domain (PV)***
Customer needs or attributes that the customer is	*It contains Functional requirements & it is*	*It contains Design*	*It contains the process variables*

looking for in product or process or systems or materials	*defined by engineering specifications & constraints.*	*parameters to satisfy the FR*	*that can produce the DP.*

Table 4: Four Domains for Product Design

Mapping Process in Axiomatic Design:

"Axiomatic Design" is done by means of "Mapping Process", The mapping process between the domains can be expressed mathematically in terms of the characteristic vectors that define the design goals and design solutions.

The functional domain is the set of functional requirements to specify the design goals which are characterized by "FR Vector". Similarly, the set of DPs in the physical domain has been chosen to satisfy the FRs establishes the "DP" vector. The relationship between the vectors can be written as

$$\{FR\} = [A]\{DP\}$$

Where [A] is the design matrix that characterizes the product design.

So, there are two functional requirements of "Sliding Door Trolley" which are given below:

Functional Requirements (FRs):

- FR_1 = To support the door weight.
- FR_2 = To allow the door movement.

Design Parameters (DPs):

- DP_1 = Positioning of doors & Connection of parts.
- DP_2 = Reduction in friction.

Before the construction of matrix, we need to know how to construct the matrix design which is needed to stick with the 1st Axiom & 2nd Axiom. The good design has the design matrix in which each one of the diagonal elements is X and each of the off-diagonal elements is 0, this design is also called as uncoupled design matrix (a).

Another design matrix is decoupled design matrix which has a triangular design matrix. (b) Both uncoupled and decoupled matrix are acceptable.

$$\begin{bmatrix} \boldsymbol{x} & \mathbf{0} \\ \mathbf{0} & \boldsymbol{x} \end{bmatrix} \text{(a)} \quad \text{is the uncoupled Design matrix.}$$

$$\begin{bmatrix} \boldsymbol{x} & \mathbf{0} \\ \boldsymbol{x} & \boldsymbol{x} \end{bmatrix} \text{(b)} \quad \text{is the decoupled Design matrix.}$$

Here I Started to design the matrix for "Sliding Door Trolley" based on FRs & DPs if FR_1 as "**W**" related to weight to support and FR_2 as **"ʋ"** speed of the door movement. In order to create the trolley that can provide support **"W"** and sliding **"ʋ"** to satisfy the Independence Axiom. I created the equation for design matrix of "Sliding Door Trolley".

$$\begin{Bmatrix} W \\ \upsilon \end{Bmatrix} = \begin{bmatrix} \boldsymbol{x} & \mathbf{0} \\ \mathbf{0} & \boldsymbol{x} \end{bmatrix} \begin{Bmatrix} A \\ \mathbf{B} \end{Bmatrix}$$

From that above equation I designed a "Sliding Door Trolley" with centre shaft (Body) to support the door weight "**W"** and wheels movement **"ʋ"** to provide sliding movement for doors. This equation satisfies the Independence Axiom. Where, A = ϑ angle in which angle the trolley must hanged in the doors and B = l length of the door.

Then the Information content Axiom, from laws of friction, third law states that the friction force also depends on the types of surfaces in contact. For sliding wheel friction plays an important role while moving the door along with the door weight.

So, this equation satisfies both Independence Axiom and Information content, moreover the design matrix which I constructed for my thesis which is the uncoupled design matrix which follows the principle of Axiomatic design and satisfies the both independence axiom and information content axiom.

3.17 Track types and Selection of Track for Sliding Door Trolley

Before designing of alternative parts in design phase, first thing is needed to define the types of track for wheel maneuver for the movement of sliding doors. Because the track configurations will vary depending upon various applications such as doors used in Industries, Houses etc. and based on usage of doors track must be selected properly.

Generally, the movement for wheel track is defined into two types

1) Above Track Sliding Door
    a. Box type Rail
    b. Round Rail
2) Below Track Sliding Door
    a. V – Type Track
    b. O – Type Track
    c. Ω – Type Track
    d. IBBI – Type Track

In my thesis, “Above track” method of configuration which consists of two types of rails, which is most suitable track method for “Sliding Door Trolley” and for house applications.

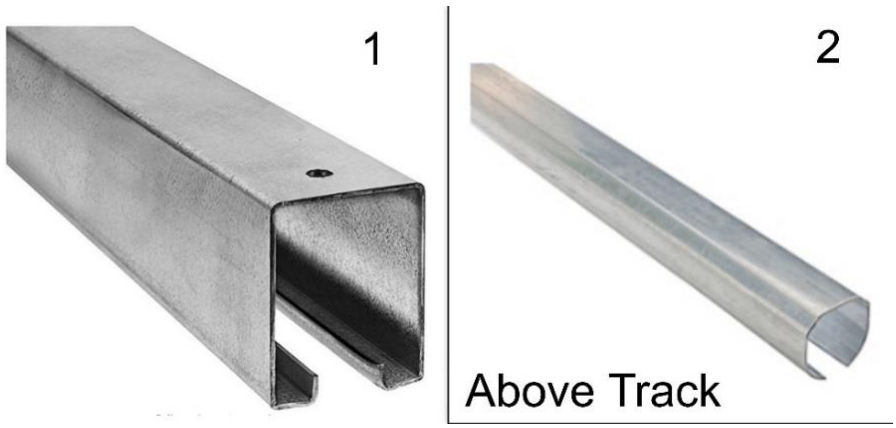


Fig 24: Types of Above track method.

Furthermore, the wheels also designed based on track models, length, width and thickness of the track.

3.18 Design of Different Alternatives & Comparison of Different Parts

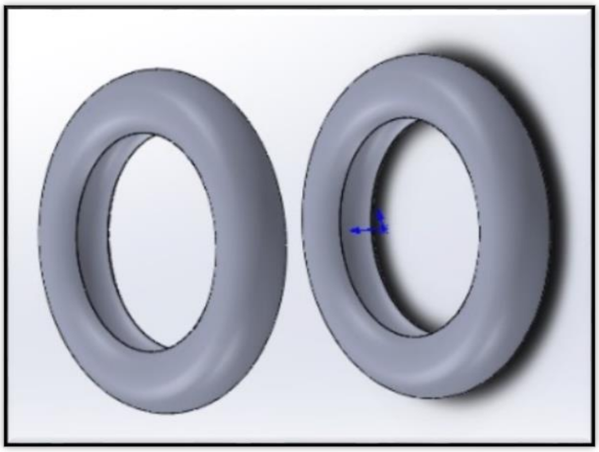
From the Initial product design, we have an overall idea for creating the "Sliding Door Trolley" with different parts such as wheels for rolling in tracks, plate to support the door, Shaft for connection of parts. In additional to that, lot of parts that are required to design the whole product: **"Sliding Door Trolley".**

In this section I drawn different alternatives for different parts which are more suitable to satisfy the functional requirements mentioned in fig 25.

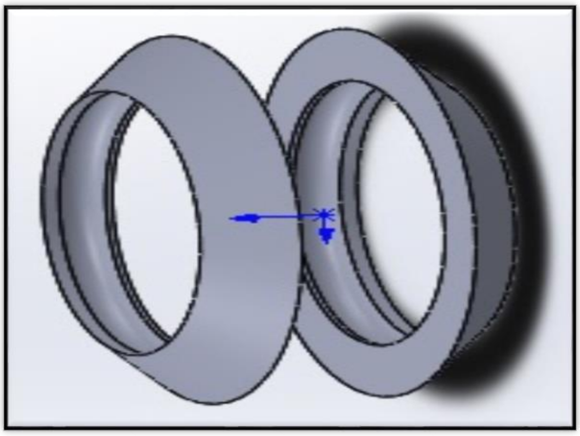
I initiated to draw some different alternatives types of wheels, bearings types, fasteners types and bracket type to support the door which is the important part of product "Sliding Door Trolley".

Wheels:

Generally, the wheels are used for rolling on the surface. But in my case, I need wheels to roll over some predefined type of tracks with less friction and need to provide free rolling of doors.

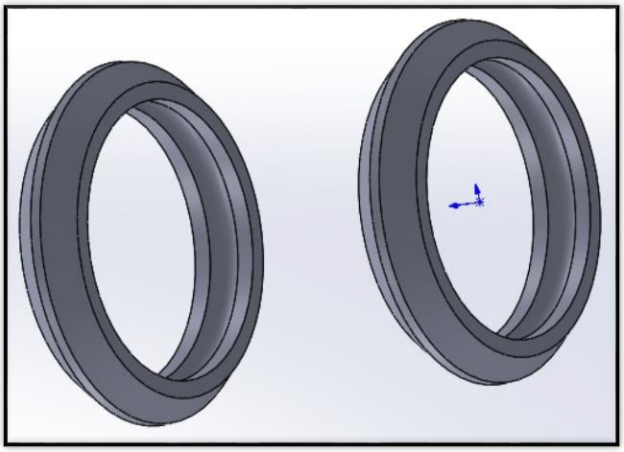


(A)– Circular Wheels

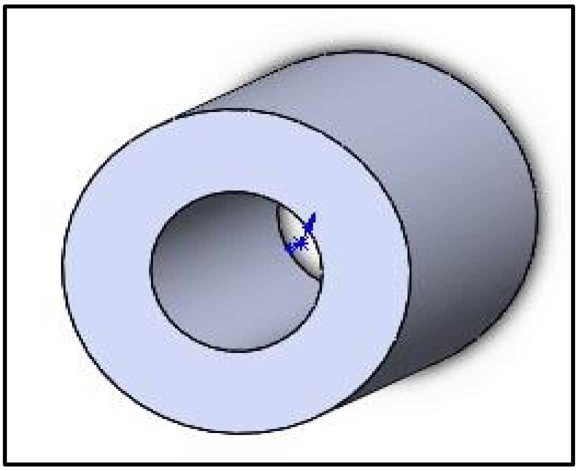


.

B– Conical Wheels



(C)– Circular wheel with Groove Type



(D)– Cylindrical Wheel

Fig 25: Wheel Types

Here I design 4 different alternatives of wheels for the most possible solutions for designing of wheels. In order to get the results which wheels is must suitable for the product “Sliding Door Trolley “is by comparing each wheel by means of selection criteria. In the below table I compared the three possible solutions wheels which are perfectly suited for “Above Track Types”. From the Comparison table I selected “Circular wheel with V groove types”, which is more suitable for my product.

Selection Criteria	***Conical Wheel***	***Circular Wheel***	***Circular Wheel with V Groove***
Contact Surface Area	*Wider contact area*	*Large area*	*Small area*
Friction types	*Rolling & Sliding*	*Rolling & Sliding*	*Rolling & Sliding*
Track types	*Above track*	*Both types of tracks*	*Above Track types*
Reaction forces	*Lateral & Longitudinal*	*Lateral & Longitudinal*	*Lateral & Longitudinal*
Foreign substances Deposition	*Medium*	*Less*	*High*

Table 5: Comparison between wheel types

3.19 Bearings

Bearings is the important parts for wheels rolling in track. Bearings enables smooth motion for wheels, withstand both axial and radial loads.

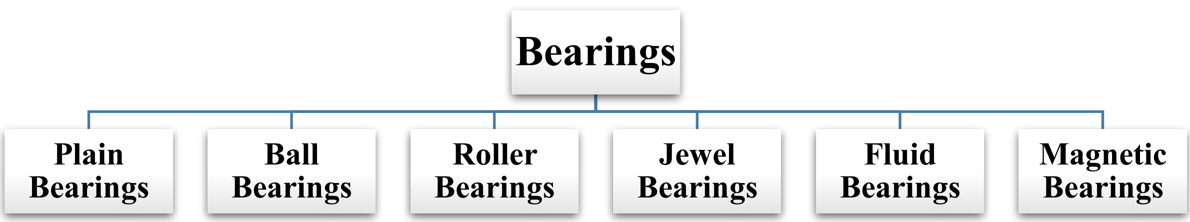


Fig 26: Classification of Bearings.

Bearings Types:

From the below fig:1.29 shows some basic types of bearings which are generally used in sliding door for free movement of door, to reduce friction and to provide long life with less maintenance.

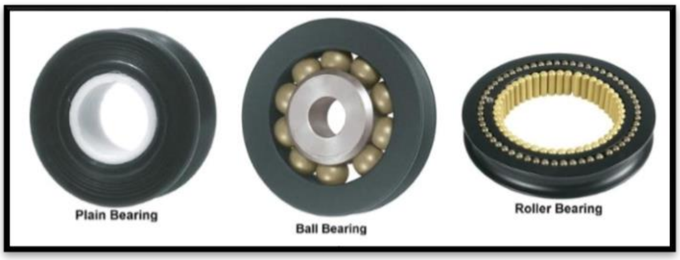


Fig 27: Basic bearing types

Here I done comparison tables between basic three types of bearings by using selection criteria. In addition to that, Bearings which is more suitable for V groove types of wheels and based on Maximum load capacity of sliding door trolley which is 200kg.

Selection Criteria	***Plain Bearing***	***Ball Bearing***	***Roller Bearing***
Load Types	*Light Axial Load*	*Axial & Radial Load*	*Axial & Radial Load*
Friction Co. Efficient	*0.0015*	*0.0015*	*0.0020*
Lubrication	*Grease*	*Grease*	*Grease & Oil lubrication*
Temperature	*Low Range*	*Low to Medium Range*	*Medium to High Range*
Cost	*Very Low*	*Low*	*High*

Table 6: Comparison between Bearing types

From below table 10: gives more detailed information of ball bearings types. Describing more detail information about some technical parameters such as friction coefficient, bearing stiffness, velocity, life span to get over all idea of bearings which I supposed to use for the product “Sliding Door Trolley”.

Bearing Type	***Description***	***Friction***	***Bearing Stiffness***	***Velocity***	***Life Span***	***Comments***
Ball Bearing	*Ball are used to prevent or minimize rubbing*	*0.0015*	*Good, but slack is present*	*Moderate to high*	*Moderate to high*	*Used for higher moment loads than plain bearings with plain bearings*

Table 7: Ball Bearings Characteristics

From the above two table I selected the ball bearings which is most suitable for wheels. After selecting the ball bearings, we need to know which the best suitable diameter of ball bearings is to withstand dynamic capacity of bearings, reliability of bearing. These things have done by bearings methodology calculation for selection of bearings.

3.20 Calculation for Selection of Bearings

Methodology which I followed is "Trial & Error method", which is best method for choosing the diameter of bearings. Diameter of bearings is chosen based on the load duty applications. [8]

Light Duty	***Medium Duty***	***Heavy Duty***
10 mm to 60 mm diameter	*30 mm – 120 mm diameter*	*100 mm to 160 mm diameter*

Table 8: Ball Bearings Characteristics

In my case, the sliding door trolley need to withstand the maximum load capacity of 200kg which fall in "***Light Duty".*** applications.

Features \ Bearing Type	Deep Groove Ball Bearings	Magneto Bearings	Angular Contact Ball Bearings	Double Row Angular Contact Ball Bearings	Duplex Angular Contact Ball Bearings	Self Aligning Ball Bearings	Cylindrical Roller Bearings	Double Row Cylindrical Roller Bearings	Cylindrical Roller Bearings	Cylindrical Roller Bearings with Angle Ring
Load Carrying Capacity: Radial Load	Fair	Poor	Good	Good	Good	Fair	Good	Excellent	Good	Good
Load Carrying Capacity: Axial Load	↔ Fair	← Poor	← Good	↔ Good	↔ Good	↔ Poor	×	×	← Fair	↔ Fair
Load Carrying Capacity: Combined Load	Fair	Poor	Good	Good	Good	Poor	×	×	Fair	Fair
High Speeds	Excellent	Good	Excellent	Fair	Good	Good	Excellent	Good	Good	Good
High Accuracy	Excellent		Excellent		Excellent		Excellent	Excellent		
Low Noise and Torque	Excellent						Good			
Rigidity					Good		Good	Excellent	Good	Good
Angular Misalignment	Good	Poor	Poor	Poor	Poor	Excellent	Fair	Poor	Fair	Fair
Self-Aligning Capability						Yes				
Ring Separability		Yes					Yes	Yes	Yes	Yes
For Use on Fixed-end	Yes			Yes	Yes	Yes				Yes
For Use on Free-end	Yes*			Yes*	Yes*	Yes*	Yes*	Yes*		
Tapered Bore of Inner Ring						Yes*		Yes*		
Remarks		Two bearings are usually mounted in opposition.	Contact angle 15, 30, 40. Two bearings are usually mounted in opposition. Clearance adjustment is necessary.		Any arrangement of the pairs is possible.					

Legend: Excellent, Good, Fair, Poor, × Impossible; ← One direction only; ↔ Two directions

* Can be used as free-end bearings if tap fit allows axial motion.

Table 9: Types of rolling bearings

From above images bearing classification based on bearing types and features. Based on this I made some assumptions that are needed for product "Sliding Door Trolley".

Assumptions:

- Operating time of sliding door trolley --- 2 hours per day
- Lifetime of sliding door trolley --- 10 years
- Wheel moving speed --- 0.25 m/s, N= 110 rpm
- Diameter of ball bearings --- 12 mm
- Bearing types --- Deep groove Ball bearings SKF Series 62, SKF/01 – 12BCO2

Here, I selected Deep groove bearings based on machine design data book, and I used several tables and figures to take some data which are necessary for my calculation. [9]

Fr = 981 N Radial load, Fa = 981 N Axial load, N = 110 rpm

L_h = 10 years / 2 hours /day, L_h = 7300 hours of operating for 10 years.

Ball Diameter = 12 mm, Reliability = 95%

Step 1: Based on bearing types:

Deep groove Ball bearings SKF Series 62, SKF/01 – 12BCO2.

From Table: ***d = 12 mm, D = 32 mm, B = 10 mm, R = 0.6 mm***

Static Capacity, Co = 3100 N, Dynamic Capacity, C = 6890 N

These are data which I obtained from the table.

Step 2: Calculation of Equivalent Load (P)

$$P = [x * Fr + Y * Fa]$$

$$P = [0.56 * 981 + 1.2 * 981] = 1726.56 \text{ N (Equivalent Load P).}$$

Where, X = Radial factor, X = 0.56

X = 0.56 which chosen from table based on ratio between Fa/Co = 981 / 3100 = 0.327, Fr/Fa = 981 / 981 = 1

Y = Axial / Thrust factor, Y = 1.2.

Step 3: Bearing Capacity (C): ***For N = 110 rpm, L_h = 7300 hours***

$$C = (c/p) * P$$

$$C = 3.91 * 1726.56 \text{ N} = 6751 \text{ N} < \text{Dynamic Capacity (C)} = 6890 \text{ N.}$$

Where, (c/p) = ***Loading Ratio***

The results which I obtained that bearing capacity (C) is about 6751 N which is almost equal to the Actual Dynamic Capacity (C) of bearings. For safer side of Ball bearings, I changed the diameter d = 15 mm. I repeated the above procedure for calculating the Bearing capacity (C).

Based on bearing types: Deep groove Ball bearings SKF Series 62, SKF/01 – 15BCO2.

From Table: ***d = 15 mm, D = 35 mm, B = 11 mm, R = 0.6 mm***

Static Capacity, Co = 3750 N, Dynamic Capacity, C = 7800 N

These are data which I obtained from the table.

Step 2: Calculation of Equivalent Load (P)

$$P = [x^* Fr + Y * Fa]$$

$$P = [0.56 * 981 + 1.2 * 981] = 1726.56 \text{ N (Equivalent Load P).}$$

Where, X = Radial factor, X = 0.56, which chosen from table based on

Fa/Co = 981 / 3750 = 0.327, Fr/Fa = 981 / 981 = 1

Y = Axial / Thrust factor, Y = 1.2.

Step 3: Bearing Capacity (C), ***For N = 110 rpm, L_h = 7300 hours.***

$$C = (c/p) * P$$

$$C = 3.91 * 1726.56 \text{ N} = 6751 \text{ N} < \text{Dynamic Capacity (C) 7800 N.}$$

From the calculation of Bearing selection by "Trial and Error Method", Initially I selected diameter of Ball bearings is 12mm, selected the bearings type, calculating equivalent load (P) and Bearing capacity (C) the solution which I obtained is about 6751 N is more or less equal to actual dynamic bearing capacity of 6890 N mentioned in design data book. For safety considerations I changed the diameter of bearings as 15mm and repeated the same procedure the result is almost the same 6751 N because radial factor and axial factor remains the same value, only static and dynamic capacity were changed, and values are chosen from design data book. So, 6751 N is less than actual dynamic bearing capacity of 7800 N.

3.21 Lubrication in Bearings

In a bearing, lubrication forms a thin oil fil on both the rolling surface and sliding surface to prevent metal-to-metal contact. Some of the benefits lubricating a rolling bearing as follows:

- ✓ Dissipation of friction heat.
- ✓ Prolonged bearing life.
- ✓ Prevention of rust
- ✓ Reduction of friction and wear.
- ✓ Protection against contamination by foreign matter.

In my thesis I proposed to add Grease lubrication which is cheaper in cost and easily available of lubrication. Because the product is used in household applications. The actual operating temperature range is up to maximum of 40 degree Celsius. For long life of product, to prevent foreign substance deposition and smooth rolling of wheels in track lubrication is mandatory.

3.22 Fasteners

Generally, fasteners are used for connection of parts togther and to withstand certain of forces such as shear,tension and compression forces

Fasteners are classified into two types

- ➢ Threaded Fasteners such as screws, tapping screws, screw threads, bolts and nuts are the example of threaded fasteners.
- ➢ Unthreaded fasteners such as rivets, pins, Eyelets and grommets retaining rings, keys, washers are come under the example of Unthreaded fasteners.

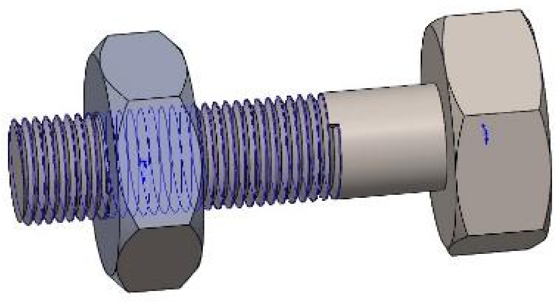


Fig 28: Nuts & Bolts

Pros:

- ➢ Higher strength bolts are much stronger than rivets.
- ➢ Bolts can be removed, replaced or retightened easily in the event of failure.

Cons:

Fastener loosening that leads to slipping of connected parts and loosening occurs due to between the mating threads and between bolt or nut and the mating parts.

- Lesser strength in axial tension
- Under vibratory load strength is reduced.

Unthreaded Fasteners: Pins

When a joint is assembled in which principal loading shear, then the use of pin should be considered as a cost-effective method.

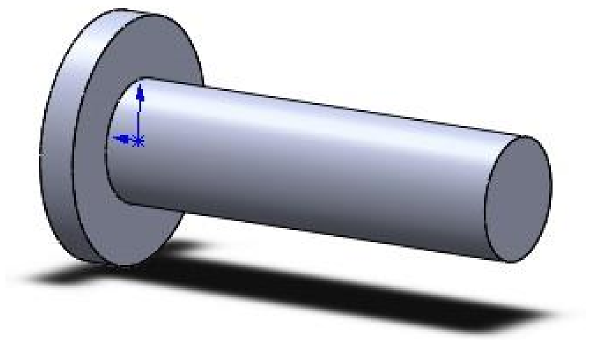


Fig 29: Dowel Pin

Selection Criteria	***Nut & Bolts***	***Rivets***	***Dowel Pin***
Force Types	*Tension force*	*Tension and Shear force*	*Shear force*
Assembly time	*Less*	*Very less*	*Very Less*
Alignment of parts	*Fair*	*Very good*	*Good*
Resist of Movement & vibration	*Possible of Lateral movements*	*With stand vibrations*	*Lateral movements*
Fastener Types	*Replaceable*	*Permanent*	*Replaceable*

Table 10: Comparison between Fasteners types

Difference between Nut and Bolts Vs Pins

Nuts & Bolts	*Pins*
Possible of lateral movements	*Prevent lateral movements*
Used mainly in die set. The tooling is bolted into place and then aligned properly.	*Precise alignment of parts*
Used mainly for tooling to the die set.	*Installing with a tight fit & tight tolerance.*
	Control positioning and variations and possible to obtain repeatable assembly quality.

Table 11: Difference between Nuts & Bolts Vs Pins

3.23 Fundamentals related to Friction and its types

Laws of Friction:

According to Newton's third law of motion when a body exerts a force on a second body, the second body simultaneously exerts a force equal in magnitude and opposite in direction on the first body.

Friction & Types

- **Sliding friction**:
  Sliding friction also called as kinetic friction that acts on objects when they are sliding over a surface. It is a contact force that resists the sliding motion of two objects. Sliding friction is much weaker than static friction.

  $$F = \mu * N$$

  Where,

  F = Friction force, N = Normal force, μ = Co. Efficient of friction.

- **Rolling friction**:

  Rolling friction is friction that acts on objects when they are roll over a surface. Rolling friction is much lower than sliding or static friction.

From the below table, for better understanding about the Rolling friction Vs Sliding friction which gives an idea about which types of friction will acts on the wheels and track types.

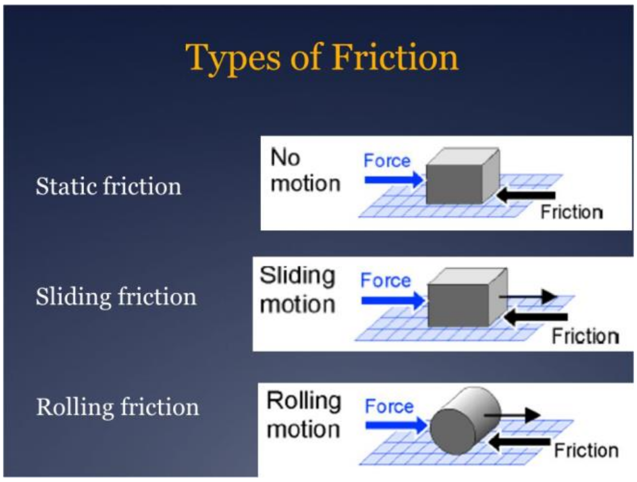


Fig 30: Friction types

Rolling Friction	***Sliding Friction***
Rolling friction takes place when an object rolls on the surface.	*Sliding friction takes place when two surfaces are rubbed against each other.*
Rolling friction takes place due to deformation of surfaces.	*Sliding friction takes place due to interlocking between microscopic surfaces.*
The coefficient of rolling friction is dependent on radius of the rolling object, depth to which object can sink, and the toughness of the surface.	*The coefficient of sliding friction depends on the texture of the surface and temperature to certain extent. It is independent of external factors.*
The coefficient of Rolling friction: $F_r = \mu_r * N$	*The coefficient of Rolling friction:* $F_k = \mu_r * N$

Table 12: Comparison between Rolling Vs Sliding Friction

3.24 Results obtained from Various Steps

Track Design

After comparing several tracks models such as above track and below track models in my project I selected the above track models with includes both box type and round rail types for my product sliding door trolley.

Axiomatic Design

From Axiomatic design I designed the design matrix which is decoupled matrix design. By that equation possible to design “Sliding Door Trolley”, by assuming and giving more importance to FRs and DPs to make the design perfect according to customer attributes.

Design of Different alternatives of parts:

In the above section design of alternative parts I draw different models for each type of parts named as wheels which includes circular, conical, cylindrical and circular wheels with V groove type design. In case of bearings comparing the three types of bearings and chosen the best bearing which is suitable by means of selection criteria in terms of loads, friction coefficient, cost and lubrication. In addition to that, I done the calculation for selection of bearing diameter by “Trial & Error” method to evaluate bearing dynamic capacity (C) of bearings.

In order to connect the different parts wheels, bearings there is a need of one type of fasteners i.e. Threaded Vs Un Threaded fasteners. By comparing several types of threaded and unthreaded types of fasteners I selected the best one that perfectly aligned to withstand shear forces that will act during the operation of doors and it helps indirectly to support the door weight also.

3.25 Designing of Two Different Models of Sliding Door Trolley

Obtaining the results from above section I designed two different types sliding door trolley configurations in solid works first one is 4 wheels configuration and second one is 2 wheels configuration. These two configurations best suitable for above track models with box types and round rail type. Based on track dimensions length, width and thickness of rail types I draw two types of configurations.

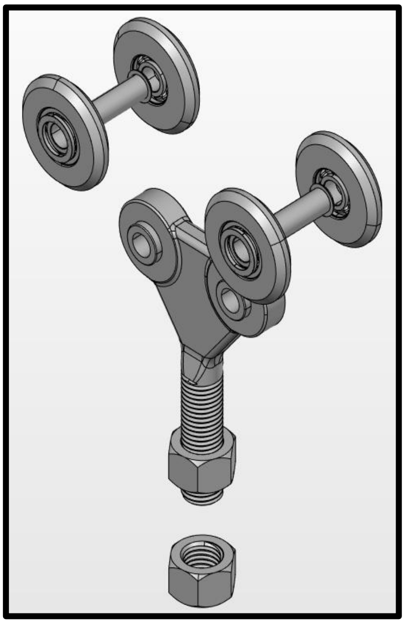


Fig 31: 4 wheels configuration of sliding door trolley.

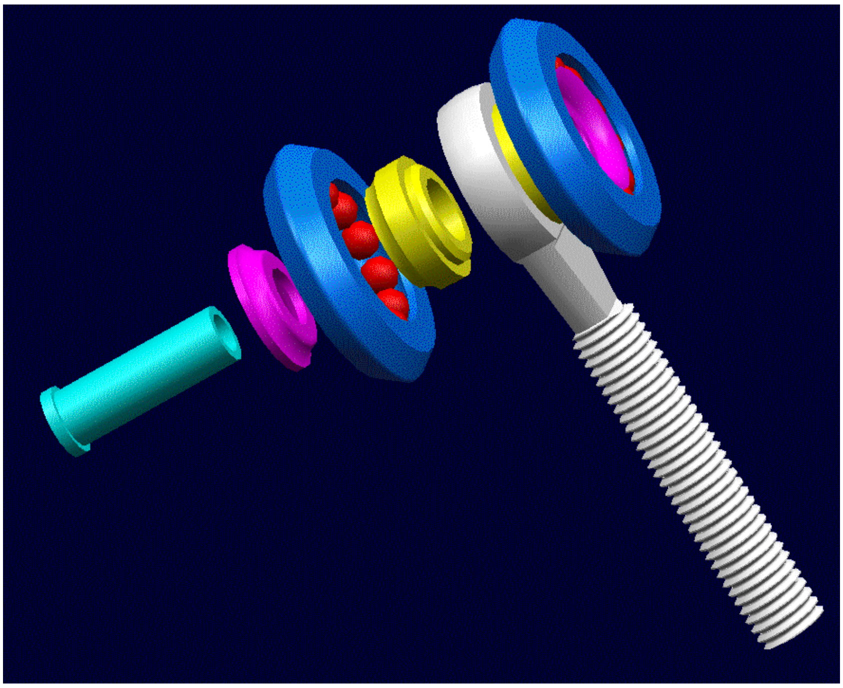


Fig 32: 4 wheels configuration of sliding door trolley.

As a result of two different design configurations 4 wheels & 2 wheels types of sliding door trolley there are two more steps Design for Manufacture & Assembly to know whether these two types of configuration will be chosen based on Design Efficiency Index, Assembly time for whole product. After doing several selection criteria and by comparing the design to finalize the design of actual product "Sliding Door Trolley".

3.26 Design for Manufacture and Assembly (DFMA)

DFMA is an acronym which means "Design for Manufacture and Design for Assembly".

DFM means that the Design the collection of parts which are easy to manufacture finally it will form a final product after the assembly. **DFA** means that the designing of the product that are easy to assembly. Main Goal is to product structure simplification and part count reduction and detailed analysis for easy for assembly.

Both DFM & DFA are more essential for reducing assembly time, manufacturing cost etc. by classifying product design features.

Why DFMA are used?

DFMA is used for three main activities:

1. As the basis for concurrent engineering (CE) studies and research to provide guidance to the design team in simplifying the product structure to reduce manufacturing and assembly costs, and to quantify the improvements.
2. As a benchmarking tools to study competitors, products and quantify manufacturing and assembly difficulties.

Reasons for adopting DFMA

Generally, the design states that the detailing of materials, shapes and tolerances of the individual part as well as the whole product. since the product design evolves through certain stages starting from sketching of individual parts and then it progresses to computer aided design (CAD) to get more detailed parts drawing and assembly drawings are created. Finally, these drawings go to production and manufacturing engineer where they create processes for production of final product.

In this stage lot of problems should need to address by the industries. Mainly in manufacturing and assembly problems are encountered and they are requested to the designer for possible design changes. In addition, in case if there are lots of design changes also occurs this will affect in delay in final product release and causes major changes in product design and development cycle and it became more expensive in terms of time and cost.

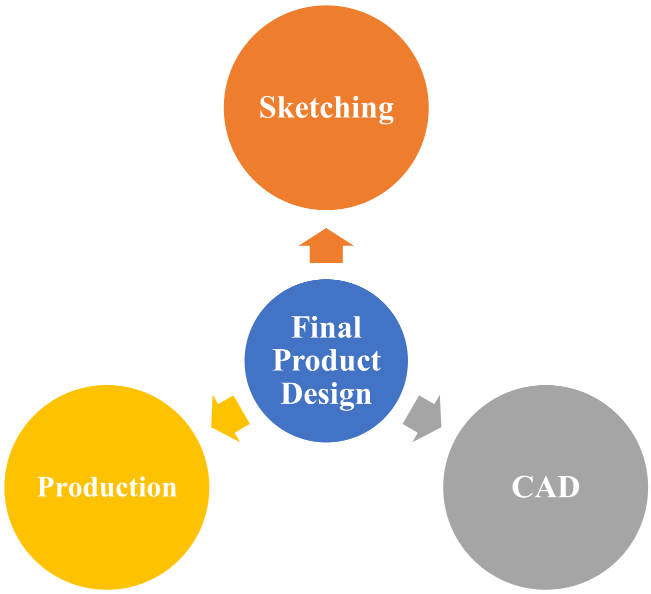


Fig 33: Process involved to get final product design

From the below fig 1.34: it shows that extra time spent early in the design process is more than compensated by savings in time when prototyping takes place.

By using the application of DFMA, major changes occur in overall development time and possible reduction in product cost and shortens the time to market (TTM).

Moreover, many companies adopted DFMA methods for new product design to obtain very successful results in redesign of existing products, creating interaction between manufacturing engineers who are involved in product development team and also with R&D team members.

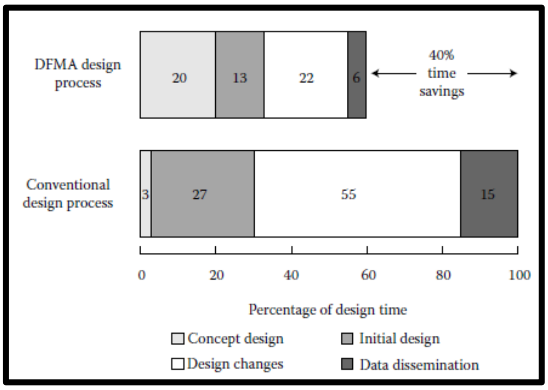


Fig 34: Time for Each Stages

Steps to follow for DFMA Process:

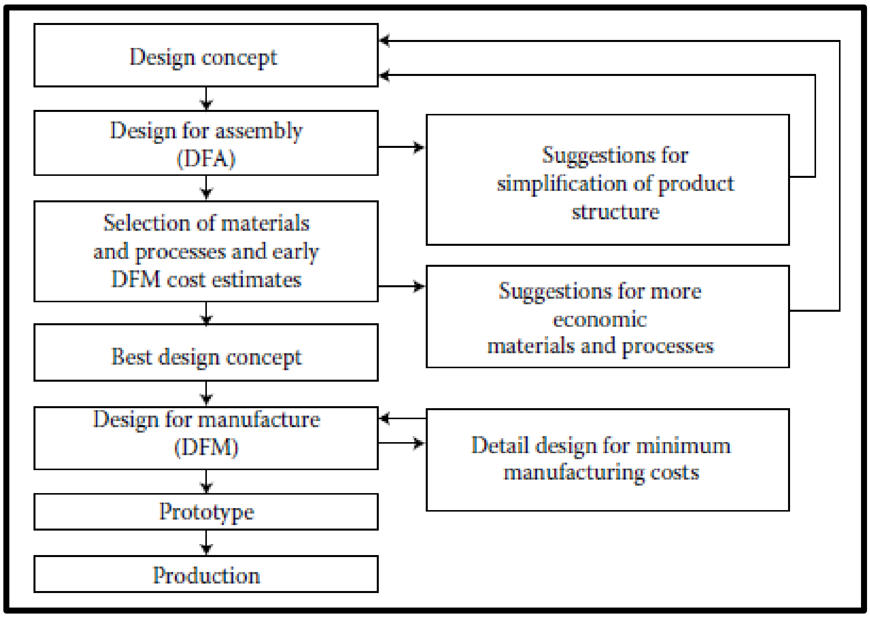


Fig 35: DFMA process flow

Guidance to Designer for Reducing Part counts:

1) During operation of the product, does the part move relative to all other parts already assembled. Only gross motion should be considered --- small motions that can be accommodate by integral elastic elements, for example, are not enough for positive answer.
2) Must the part be of different material than or be isolated from all other parts already assembled? Only fundamental reasons concerned with material properties are acceptable.

3) Must the part be separate from all parts already assembled because otherwise necessary assembly or disassembly of other separate parts would be impossible.

3.27 Design for Assembly of Sliding Door Trolley

From the Guidance to designer for reducing part counts, I construct the theoretical part count of sliding door trolley. For bearing theoretical part count is zero, because the bearings are placed inside the wheels and bearings is relatively roll with the wheels. Remaining all the parts has theoretical part count of value 1 which follows the 3 guidance to designer for reducing part counts. [10]

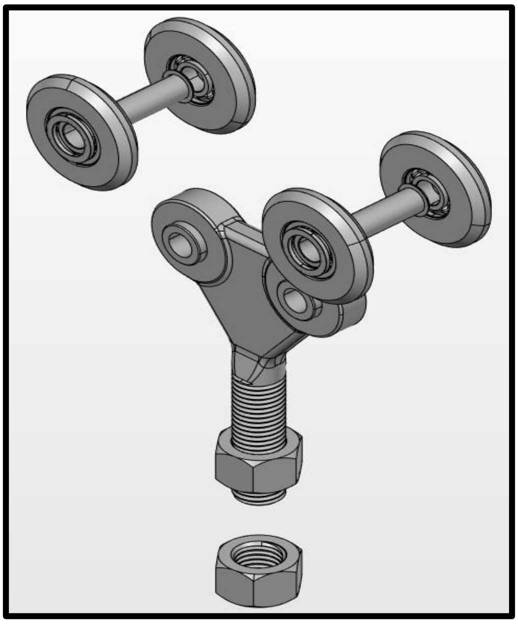


Fig 36: 4 Wheels Configuration of Trolley

Part Name	*No.*	*Theoretical part count*
Wheels	*4*	*1*
Internal ring	*4*	*1*
Shorter Internal Ring	*2*	*1*
Pin	*2*	*1*

Roller bearing	*2*	*0*
White Galvanized Bracket	*1*	*1*
Nut 12 MM	*2*	*1*
Totals	***17***	***6***

Table 13: Theoretical Part count Analysis 4 Wheels Configuration

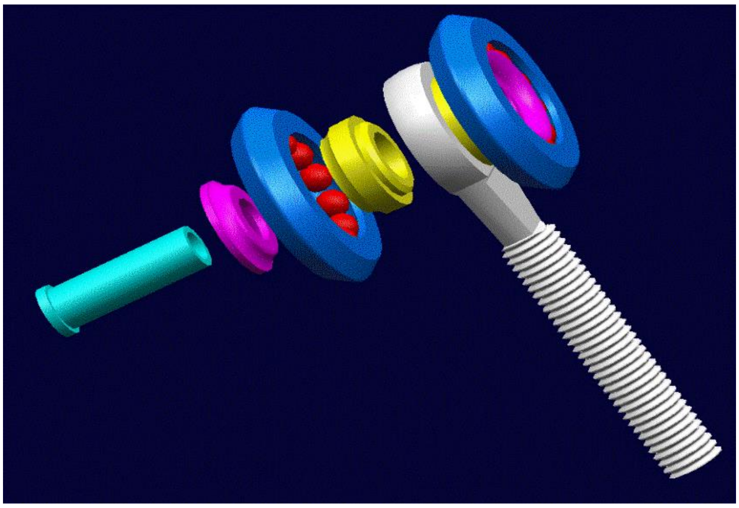


Fig 37: 2 Wheels Configuration of Trolley

Part Name	***No.***	***Theoretical part count***
Wheels	*2*	*1*
Internal ring	*2*	*1*
Shorter Internal Ring	*2*	*1*
Pin	*1*	*1*
Ball bearings	*24*	*0*
White Galvanized Bracket	*1*	*1*
Nut 12 MM	*2*	*1*
Totals	***34***	***6***

Table 14: Theoretical Part count Analysis 2 Wheels Configuration

From above table I determine part count analysis for two configurations 2 wheels Vs 4 wheels of sliding door trolley by assembly design. While comparing two-assembly design in DFA analysis the theoretical part count is less is about 17 in 4 wheels configuration used roller bearings but in 2 wheels configuration I used ball bearings instead of roller bearings.

Next step is to estimate the assembly time & assembly cost for two configurations of wheels so that possible to understand more deeply about this design which has the least total assembly time and cost for DFA analysis procedure.

3.28 Calculation of Manual Assembly Time by using MTM Analysis

After defining the Theoretical part count by using DFA Guidance for reducing part counts next step is to assembly time for "Sliding Door Trolley" for two configurations. In this thesis I followed the MTM Analysis method for calculating assembly time for each motion that is described and coded has a specific time allowed for its completion, by completely identified all of the motions that are required for whole assembly of sliding door trolley. So that, it's possible to find out the motions occurs in Left- or Right-hand side for Handling of tools, visual inspection, Get and place the parts by assuming actual assembling line. Finally, find out the time required for assembling all the parts. [11].

Basic Time Unit: TMU – Time Measurement Unit

1 TMU = 0.00001 hour

= 0.0006 min

= 0.036 sec

Below in MTM - UAS table, code is given by alpha-numeric series which identifies the type of operation and additional factors that influence the time needed for accuracy of task. In MTM UAS has some basic operations such as

1) Get and place – Get the object from Car and place it on table (It includes distance range also).

2) Place – Place it tight or loose on table (it includes distance range also).
3) Handling Tools – Using of Punch, hammer etc. (it includes distance range also).
4) Operate – Easy or Difficult operation to do.
5) Body Motion – Walk inside the assembly line, Sitting and bending while taking parts.
6) Visual control – Visual inspection of all parts.

By using the MTM UAS table I calculated assembly time that are needed for assembly of parts of Sliding door trolley.

Get and place			DT	1	2	3
			Code	TMU		
<= 1 daN	Easy	aprox.	AA	20	35	50
		loose	AB	30	45	60
		tight	AC	40	55	70
	Difficult	aprox.	AD	20	45	60
		loose	AE	30	55	70
		tight	AF	40	65	80
	Handful	aprox.	AG	40	65	80
> 1 to <= 8 daN		aprox.	AH	25	45	55
		loose	AJ	40	65	75
		tight	AK	50	75	85
> 8 to <= 22 daN		aprox.	AL	80	105	115
		loose	AM	95	120	130
		tight	AN	120	145	160
Place			Code	1	2	3
approximate			PA	10	20	25
loose			PB	20	30	35
tight			PC	30	40	45

Handling Tools	Code	1	2	3
approximate	HA	25	45	65
loose	HB	40	60	75
tight	HC	50	70	85
Operate	Code	1	2	3
easy	BA	10	25	40
difficult	BB	30	45	60
Motion Cycles	Code	1	2	3
single motions	ZA	5	15	20
compounded motions	ZB	10	30	40
compounded motions + place	ZC	30	45	55
tighten / untighten	ZD		20	
Body Motions	Code			
walk / m	KA		25	
bend,stoop,kneel incl.arise	KB		60	
sit and stand	KC		110	
Visual Control	VA		15	

Table 15: MTM UAS Table

Description	***Code***	***Quantity***	***TMU***	***L***	***R***	***TMU (Total)***	***Time in Sec***	***TMU in Sec***
Walk to Assembly line (1 m)	***KA***	*1*	*25*	*0*	*0*	*25*	*0.9*	***0.036***
Get & Place a Bracket	***AC 2***	*1*	*55*	*0*	*2*	*55*	*1.98*	***0.036***
	AC 1	*1*	*40*	*2*	*0*	*40*	*1.44*	***0.036***
Get & Place the Internal Ring in Bracket	***AC 2***	*1*	*55*	*0*	*2*	*55*	*1.98*	***0.036***
	AC 1	*1*	*40*	*2*	*0*	*40*	*1.44*	***0.036***
Tighten Parts	***ZD***	*1*	*20*	*1*	*1*	*20*	*0.72*	***0.036***
Get & Place Wheel	***AC 2***	*1*	*55*	*0*	*2*	*55*	*1.98*	***0.036***
	AC 1	*1*	*40*	*2*	*0*	*40*	*1.44*	***0.036***
Get & Place Short Internal Ring Inside the Wheel	***AC 2***	*1*	*55*	*0*	*2*	*55*	*1.98*	***0.036***

	AC 1	1	40	2	0	40	1.44	0.036
Position short internal ring	PB 1	1	20	0	1	20	0.72	0.036
Get & Place Ball Bearings	AA 2	6	35	0	6	210	7.56	0.036
	AA 1	6	20	6	0	120	4.32	0.036
Place Wheel in Bracket	PC 1	1	30	0	1	30	1.08	0.036
Tighten Parts	ZD	1	20	1	1	20	0.72	0.036
Get & Place the Internal Ring in Bracket	AC 2	1	55	0	2	55	1.98	0.036
	AC 1	1	40	2	0	40	1.44	0.036
Tighten Parts	ZD	1	20	1	1	20	0.72	0.036
Get & Place Wheel	AC 2	1	55	0	2	55	1.98	0.036
	AC 1	1	40	2	0	40	1.44	0.036
Get & Place Short Internal Ring Inside the Wheel	AC 2	1	55	0	2	55	1.98	0.036
	AC 1	1	40	2	0	40	1.44	0.036
Position short internal ring	PB 1	1	20	0	1	20	0.72	0.036
Get & Place Ball Bearings	AA 2	6	35	0	6	210	7.56	0.036
	AA 1	6	20	6	0	120	4.32	0.036
Place Wheel in Bracket	PC 1	1	30	0	1	30	1.08	0.036
Get & Place Pin	AB 2	1	45	0	2	45	1.62	0.036
	AB 1	1	30	2	0	30	1.08	0.036
Tighten Parts	ZD	1	20	1	1	20	0.72	0.036
Get 2 Nut of 12 mm to Threaded Part	AF 2	1	65	0	2	65	2.34	0.036
	AF 1	1	40	2	0	40	1.44	0.036
Turn both the screws	ZB 1	10	10	10	10	200	7.2	0.036
Visual Inspection	VA	1	15	0	0	15	0.54	0.036
			Total Time in Sec				**80.1**	

Table 16: MTM UAS Analysis of 2 wheels Sliding Door Trolley

3.29 Results Obtained from MTM Analysis

From the output of MTM analysis for manual assembly of whole product “Sliding Door Trolley”. The total time required for assembling the product is 80.1 secs. In the below table, I done the calculation of assembly time for each individual part assembly for wheels, internal ring, short internal ring, pin, ball bearings, brackets and nuts. By using of assembly time possible to calculate the assembly cost for each part.

Part Name	*No.*	*Theoretical part count*	*Assembly time*	*Assembly cost*
Wheels	*2*	*1*	*13.86*	*11.05*
Internal Ring	*2*	*1*	*4.14*	*3.30*
Shorter Internal Ring	*2*	*1*	*8.28*	*6.60*
Pin	*1*	*1*	*2.7*	*2.15*
Ball Bearings	*24*	*0*	*34.56*	*9.47*
White Galvanized Bracket	*1*	*1*	*16.02*	*12.77*
Nut 12 mm	*2*	*1*	*11.52*	*9.18*
Total	***34***	***6***	***80.1***	***54.53***

Table 17: Results of DFA Analysis 2 Wheels Sliding Door Trolley

Calculation of Assembly cost for each part of the product and to find out the total cost for assembly.

Assembly cost = (Labor cost per hour * Assembly time / 3600) * 100.

Assembly Index = Theoretical part count * 3s / Total Assembly Time.

i.e. 3s is the minimum time for assembly of each part for manual assembly.

By calculating using above formula the results which is 23 % of design efficiency of the product “Sliding Door Trolley”. Similarly, the assembly cost for “Sliding Door Trolley “is about 54.53 Euros/ hr.

Furthermore, I am calculating the assembly time and assembly cost for 4 Wheels Sliding door trolley by using same procedure of 2 wheels sliding door configuration in order to finalize which is the best design solution.

Description	*Code*	*Quantity*	*TMU*	*L*	*R*	*TMU (Total)*	*Time in Sec*	*TMU in Sec*
Walk to Assembly line (1 m)	***KA***	*1*	*25*	*0*	*0*	*25*	*0.9*	***0.036***
Get & Place a wheel	***AC 2***	*4*	*55*	*0*	*8*	*220*	*7.92*	***0.036***
	AC 1	*4*	*40*	*8*	*0*	*160*	*5.76*	***0.036***
Get & Place Roller Bearings	***AC 2***	*4*	*55*	*0*	*8*	*220*	*7.92*	***0.036***
	AC 1	*4*	*40*	*8*	*0*	*160*	*5.76*	***0.036***
Place it tight inside wheels	***PC 1***	*4*	*30*	*0*	*4*	*120*	*4.32*	***0.036***
Get Short internal Ring	***AB 2***	*2*	*45*	*0*	*2*	*90*	*3.24*	***0.036***
Tighten Parts	***ZD***	*4*	*20*	*4*	*4*	*80*	*2.88*	***0.036***
Get & Place the Bracket	***AC 2***	*1*	*55*	*0*	*2*	*55*	*1.98*	***0.036***
	AC 1	*1*	*40*	*2*	*0*	*40*	*1.44*	***0.036***
Get Short internal Ring	***AB 2***	*2*	*45*	*0*	*2*	*90*	*3.24*	***0.036***
Place it tight inside the bracket	***PC 1***	*2*	*30*	*0*	*2*	*60*	*2.16*	***0.036***
Get & Place Pin	***AB 2***	*1*	*45*	*0*	*2*	*45*	*1.62*	***0.036***
	AB 1	*1*	*30*	*2*	*0*	*30*	*1.08*	***0.036***
Tighten the pin	***ZD***	*1*	*20*	*0*	*1*	*20*	*0.72*	***0.036***
Place both wheel and pin	***PC 1***	*1*	*30*	*0*	*1*	*30*	*1.08*	***0.036***
Tighten the parts	***ZD***	*1*	*20*	*1*	*1*	*20*	*0.72*	***0.036***
Get & Place Pin	***AB 2***	*1*	*45*	*0*	*2*	*45*	*1.62*	***0.036***
	AB 1	*1*	*30*	*2*	*0*	*30*	*1.08*	***0.036***
Tighten the pin	***ZD***	*1*	*20*	*1*	*1*	*20*	*0.72*	***0.036***
Place both wheel and pin	***PC 1***	*1*	*30*	*0*	*1*	*30*	*1.08*	***0.036***
Tighten the parts	***ZD***	*1*	*20*	*1*	*1*	*20*	*0.72*	***0.036***
Get the punch	***HB 2***	*1*	*60*	*1*	*1*	*60*	*2.16*	***0.036***
Place punch on tighten the parts	***ZB 1***	*4*	*10*	*1*	*1*	*40*	*1.44*	***0.036***

Get 2 Nut of 12 mm to Threaded Part	***AF 2***	*1*	*65*	*0*	*2*	*65*	*2.34*	***0.036***
	AF 1	*1*	*40*	*2*	*0*	*40*	*1.44*	***0.036***
Turn both the screws	***ZB 1***	*10*	*10*	*10*	*10*	*200*	*7.2*	***0.036***
Visual Inspection	***VA***	*1*	*15*	*0*	*0*	*15*	*0.54*	***.036***
			Total Time in Sec				***65.52***	

Table 18: Results of MTM UAS for 4 Wheels Sliding Door Trolley

Part Name	***No.***	***Theoretical part count***	***Assembly time***	***Assembly cost***
Wheels	*4*	*1*	*18.9*	*9.92*
Internal Ring	*4*	*1*	*9.86*	*7.86*
Shorter Internal Ring	*2*	*1*	*3.12*	*2.5*
Pin	*2*	*1*	*6.84*	*5.45*
Roller Bearings	*2*	*0*	*6.48*	*5.2*
Galvanized Bracket	*1*	*1*	*8.8*	*7.01*
Nut 12 mm	*2*	*1*	*11.52*	*9.18*
Total	***17***	***6***	***65.52***	***47.75***

Table 19: Results of DFA Analysis 4 Wheels Sliding Door Trolley

Assembly cost = (Labor cost per hour * Assembly time / 3600) * 100.

Assembly Index = Theoretical part count * 3s / Total Assembly Time.

i.e. 3s is the minimum time for assembly of each part for manual assembly.

By calculating using above formula the results which is 27 % of design efficiency of the product "Sliding Door Trolley" of 4 wheels configuration. Similarly, the assembly cost for "Sliding Door Trolley "is about 47.75 Euros/ hr.

As a result of two different configuration 2 wheels Vs 4 wheels sliding door trolley,4 wheels configuration has less assembly time 65.52sec when compared to assembly time of 2 wheels about 80.1 secs.

As a result, I found that the assembly time and assembly cost for "Sliding Door Trolley" by using DFA Analysis and by calculating the assembly time by using MTM UAS Analysis.

3.30 Actual Product Design

In this stage of actual product design, one need to think which is the best options for selecting the type of wheel configuration with respective to the type of track methods.

Here I implemented two tables one for selection of wheel configuration by "Trade off analysis" between "Cost Vs Load" carrying capacity for different configurations for finalizing the actual product design of sliding door trolley.

From the below table, there are three different configurations of wheels, i.e.,single wheels, 2 wheels and 4 wheels configurations.

Selection Criteria	***Single wheel***	***2 wheels***	***4 wheels***
Cost	*Low*	*Medium – High*	*High*
Load Carrying Capacity	*Very Light*	*Light to Medium*	*Medium to High*
Bearing types	*Plain bearing*	*Roller bearing*	*Roller bearing*

Table 20: Wheel configuration comparison

I constructed another comparison table for results of Design for Assembly (DFA) analysis to find out best design by DFA assembly index expressed in percentage.

As a result, obtained by DFA analysis, 2 wheels has more assembly time around 80.1 secs which is slightly higher than 4 wheels assembly time. The main reasons for this is increase in assembly time from table MTM analysis the ball bearings contribute 34.56 secs in 2 wheels configuration but in 4 wheels configuration the assembly time is 6.48 secs. So, the assembly time of 4 wheels balance the time of 2 wheels assembly time.

Selection Criteria	*4 wheels*	*2 wheels*
Assembly Time	*65.52*	*80.1*
Assembly Cost	*47.72*	*54.53*
Design Index (%)	*27%*	*23%*

Table 21: Results of DFA Analysis 2 wheels Vs 4 wheels configuration

3.31 Final Product Design

Up to this section I obtained various results by comparing all the tables by selection criteria. I summarize the final design which is 2 wheels configuration suitable for above track method. In my final product design load capacity is up to 200 kg which falls under the category light – medium category, the bearings which I used is ball bearings.

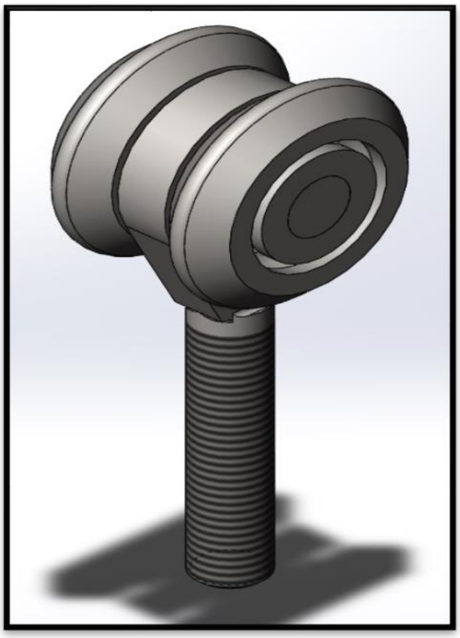


Fig 38: 2 Wheels Configuration of Sliding Door Trolley

Next step is to analyse the Trolley to know possible failure will occurs of each parts of products. In order to determine that Product Failure Mode Effect Analysis (PFMEA) has done. With general introduction of FMEA, Types of FMEA, When FMEA must be used.

3.32 Failure Mode Effective Analysis (FMEA)

FMEA is also called Potential failure mode and effects analysis or failure modes, effects and critically analysis.

FMEA: is a best tool and it is a step by step approach for identifying all possible failures in a design, a manufacturing or assembly process, or a product or service; studying the consequences, or effects, of those failures; and eliminating or reduce failures; and eliminating or reducing failures, starting with the highest priority ones. [12]

- **Failure modes:** Means the ways, or modes, in which something might fail. Failures are any errors or defects, especially ones that affect the customer, and can be potential or actual.
- **Effect analysis**: refers to studying the consequences of those failures.

Failures are prioritized according to how serious their consequences are, how frequently failures occur, and how easily failure can be detected. ***The purpose of the FMEA is to take actions to eliminate or reduce failures, starting with the highest- priority ones.***

FMEA for Product "Sliding Door Trolley"

Here I done FMEA for individual parts of product "Sliding Door Trolley" and for the whole product in order to verify the design, possible failure can occur during the operation, and try to detect the possible failure can occurs. Generally, the FMEA begins during the earliest conceptual stages of design and continues throughout the life of the product or service. The first step of FMEA is used during design stages to prevent failures, later it's used for control, before and during ongoing operations of the process.

- After the Quality function deployment (QFD) process, when a process, product, or service is being designed or redesigned.
- When an existing process, product or service is being applied in a new way.
- Before developing control plans for a new or modified process.
- When analysing failures of an existing process, product or service.
- Periodically throughout the life of the process, product or service.

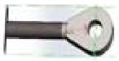
Item/ Function	***Images***	***Requirements***	***Potential Failure Mode***	***Potential Effect(s) of Failure***	***Severity (S)***	***Classification (CC)***
White Galvanized Brackets		the thread and eye end of the body must withstand radial loads from the weight of the door	breakage of sphere shape and body	the trolley losses its functions and door falls	10	
Pin		must withstand radial loads from the weight of the door	breakage of the shaft	the trolley losses its functions and door falls	10	
Internal Ring		to lock all outer parts	locking issue	Failure in assemblilng of parts	10	
Short Internal Ring		to lock parts with body	locking issue	Failure in assemblilng of parts	10	
Wheel		Slide on Rails	Failure of wheel due to wear	Door sliding movements gets locked	10	

Table 22: DFMEA Process for Parts of Sliding Door Trolley

Potential Cause/ Mechanism (s) of Failure	***Occurrence***	***Control Prevention***	***Control Detection***	***Detection***	***RPN***	***Recommended Action (s)***
Overloading		diameter of rod eye end, thread selection	FEA	2	40	proper material selection, load range within the permissible limit in (kg)
bending, wrong material selection, rusting, fatigue, vibration, load		diamter,material, cross sections	FEA	2	0	proper selection of material,dimensions based on load (kg), best surface finish wear resistance
diameter, surface finishing		diameter, strength, stress	FEA	2	0	proper finishing surface,
diameter, surface finishing		diameter, strength, stress	FEA	2	0	proper finishing surface,
Contact surface Area and wear of wheels in Rails, fatigue, ball bearings		use better material selection to reduce wear on wheels, ball bearings	FEA	2	0	proper selection of material,dimensions based on load (kg). best surface finish, wear resistance, quality ball bearings

Table 23: DFMEA Process for Parts of Sliding Door Trolley

Item/ Function	*Images*	*Requirement s*	*Potential Failure Mode*	*Potential Effect(s) of Failure*	*Severity (S)*	*Classification (CC)*
Sliding Door Trolley		Should have the Life Time of 10 years	Failure due to load predefined load capacity, or overload	Trolley cannot able to with stand load and movements	10	
			Failure in Life cycle	possible wear resistance	10	
			Failure of Design	product fails to work, cannot produce	8	
			Over all product Failure	increase in development cost,product not feasible for production	10	
			Poor Quality Product	product fails to work	8	
			Defects	leads to product damage	4	
			Price	Less sales of product	6	
			Decline in Market demand	lossing customers and negative image of product	6	

Table 24: DFMEA for whole product of Sliding Door Trolley

Potential Effects is Evaluated According to a Decimal Scale Value		
Effects	*Criteria : Severity of Effect*	*Rank*
Hazardous without Warning	When a Failure mode affects safe devoce Operation without Warning	*10*
Hazardous with Warning	When a Failure mode affects safe devoce Operation with Warning	*9*
Very High	Device Inoperable: Primary Function Loss	*8*
High	Device Operable: At a Highly reduced level of performance	*7*
Moderate	Device Operable: At at reduced level of performance	*6*
Low	Device Operable: At a slightly reduced level of performance	*5*
Very Low	Device Operable: Defect noticed by Most Customers	*4*
Minor	Device Operable: Defect noticed by Average Customers	*3*
Very Minor	Device Operable: Defect noticed by discriminating Customers	*2*
None	Almost No Effect	*1*

Table 25: Severity Selection Criteria for DFMEA Process

Potential Effects is Evaluated According to a Decimal Scale Value			
Probability of Failure	***Criteria : Occurence of Cause (DFMEA)***	***Criteria : Possible Failures Rates***	***Rank***
Very High	New technology/ new design	≥ 100 per thousand ≥ 1 in 10	*10*
High	Failure is unavoidable in new design, new application	50 per thousand 1 in 20	*9*
	Failure is acceptable with new design, new application	20 per thousand 1 in 50	*8*
	Failure is unrelaible with new design, new application	10 per thousand 10 in 100	*7*
Moderate	Frequent failures related with similar design, simulation and Testing	2 per thousand 1 in 100	*6*
	Occassional failures related with similar design, simulation and Testing	.5 per thousand 1 in 2,000	*5*
	Detached failures related with similar design, simulation and Testing	.1 per thousand 1 in 10,000	*4*
Low	Only Detached failures related with similar design, simulation and Testing	0.1 per thousand 1 in 1,00,000	*3*
	No observed failures related with exact design, simulation and Testing	≤001 per thousand 1 in 1,00,000	*2*
Very Low	Failure is neglected through preventive measures	Failure is eliminated through preventive measures	*1*

Table 26: Occurrence Selection Criteria for DFMEA Process

Likelihood of Detection of Design Failures			
Opportunity for Decision	***Criteria: Detection of Design Control***	***Rank***	***Likelihood of***
No Detection Opportunity	No current Design control	**10**	Almost Impossible
Not likely to detect at any stage	Weak Detection by Design Analysis/Detection controls. Not correlated to actual operating conditions	**9**	Very Remote
Post Design freeze and prior to launch	With pass/fail testing prior to launch for product verification/validation after design freeze	**8**	Remote
	With test to failure testing prior to launch for product verification/validation after design freeze	**7**	Very Low
	With degradtion testing prior to launch for product verification/validation after design freeze	**6**	Low
Prior to Design Freeze	Product validation, relability, Development & Testing prior to design Freeze using pass/ Fail	**5**	Moderate
	Product validation, relability, Development & Testing prior to design Freeze using test to failure	**4**	Moderately High
	Product validation, relability, Development & Testing prior to design Freeze using degradation	**3**	High
Virtual Analysis - Correlated	Virtual Analysis (CAE, FEA) is higly correlated with actual or expected operating conditions prior to design	**2**	Very High
Detection not Applicable; Failure Prevention	Preventation of Failure Mode or Failure Cause using through Design Solutions	**1**	Almost Certain

Table 27: Detection Selection Criteria for DFMEA Process

3.33 Results Obtained from Phase 2 Product Design

In this section 3.33 I discussed some of results obtained from various section starting from section 3.25 I designed some of possible solutions and configurations of product “Sliding Door Trolley” i.e., 4 wheels configuration vs 2 wheels configuration types of sliding door trolley. Since, I obtain results from section 3.24 designing of track types etc. Next step is to analyse two types of configuration by design for manufacture and assembly (DFMA) by using DFMA “Theoretical Part Count Analysis”. Once obtaining the results by comparing results of part count analysis, determined the manual assembly time for 2 wheels Vs 4 wheels configurations. Then evaluate the assembly cost and DFA design index to finalize the design which is more feasible to produce the product in terms of cost and time.

In section 3.30 actual product design by comparing the results by selection criteria in terms of assembly index, assembly time and assembly cost. Next section 3.31 is the final product design and made some assumptions types of bearing I supposed to use for product ***“2 wheels configuration of Sliding Door Trolley”.***

In section 3.32 Failure Mode Effective Analysis (FMEA) aimed to list all Potential failure mode, effects of failure and finding the severity rank for each part and also for complete product of “Sliding Door Trolley” to improve in quality of design and to decrease the risk of product failures. By using different table 27,28,29 to find out the scale range from 1 – 10 to determine the Severity, Occurrence, Detection range. Finally, Risk priority index number RPN number has been determined to know that how much risk is associated with product.

Phase 2 Process Design

In this section Phase 2 process design it is a sub section of design phase 2 i.e., Product design and Process design. In section 3.33 discussing about the general description of manufacturing process and by following the process flowchart for Product Design specification to final design. Using PRIMAs selection strategy for the selection of materials and best manufacturing methods for production. Parallelly, creating Bill of Materials (BOM), Manufacturing process plan (MPP), Make or Buy decision discussing about which product is feasible to make or buy the products from outside suppliers. Additionally, I created sequence of operation flowchart for manufacturing operation for product "Sliding Door Trolley" which includes visual quality inspection to increase the quality in production, parallelly documentation work has done to know about the quantity that produced during the actual production process. Process Failure Mode Effective Analysis (PFMEA) to identify and evaluate the potential failure of a process. This PFMEA document is a key document for production process and documents has stored, maintained throughout the product lifecycle.

3.33 Introduction to Manufacturing Process

In this Industrial V4.0, As a production manufacturing engineer need to understand latest advancement in technological capabilities and need to use best manufacturing process. By using of this manufacturing process, it's possible to offer good quality of products for our customers so that we can reach good profits. In addition to that, production engineer has more responsibility to select which manufacturing process will suitable for production. [13]

On the other hand, designer need to conform that this product must satisfy the customer requirements, comply with specification and ensuring the quality in every aspect of the product. In addition to that, the designer has more design risk, once the product is produced in terms of quality and cost, it must be competitive in the market. So, we cannot finalize the decision in terms of increasing the manufacturing efficiency, improvement in quality and reduction in cost of the product using advanced machine tools.

Process Selection for Design for Manufacture (DFM)

Initially process for DFM for selecting the manufacturing process i.e., the selection strategies based on key economic and technical factors transformed from the "Product Design Specification (PDS)". PDS is nothing but the lists of all customer requirements, customers end users and business need to be satisfied. Product team plays a vital role for writing Product design specification and these PDS forms a reference point for creating the designing or prototyping.

- The first step of this process is to aim of simplifying the product structure and optimizing part-count by means of analysing the design or prototyping.
- Selection of materials based on general classification of engineering materials.
- Selection of appropriate manufacturing process to avoid problems of component handling and fitting process.
- By using target costs and trade- off analysis to evaluate the component manufacture and assembly cost during the design process.

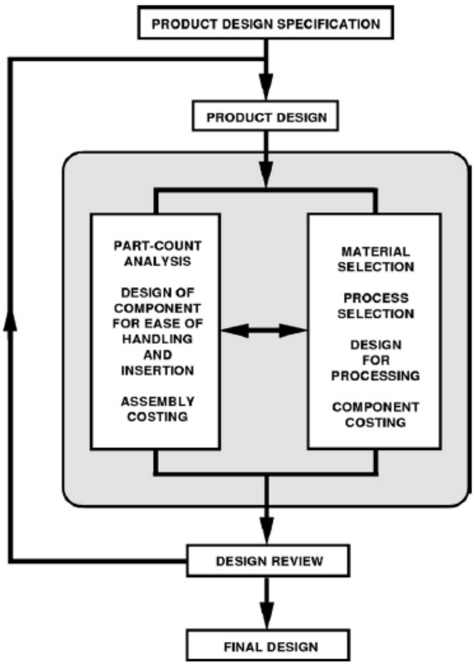


Fig 39: Process Chart from PDS to Final Design.

From the above fig: left-hand side is related to Design for Assembly (DFA) and the right-hand side for Design for Manufacturing (DFM) related to material selection, process selection and component design for processing.

3.34 General Process Selection Flowchart

In process selection, from Product Design Specification (PDS) is about customer requirements of product "Sliding Door Trolley", next step is to select the proper manufacturing process by using PRIMA's strategies.

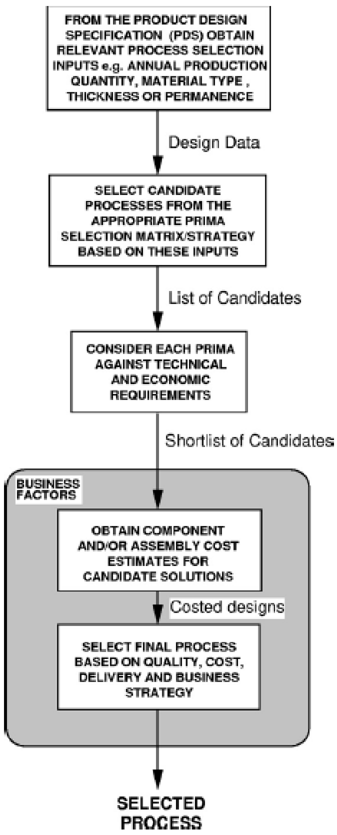


Fig 40: Process Chart for manufacturing Process Plan

3.35 PRIMAs Strategy

In order to support both production and manufacturing engineers in terms of quality considerations, design considerations material suitability, economics and process fundamentals and process variants Process Information Maps (PRIMA's) strategy for process selections and to promote the generation of design ideas and facilitate the matching and tuning of a design to a process. Three main reasons for using PRIMA's strategy

1) To provide the best functions and it gives over all idea how it works.
2) To provide information in case is there any present limitations and opportunities.

3) To estimate costs of component manufacture and assembly for designs at an early stage of product development.

With the help of PRIMA's selection first thing is to identification of candidate processes based on strategic criteria such as material, processes technology and production quantity. After that, with the help of identified possible targets, the data that are available in PRIMAs selection matrix more helpful to select the process. Since the PRIMAs includes 5 different types of manufacturing process groups:

1) Casting processing methods.
2) Plastic and Composite processing methods.
3) Forming processing methods.
4) Machining processing methods.
5) Non- traditional processing methods.

There is a development and advancements in technologies manufacturing process methods also varies and more helpful during the product development to support designers.

1) Rapid prototyping.
2) Surface engineering methods.
3) Joining methods.
4) Assembly systems.

Outcomes from PRIMAs Structure:

By using of PRIMAs Structure possible to select the right process and optimize the design that suits the selected process. If decisions are made wrong it will affect in all factors in terms of cost, quality of each components and assembly section. Finally, it will affect the product success in the market. The main goal of PRIMAs is to provide the data that are needed for selection of manufacturing processes, such manufacturing processes has the capability to satisfy the engineering needs of the application, including those associated with conformance to quality requirements.

3.36 Materials and Processes Classification

In production and manufacturing process, the transforming of raw materials to the product evolves certain stages of process such as primary shaping processes, secondary processes and final assembly/test process. From the below fig:1.42 shows the hierarchy of manufacturing process.

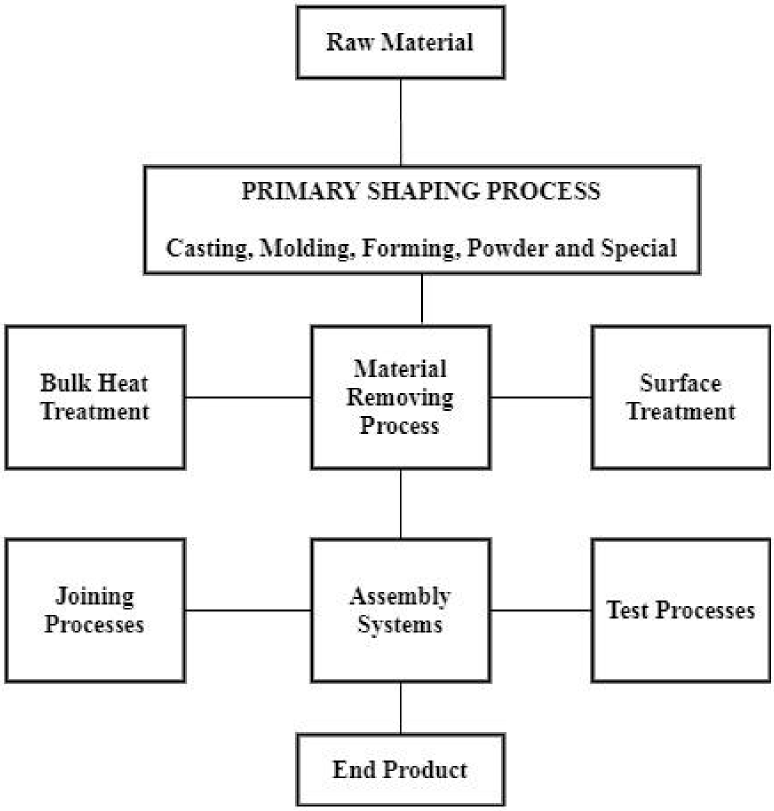


Fig 41: Hierarchy of manufacturing processes.

3.37 Selection strategy for Manufacturing Process

As we are the engineers, while selecting the manufacturing process lots of technical factors need to consider for process selection. In case of components terms such as size, geometry, tolerances, surface finish, capital equipment and labor costs. But some of the process selection drivers which are listed below. But here I mentioned some of the drivers which are suitable for this thesis and for development of product.

Important process selection drivers are

- ✓ Product Quantity.

- ✓ Tolerance requirements.
- ✓ Material to process capability.
- ✓ Surface finish needs.
- ✓ Component form and dimensions.
- ✓ Processing times.
- ✓ Maintenance.

The strategy for selecting manufacturing processes are defined by 6 points that are main criteria for selection of manufacturing process:

- Obtain an estimate of the annual production quantity
- Choose the material type to satisfy the PDS.
- By referring the fig: to select candidate PRIMAs.
- Consider each PRIMA against the engineering and economic requirements:
    a) Understand the process and variations.
    b) Consider the material compatibility.
    c) Assess conformance of component concept with design rules.
    d) Compare tolerance and surface finish requirements with process capability data.
- Consider the economic positioning of the process and obtain component cost estimates for alternatives.
- Review the selected manufacturing process against business requirements.

The PRIMAs selection matrix is used for the selection of manufacturing process once after the finalization of component design to avoid any specific constraints in both design and materials selection. The manufacturing process PRIMA selection matrix is based on two specific requirements:

1) Material type – it is the main key technical selection factor because all the parts in the product need to manufacture.

2) Production Quantity per annum: the number of components to be produced to be taken in account for the economic feasibility of the manufacturing process. The quantities specified for selection process are in the following ranges:

- Very low volume = 1 to 100.
- Low volume = 100 to 1000.
- Medium volume = 1,000 to 10,000.

- Medium to high volume = 10,000 to 100,000
- High volume = 100,000+.
- All quantities.

3.38 Material Selection Process of Sliding Door Trolley

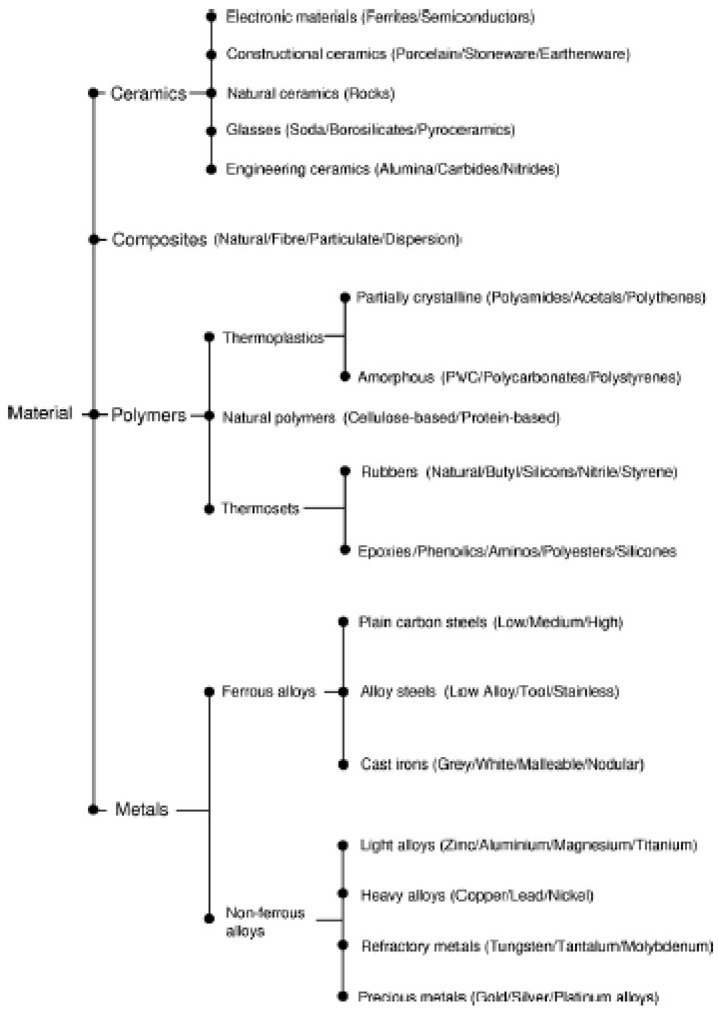


Fig 42: Material Selection Classification

3.39 Process Design for Sliding Door Trolley

Based on the output from “Market Analysis”, the quantity which are needed to produce are 588,116 of units/ year. It is the annual production volume sliding door trolley. By using “PRIMA Strategies” based on production volume which is 6A comes under the category machining process.

MATERIAL / QUANTITY	IRONS	STEEL (carbon)	STEEL (tool, alloy)	STAINLESS STEEL	COPPER & ALLOYS	ALUMINIUM & ALLOYS	MAGNESIUM & ALLOYS	ZINC & ALLOYS	TIN & ALLOYS	LEAD & ALLOYS	NICKEL & ALLOYS	TITANIUM & ALLOYS	THERMOPLASTICS	THERMOSETS	FR COMPOSITES	CERAMICS	REFRACTORY METALS	PRECIOUS METALS
VERY LOW 1 TO 100	[1.5] [1.6] [1.7] [4.M]	[1.5] [1.7] [3.10] [4.M] [5.1] [5.5] [5.6]	[1.1][1.5][1.7] [3.10] [4.M] [5.1] [5.5] [5.6] [5.7]	[1.5] [1.7] [3.7] [3.10] [4.M] [5.1] [5.5] [5.6]	[1.5] [1.7] [3.10] [4.M] [5.1]	[1.5] [1.7] [3.7] [3.10] [4.M] [5.5]	[1.6] [1.7] [3.10] [4.M] [5.1] [5.5]	[1.1] [1.7] [3.10] [4.M] [5.5]	[1.1] [1.7] [3.10] [4.M] [5.5]	[1.1] [3.10] [4.M] [5.5]	[1.5] [1.7] [3.10] [4.M] [5.1][5.5][5.6]	[1.1] [1.6] [3.7] [3.10] [4.M] [5.1] [5.5][5.6][5.7]	[2.5] [2.7]	[2.5] [5.7]	[2.2] [2.8] [5.7]	[1.5] [5.1] [5.5] [5.6] [5.7]	[1.1] [5.7]	[5.5]
LOW 100 TO 1,000	[1.2] [1.5] [1.6] [1.7] [4.M] [5.3] [5.4]	[1.2] [1.5] [1.7] [3.10] [4.M] [5.1] [5.3][5.4][5.5]	[1.1][1.2][1.7] [4.M] [5.1] [5.3] [5.4] [5.5][5.6][5.7]	[1.2] [1.7] [3.7] [3.10] [4.M] [5.1] [5.3][5.4][5.5]	[1.2] [1.5] [1.7][1.8][3.5] [3.10][4.M][5.1] [5.3] [5.4]	[1.2][1.5][1.7] [1.8][3.7][3.10] [4.M] [5.3] [5.4] [5.5]	[1.6] [1.7] [1.8] [3.10] [4.M] [5.5]	[1.1] [1.7] [1.8] [3.10] [4.M] [5.5]	[1.1] [1.7] [1.8] [3.10] [4.M] [5.5]	[1.1] [1.8] [3.10] [4.M] [5.5]	[1.2][1.5][1.7] [3.10] [4.M] [5.1] [5.3] [5.4] [5.5]	[1.1][1.6][3.7] [3.10][4.M][5.1] [5.3][5.4][5.5] [5.6] [5.7]	[2.3] [2.5] [2.7]	[2.2] [2.3]	[2.2] [2.3] [2.8] [5.7]	[5.1] [5.3] [5.5] [5.6] [5.7]	[5.7]	[5.5]
LOW TO MEDIUM 1,000 TO 10,000	[1.2] [1.3] [1.5] [1.6] [1.7] [3.11] [4.A] [5.2]	[1.2][1.3][1.5] [1.7][3.1][3.3] [3.10] [3.11] [4.A][5.2][5.3] [5.4] [5.5]	[1.2][1.5][1.7] [3.1][3.4][3.11] [4.A][5.2][5.3] [5.4] [5.5]	[1.2][1.5][1.7] [3.1][3.3][3.7] [3.10] [3.11] [4.A][5.2][5.3] [5.4] [5.5]	[1.2][1.3][1.5] [1.8][3.1][3.3] [3.10][3.11][4.A] [5.2][5.3][5.4]	[1.2][1.3][1.5] [1.8][3.1][3.3] [3.7][3.10][3.11] [4.A][5.3][5.4][5.5]	[1.3] [1.6] [1.8] [3.1] [3.3][3.4][3.10] [4.A] [5.5]	[1.3] [1.8] [3.3] [3.10] [4.A] [5.5]	[1.3] [1.8] [3.3] [3.10]	[1.3] [1.8] [3.3] [3.10]	[1.2][1.3][1.5] [1.7][3.1][3.3] [3.11][4.A][5.2] [5.3][5.4][5.5] [3.10]	[3.1] [3.7] [3.10] [3.11] [4.A] [5.2] [5.3][5.4][5.5]	[2.3] [2.5] [2.6] [2.7]	[2.2] [2.3] [2.4]	[2.1] [2.2] [2.3]	[5.2] [5.3] [5.4] [5.5]		[5.5]
MEDIUM TO HIGH 10,000 TO 100,000	[1.2] [1.3] [3.11] [4.A]	[1.9][3.1][3.3] [3.4] [3.5] [3.11] [3.12] [4.A][5.2][5.5]	[3.1][3.4][3.5] [3.11][3.12] [4.A] [5.2]	[1.9] [3.1] [3.3] [3.4] [3.5] [3.11] [3.12] [4.A]	[1.2][1.4][1.9] [3.1][3.3] [3.4][3.5][3.11] [3.12] [4.A]	[1.2][1.3][1.4] [1.9][3.1][3.3] [3.4][3.5][3.11] [3.12][4.A][5.5]	[1.3] [1.4] [3.1] [3.3] [3.4] [3.5] [3.12] [4.A]	[1.3] [1.4] [3.3] [3.4] [3.5] [3.12] [4.A]	[1.3] [1.4] [3.3] [3.4] [3.12]	[1.3] [1.4] [3.3] [3.4] [3.5] [3.12] [4.A]	[3.1][3.3][3.5] [3.4] [3.11] [3.12] [4.A] [5.2] [5.5]	[3.1][3.4] [3.11] [3.12] [4.A][5.2][5.5]	[2.1] [2.3] [2.5] [2.6] [2.9]	[2.1] [2.3] [2.9]	[2.1] [2.3]	[3.11]	[3.12]	[3.5]
HIGH 100,000+	[1.2] [1.3] [3.11] [4.A]	[1.9] [3.1] [3.2] [3.3] [3.4] [3.5] [3.12] [4.A]	[4.A]	[1.9] [3.2] [3.3] [4.A]	[1.2][1.9][3.1] [3.2][3.3][3.4] [3.5][3.7][3.8] [3.11][3.12][4.A]	[1.2][1.3][1.4] [1.9][3.1][3.2] [3.3][3.4][3.5] [3.8][3.12][4.A]	[1.3] [1.4] [3.1][3.3][3.4] [3.8][3.12][4.A]	[1.4] [3.2] [3.3] [3.4] [3.5] [4.A]	[1.4] [3.3] [3.4] [4.A]	[1.4] [3.2] [3.3] [3.4] [4.A]	[3.2] [3.3] [4.A]	[4.A]	[2.1] [2.6] [2.9]	[2.1] [2.3] [2.4] [2.9]		[3.7] [3.11]		[3.5]
ALL QUANTITIES	[1.1]	[1.1] [1.6] [3.6] [3.8] [3.9]	[1.6] [3.6]	[1.1] [1.6] [3.6][3.8][3.9]	[1.1] [1.6] [3.6] [3.8] [3.9] [5.5]	[1.1] [1.6] [3.6] [3.8] [3.9]	[1.1] [3.6] [3.8] [3.9]	[3.6] [3.8] [3.9]		[3.6]	[1.1] [1.6] [3.6] [3.8] [3.9]	[3.8] [3.9]				[5.5]	[1.6]	[1.6]

KEY TO MANUFACTURING PROCESS PRIMA SELECTION MATRIX:

CASTING PROCESSES
[3.1] SAND CASTING
[3.2] SHELL MOULDING
[3.3] GRAVITY DIE CASTING
[3.4] PRESSURE DIE CASTING
[3.5] CENTRIFUGAL CASTING
[3.6] INVESTMENT CASTING
[3.7] CERAMIC MOULD CASTING
[3.8] PLASTER MOULD CASTING
[3.9] SQUEEZE CASTING

FORMING PROCESSES
[4.1] FORGING
[4.2] ROLLING
[4.3] DRAWING
[4.4] COLD FORMING
[4.5] COLD HEADING
[4.6] SWAGING
[4.7] SUPERPLASTIC FORMING
[4.8] SHEET-METAL SHEARING
[4.9] SHEET-METAL FORMING
[4.10] SPINNING
[4.11] POWDER METALLURGY
[4.12] METAL INJECTION MOULDING
[4.13] CONTINUOUS EXT (METALS)

PLASTIC & COMPOSITE PROCESSING
[5.1] INJECTION MOULDING
[5.2] REACTION INJECTION MOULDING
[5.3] COMPRESSION MOULDING
[5.4] RESIN TRANSFER MOULDING
[5.5] VACUUM FORMING
[5.6] BLOW MOULDING
[5.7] ROTATIONAL MOULDING
[5.8] CONTACT MOULDING
[5.9] PULTRUSION
[5.10] CONTINUOUS EXTRUSION (PLASTICS)

MACHINING PROCESSES
[6A] AUTOMATIC MACHINING
[6M] MANUAL MACHINING

NON-TRADITIONAL MACHINING PROCESSES
[7.1] ELECTRICAL DISCHARGE MACHINING (EDM)
[7.2] ELECTROCHEMICAL MACHINING (ECM)
[7.3] ELECTRON BEAM MACHINING (EBM)
[7.4] LASER BEAM MACHINING (LBM)
[7.5] CHEMICAL MACHINING (CM)
[7.6] ULTRASONIC MACHINING (USM)
[7.7] ABRASIVE JET MACHINING (AJM)

Fig 43: PRIMA Selection Matrix.

3.40 Bill of Materials (BOM)

From the output of final product design, to get basic information as the part list i.e., bill of materials. Bill of materials represented by hierarchical structure of the product “Sliding Door Trolley” parts which are needed for assembly, sub assembly parts.

Level	***Code***	***Part Name***	***Quantity***	***Units***
1	*DA12MA*	*Dado Met.12 MA*	*2*	*Pz*
1	*ESTZ*	*Esterno Zincato*	*2*	*Pz*
. 2	*EST*	*Esterno Cementato*	*2*	*Pz*
. . 3	*ESG*	*Esterno Torinto*	*2*	*Pz*
. . . 4	*BR_AVP*	*Barra AVP*	*0.5*	*Kg*
1	*IATZ*	*Interno alto Zincato*	*2*	*Pz*
. 2	*IAT*	*Interno alto Cementato*	*2*	*Pz*
. . 3	*IAG*	*Interno alto Torinto*	*2*	*Pz*
. . . 4	*BR_AVP*	*Barra AVP*	*0.5*	*Kg*
1	*IBTZ*	*Interno basso Zincato*	*2*	*Pz*
. 2	*IBT*	*Interno basso Cementato*	*2*	*Pz*
. . 3	*IBG*	*Interno basso Torinto*	*2*	*Pz*
. . . 4	*BR_AVZ*	*Barra AVZ*	*0.5*	*kg*
1	*PER*	*Perno Zincato Bianco*	*1*	*Pz*
1	*SF*	*Sfere Grado 1000*	*24*	*Pz*
1	*STF*	*Staffa Zincata Bianco*	*1*	*pz*

Table 28: Bill of Material of Sliding Door Trolley

3.41 Manufacturing Plan for Sliding Door Trolley

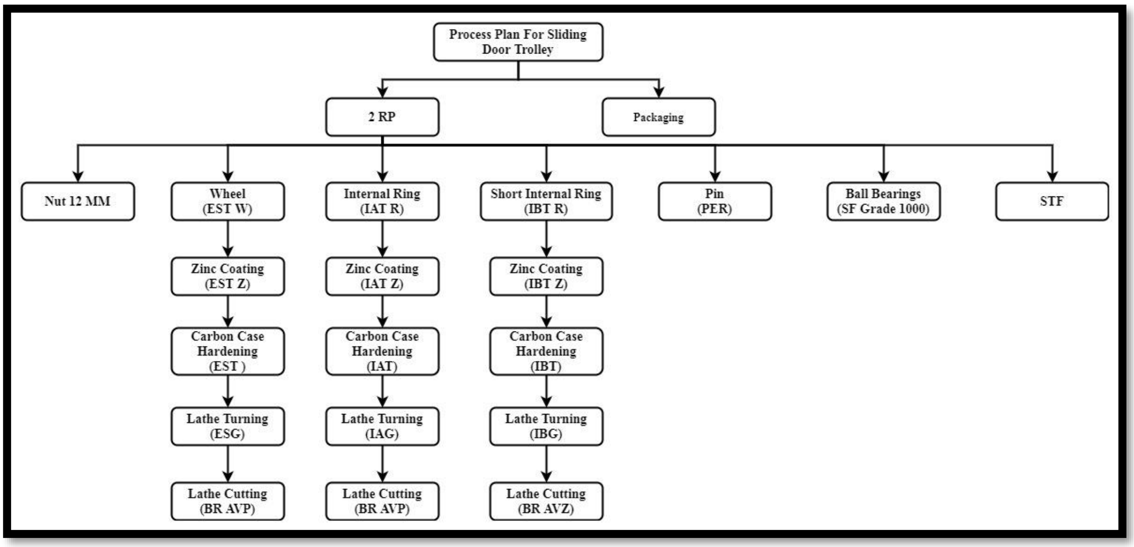


Fig 44: General Structure of Manufacturing Process Plan

3.42 A Make or Buy Decisions

Definition

A make or buy decisions is an act of selecting between the manufacturing a product inside the company or purchasing it from an external supplier.

While outsourcing decision i.e., the product get from the external supplier is made, first need to make a cost comparison which one is the best option. The decision is made normally quite straight forward and easy. In case the company had its own existing product line, understanding that what we can produce and what cannot produce. Some examples that buy from External suppliers such as ball bearings, bearings, nuts, bolts, screws, tires, Gauges, tapes etc.

Level	*Code*	*Part Name*	*Quantity*	*Units*	*Make*	*Buy*

1	*DA12MA*	*Dado Met.12 MA*	*2*	*Pz*		*Buy*
1	*ESTZ*	*Esterno Zincato*	*2*	*Pz*	*Make*	
. 2	*EST*	*Esterno Cementato*	*2*	*Pz*	*Make*	
. . 3	*ESG*	*Esterno Torinto*	*2*	*Pz*	*Make*	
. . . 4	*BR_AVP*	*Barra AVP*	*0.5*	*Kg*	*Make*	
1	*IATZ*	*Interno alto Zincato*	*2*	*Pz*	*Make*	
. 2	*IAT*	*Interno alto Cementato*	*2*	*Pz*	*Make*	
. . 3	*IAG*	*Interno alto Torinto*	*2*	*Pz*	*Make*	
. . . 4	*BR_AVP*	*Barra AVP*	*0.5*	*Kg*	*Make*	
1	*IBTZ*	*Interno basso Zincato*	*2*	*Pz*	*Make*	
. 2	*IBT*	*Interno basso Cementato*	*2*	*Pz*	*Make*	
. . 3	*IBG*	*Interno basso Torinto*	*2*	*Pz*	*Make*	
. . . 4	*BR_AVZ*	*Barra AVZ*	*0.5*	*kg*	*Make*	
1	*PER*	*Perno Zincato Bianco*	*1*	*Pz*		*Buy*
1	*SF*	*Sfere Grado 1000*	*24*	*Pz*		*Buy*
1	*STF*	*Staffa Zincata Bianco*	*1*	*pz*		*Buy*
		Final Packaging	*1*		*Make*	

Table 29: Bill of Material of Sliding Door Trolley with Make or Buy Analysis Decisions

3.43 Flowchart for Manufacturing Operations

Once I designed the general structure of manufacturing process plan, it is necessary to design the sequence of operations for the manufacturing operations for all parts that produced named as make products such as wheels, internal ring and short internal ring parts that are to buy from the external supplier such as nut, pin, ball bearings and bracket.

From the below flowchart, I created the sequence of operations starting from OP 10 it starts with visual inspection of the incoming rod for with correct dimensions in terms of diameter of rod, material of rod and any other defects in rod from the external supplier and documenting the quantity of raw materials that received helps for further management process. Once the visual inspection is passed this verification done by Decision process by three mains Status if Visual Inspection is passed, it moves to further operations of lathe cutting and lathe turning process. In case if it Not passed goes to rework and if it fails it goes to scarp. Once the operation has done lathe cutting and lathe turning again need to do visual inspection to verify the operation has done perfectly. Repeating the same three status of Passed, Not passed and Fail helps to move further manufacturing processes and this process of visual inspection is carried out also for case hardening and zinc coating. The above-mentioned operation 10 is same for remaining two parts of sliding door trolley which is internal ring and short internal ring.

After these three Operation 10, 20 and 30 has done sorting need to be done. OP 40 is to buy parts of a product. It starts with visual inspection of the incoming parts with correct dimensions in terms of diameter of rod, material of parts and any other defects from the external supplier and documenting the quantity and used in production report to know how much quantities are possible to produced.

At the summing junction, summing of all parts from make and buy products and sorting of all parts to make assembly operation made simple in Operation 50 again visual inspection, documenting the quantity for assembly report and finally moves to packaging process.

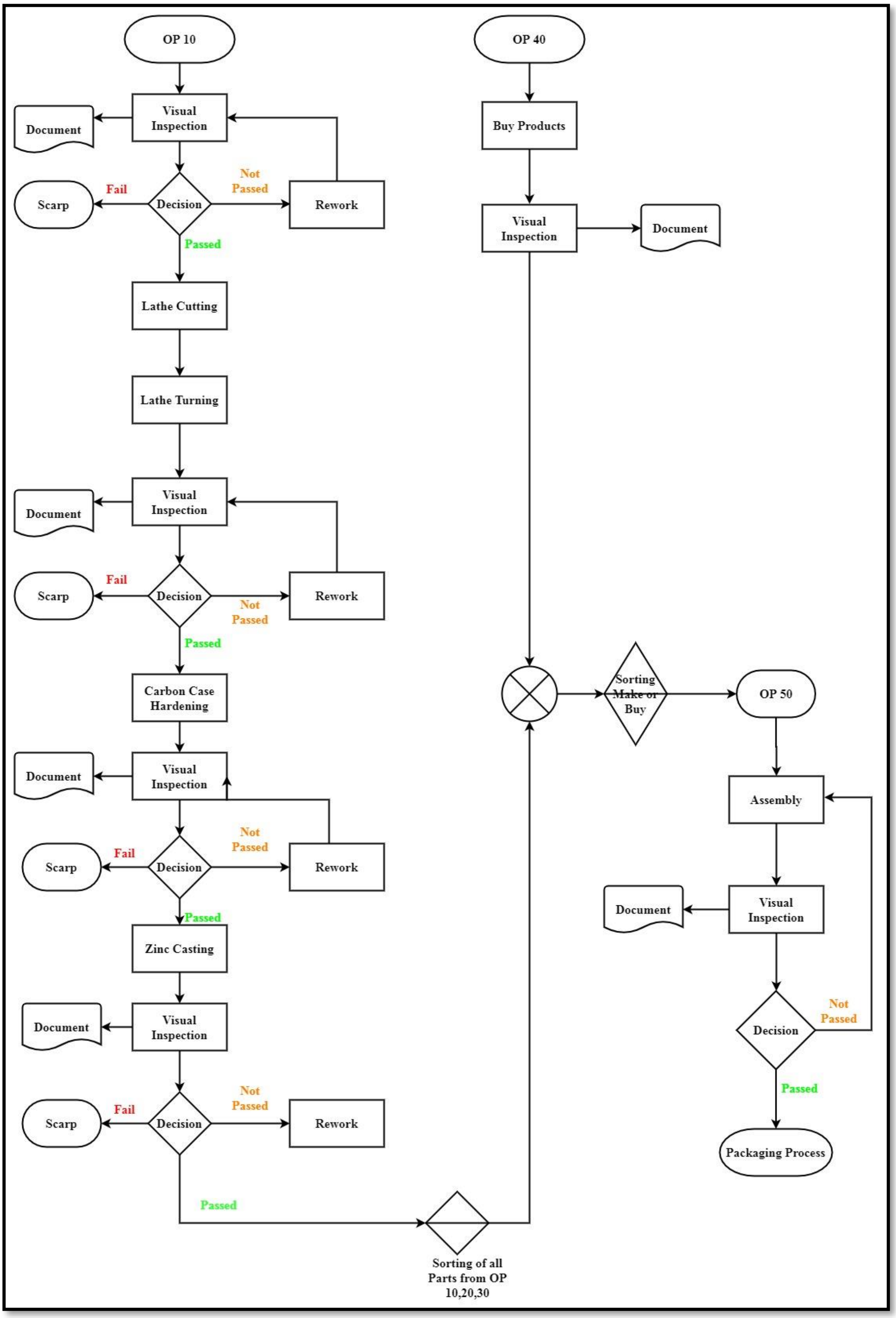


Fig 45: Operation Plan Flow chart for Sliding Door Trolley.

3.45 Process Failure Mode Effective Analysis (PFMEA)

In PFMEA, identified the process or operation being analysed. It also includes process characteristics which includes methods and procedure that permit the process operations to proceed smoothly to meet not only part quality requirements. Here, I defined the sequence of operation for part "Wheels" which is the important section in the development stage of a product "Sliding Door Trolley".

Operation #	Part Name	Process Functions / Requirements	Potential Failure Mode	Potential Effect(s) of Failure	Severity (S)	Classification (CC)	Potential Cause/ Mechanism (s) of Failure	Occurrence	Current Process Control Prevention	Current Process Control Detection	Detection	RPN
10	Wheel	Initial Quality Inspection	Incorrect dimensions in diameter, length of a Bar	Total failure in production	3		Wrong material Selection, Grades and types of steels	1	Check list, table and use of data sheet	Testing	1	3
10.1		Lathe Cutting	Wrong machine selection	Inaccurate in production of a product	2		Wrong material Selection, Grades and types of steels	1	Check list and table	Testing	1	2
			Improper machine speed and feed movement	Increase in production time	2		CNC program errors	1	CNC Hand book	Testing	2	4
			In accurate in Cutting dimensions	Overall product Failure	2		Tools selection, Program errors	2	Tool data hand book	Testing	2	8
10.2		Lathe Turning	Wear of mechanical components of machine tools	Piece surface quality is very poor	3		Decrease in life of mechanical component	4	Tool data hand book	Testing	2	24

Table 30: PFMEA for Sequence of Operation

I created PFMEA for product "Sliding Door Trolley" based on fig:1.45 starting from visual inspection of rod checking the quality with approximate dimensions such as diameter, length, material types etc. analyse the potential failure mode for each operation and effects for failure.

			CNC machine Stops	Collision in cutting tools	2		Programming errors in CNC	2	CNC Programming Hand book	Testing	2	8
			CNC program not properly executed	Non conforming parts	2		Typing or Writing program errors in CNC	3	CNC Programming Hand book	Testing	2	12
10.3		Visual Inspection	Cutting Errors	Alignment errors and Inoperative during assembly	8		Wrong Material selection, Angle of working position of tools	4	Use better material selection & Axis of machine	Testing	2	64
			Surface finishing	Cannot Mount & Noise during movement	5		Decrease in Life of Tool with increase in temperature,crack and Fracture of Tools	6	Tool data hand book	Testing	2	60
10.4		Case Hardening	Hardening processes	Less resistance to Hard Wearing and Fatigue	2		Wrong selection of hardening processes	1	Material data handbook & metallurgy	Testing	2	4
			Hardening of parts	Parts may have defects and Less hardening	6		Improper cooling rate and temperature	3	Material data handbook & metallurgy	Testing	2	36

Table 31: PFMEA for Sequence of Operation

10.5		**Visual Inspection & Hardeness Test**	Occurrence of Over heating	Changes in mechanical properties such as toughness	**6**		Composition, Temperature and Methods to manufacture	**3**	Material data handbook & metallurgy	Testing and Use of international Standard testing procedure	**2**	**36**
			Dimensional change & Resistance to crack initiation	Stress and strain related problems, quench cracks	**2**		Variations in stresses, temperature and chemical during processing	**3**	Material data handbook & metallurgy	Testing and Use of international Standard testing procedure	**2**	**12**
10.6		**Zinc Coating**	Surface contanimation	Results in adhesion Failure & Decreased in resistance against corrosion	**7**		Improper coating specification and incorrect coat timing	**3**	Material data handbook & metallurgy	Testing and Use of international Standard testing procedure	**2**	**42**
			Cracking & possible visible of cracks	Attributes to surface movement, aging, absorption of moisture	**7**		Incorrect coating selection and applying techniques.	**2**	Material data handbook & metallurgy	Testing and Use of international Standard testing procedure	**2**	**28**
10.7		**Visual Inspection**	Coating thickness/ coating weight	Decrease in duration of protection & life of the product	**5**		Inexperienced Workers & Improper testing Standards	**1**	Use trained workers	Testing and Use of international Standard testing procedure	**2**	**10**
			Finish & Appearance	Possible of uncoated areas & Irregularities in coating affect the movement in surface.	**5**		Inexperienced Workers & Improper testing Standards	**1**	Use trained workers	Testing and Use of international Standard testing procedure	**2**	**10**

Table 32: PFMEA for Sequence of Operation

3.46 Results Obtained from Phase 2 Process Design

As a result, I done the Design for Manufacture (DFM) process for product “Sliding Door Trolley” i.e., from Product Design Specification (PDS) to Design Review. In order to choose the best material and manufacturing process for product “Sliding Door Trolley” is done by using PRIMAs selection strategy. PRIMAs strategy manufacturing process selection has done based on annual production volume which is around 588,116 of units needed to be produced obtained from Phase 0 market analysis. I Created Bill of Materials (BOM) and Manufacturing process plan (MPP) for product mainly needed to create the process plan in ARAS.

Phase 4: Prototyping

General Introduction of Prototypes:

Prototype is defined as the process of developing such an approximation model of the product.

As a world full of engineers, especially engineers use prototypes for different reasons:

1) Industrial designers produce prototypes for their concepts.
2) Engineers prototype a design.
3) Software developers write prototype programs.

Pros:

1) Reduce the risk of costly iterations.
2) To build and test a prototype to detect a problem helpful for development team.
3) Lot of savings in terms of time and cost.
4) Increasing the probability of success.
5) Used also for learning, communication, integration and milestones.

Prototypes in New Product Development

For new product development project, prototypes play a key role to help engineers to make the final product to life for the first time and test it in market. There are many other reasons why using of prototypes in new product development.

1) To verify design functionality of the product.
2) Before the actual stages of production, helps to identify the critical issues as early as possible during the product development stages.
3) Reviewing of product shapes.
4) Possible to get feedback from customers if design changes needed.
5) Product samples are created for steps in parts and product approval process.

Prototyping process:

In conventional process of prototyping to develop a product is not easy to develop there is risk associated to costly iterations and probability of success is almost 70%. But in prototyping process the probability of success is increased which is almost 95%.

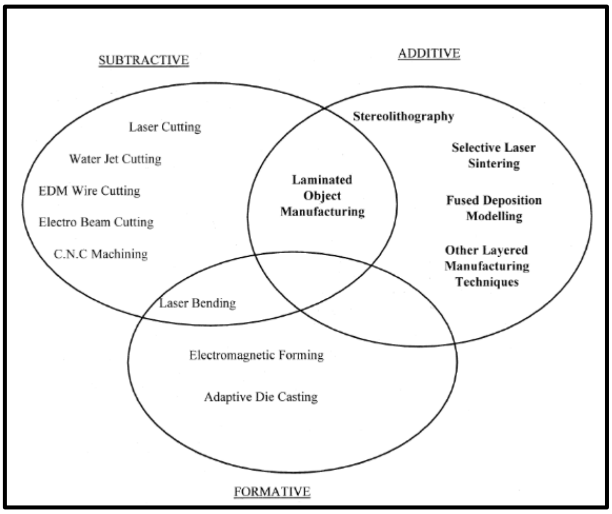


Fig 46: Manufacturing methods

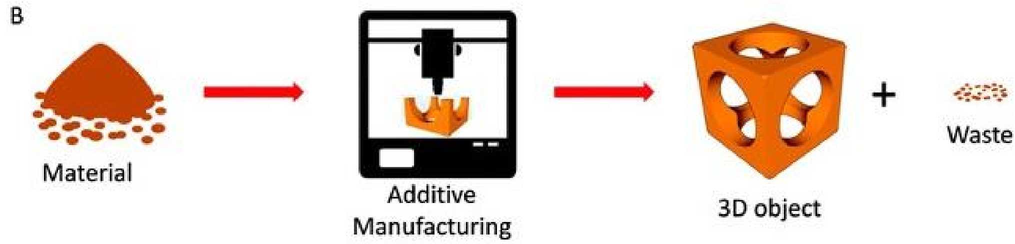


Fig 47: Additive Manufacturing method

Additive Manufacturing (AM) is composed of various technologies such as 3 D printing, Rapid prototyping (RP) etc. In Additive Manufacturing (AM) possible to produce a 3D objects by adding layer by layer of material by using various material such as plastic, metals, liquid, powder etc. to reduce the waste of material when compared to subtractive methods of manufacturing.

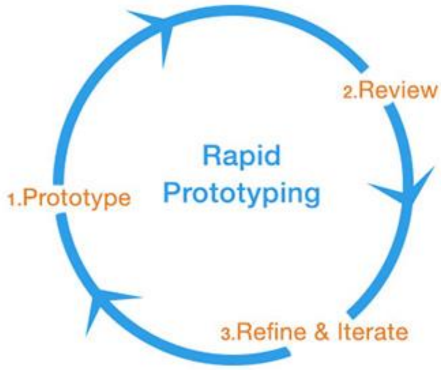


Fig 48: Rapid Prototyping Cycle

Above fig 48: shows a rapid prototyping cycle, produce a product by 3 D printing technology visualize the product, reviewing and verifying the product in terms of functionality. After performing several iterations by user experience the products to find out the defects, alteration in design, possible to change the overall design if needed.

Chapter 4

Development of Product and Process Design in PLM Platform

4.1 PLM software: ARAS Innovator

Nowadays, every companies transforming itself into a digital universe. Product Lifecycle management (PLM) technology is pivotal to applying digital to new product innovation and evolution

For developing new products in global competitive markets, PLM systems plays a vital role and help organizations in coping with the increasing complexity and engineering challenges. Moreover, PLM is the process of managing complex product and process information, engineering and manufacturing process workflows and collaboration with other departments.

As a solution for analysis of product and process design and for product lifecycle phases for product development, many IT software companies trying to sustain in markets by developing different solution for PLM software. Currently there more than 25+ PLM suppliers based on editor rating and aggregated user ratings mainly PTC Windchill, Siemens Team centre, ARAS PLM, SAP PLM, Dassault Enovia among others.

The most well-known and topmost User ratings is **Parametric Technology Corporation (PTC)** is a global technology US based company covering all key fields such as Automotive, Aerospace and Defence, Retail & consumer products, offering various solutions, technologies and Products.

PTC Windchill mainly in PLM provides better user experience, product related data such as technical product information, CAD models, documents, calculated product specifications. Moreover, it’s a compact package with all necessary tools for the transfer, distribution, visualization, and publishing of product data.

Among the most well-known suppliers is **Siemens Team Centre**, headquarters located in Texas, United States. Team centre PLM provides cross-domain product design, and simulation management through integrations with the MCAD, ECAD, software development, and simulation tools. Main key advantages in Siemens Team centre PLM is to analyse and validate 3D designs created from multiple CAD systems.

On the other hand, **ARAS Corporation** is an American developer and publisher of product development software is ARAS Innovator. From 2007, onwards providing ARAS Innovator for free as open source software with all product lifecycle management business processes. The product is used for product lifecycle management (PLM), Advanced Product Quality Planning (APQP), lean product Development, product quality control, collaborative product development and mainly for new product introduction (NPI).

SAP PLM is a German multinational software company, headquarters in Walldorf, Germany. SAP introduces SAP PLM in 2005, this application provides 360 – degree – support for all product – related processes from the first product idea, through manufacturing to product service.

Finally, **Dassault Systemes SE**, the 3D experience company, is a French Software Company. Dassault Systemes acquired full ownership of 3D PLM software Ltd. (3D PLM), joint venture in India with Geometric Ltd. ENOVIA enables the early visibility to product data and related design information before final product decisions.

In next section more detailing about ARAS software, general overview of ARAS Innovator showing all different sections helpful to create based on our needs. Moreover, it has several different modules such as Program Management for managing, controlling, monitoring all the data related to projects. In design contents it includes part and product design. In Documents CAD documents related to parts and products design. In terms related to quality, quality management system related to design and process quality documents to support the quality control, measures and other quality related to product. In Manufacturing Process Plan (MPP) defining all the operations with specific tools, machines, skills etc., creating Manufacturing BOM (MBOM) & Engineering BOM (EBOM).

4.2 General Overview of ARAS Innovator

In this section 4.2 implementing all data related to each phase of product life cycle. Apart from that, to get some insight of ARAS Innovator starting from general overview of ARAS.

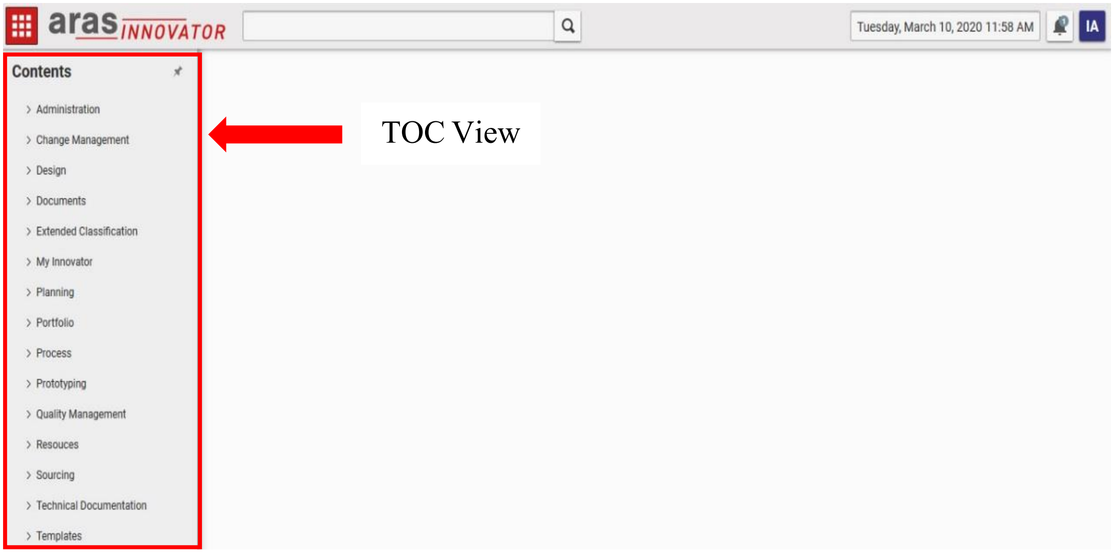


Fig 49: General Overview of Table of Contents (TOC View).

From the above fig: 1.50, shows the general table of contents (TOC view) shows some main contents of the various modules. The Design is main content view of TOC which has two sub contents such as parts and products design. There are many other several modules that are required to develop new product development process in PLM platforms. In the next upcoming sections, I used various modules such as program management (PM), Quality management system (QMS) etc., of ARAS Innovator in order to implement all the data in PLM platform.

4.3 Program Management in ARAS

The program management module of ARAS is to design the project with phases of new product development of product “Sliding Door Trolley”. There are some contents under the portfolio. In my thesis I used contents of ‘Portfolio’ with sub – contents such as ‘customer’, ‘program’ and ‘projects’. [14]

- Customers – to know about which project belongs to which customers entering all details such as company name, address, mobile numbers and all details related to customers.
- Program – Manage and view projects and processes.
- Projects – defining all data related to project, name, scheduled start & scheduled finish, phases etc.

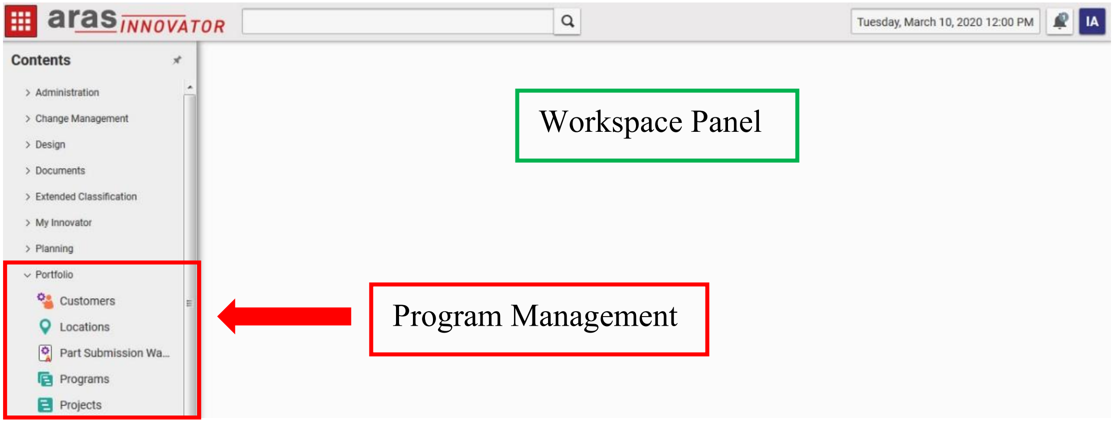


Fig 50: Program management module view

Select create new project option to enter data related to project, dates, project number etc.

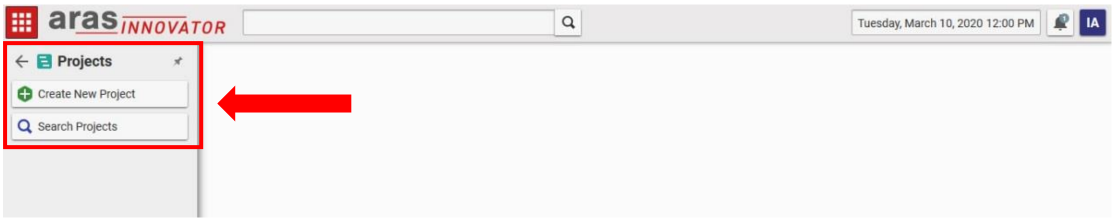


Fig 51: Defining Projects

Fig 52: Project structure overview

In ARAS, it's possible to create the sub-phases for each phase of new product development with appropriate target start and target finish, scheduled start and scheduled finish. In addition, it's possible to defining all the users according to roles and responsibilities for each specific phase.

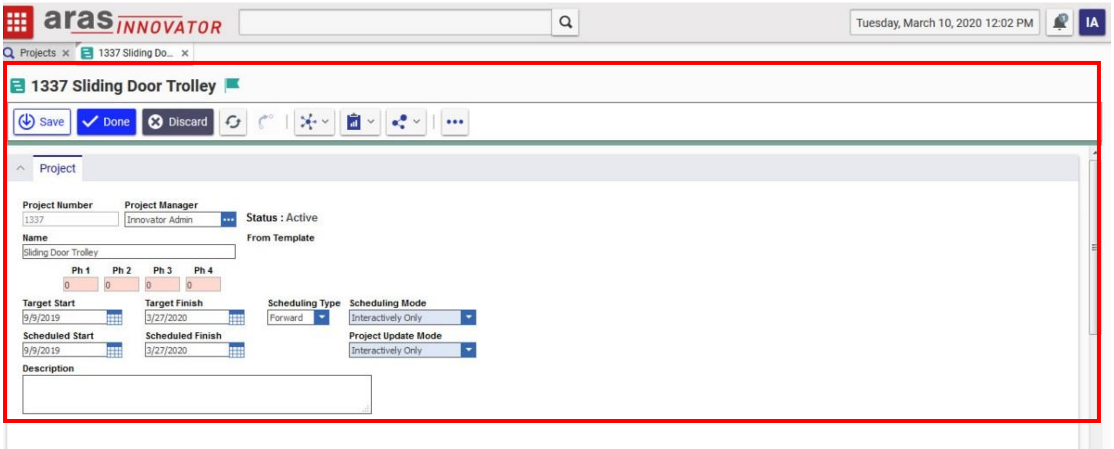


Fig 53: Project over all structure view

From below fig 54 here I defined the 4 phase of Product “Sliding Door Trolley”, enter all the dates such as plan start and plan finish.

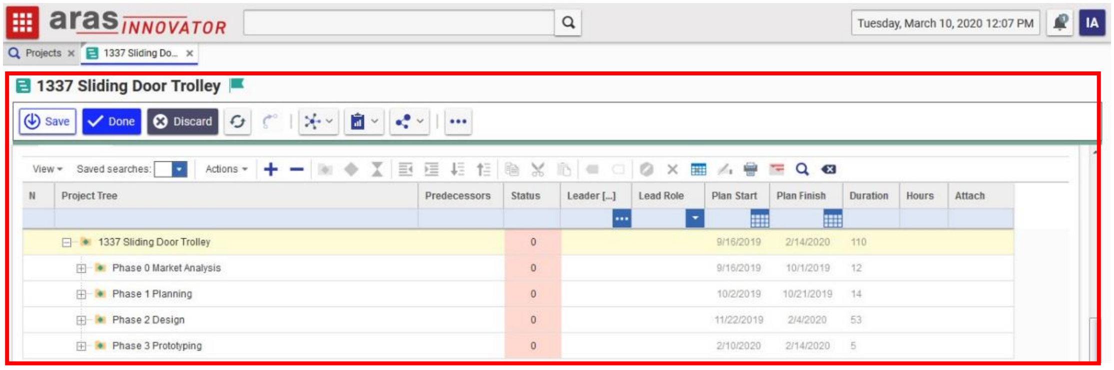


Fig 54: Project main phase view

Parallelly, attach the documents in various formats in PDF, Word, Excel etc. in the project deliverables.

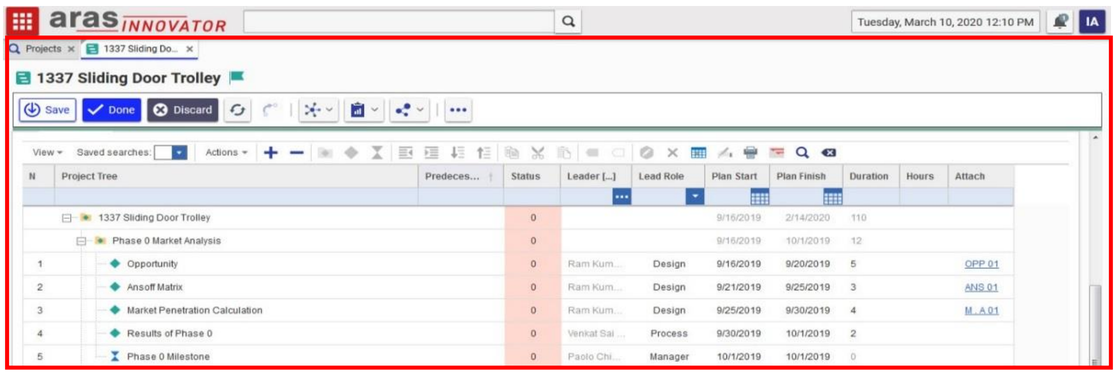


Fig 55: Sub phase view of Market Analysis

- Defining sub phase opportunity, Ansoff matrix etc. with plan start and plan finish. In addition to that, add lead role for each sub phase such as design, process and manager role of Phase 0 market analysis. From the below fig 56, I added all the remaining phases and sub phase with appropriate details required for project management.

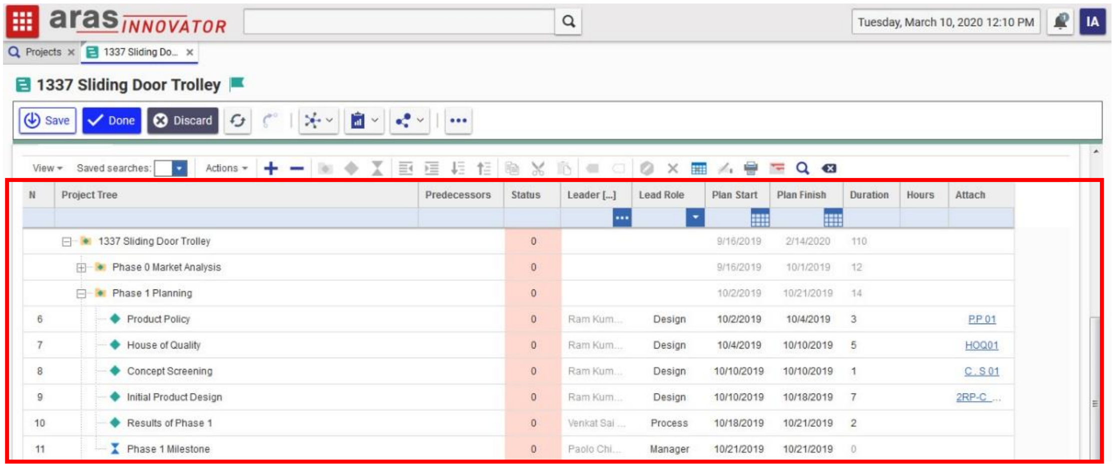


Fig 56: Sub phase view of Planning

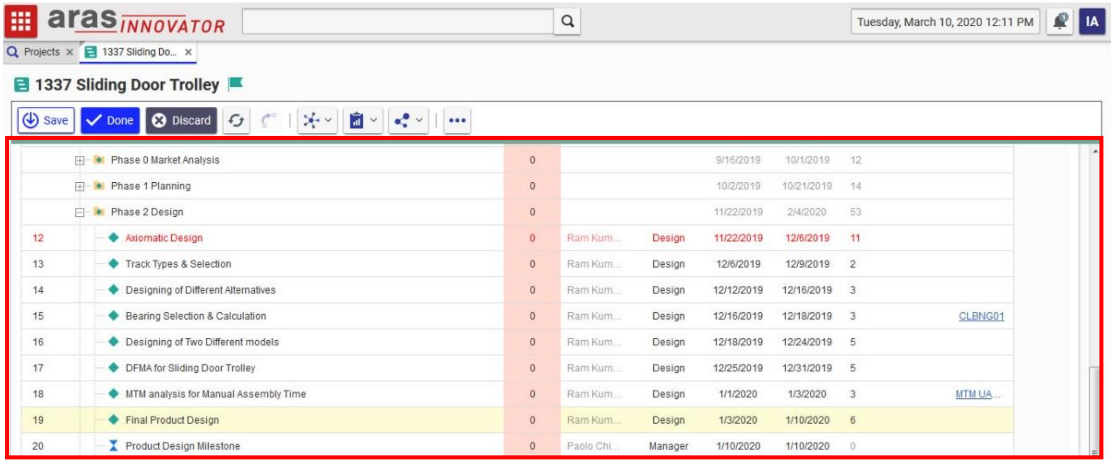


Fig 57: Sub phase view of Design

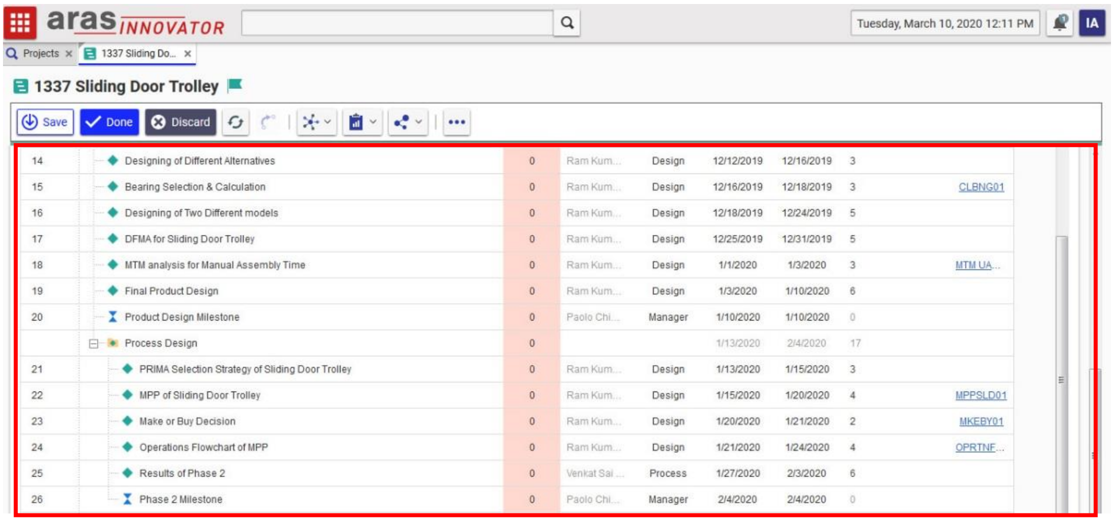


Fig 58: Sub phase view of Design

At last, in program management (PM) module all required details are added in this module for tracking, updating in regular intervals. Work is allocated to user when once it's done and status will change with respect to that user who is in charge for subphase work.

In table of contents (TOC) view, in 'documents' section, there are two types of documents called 'CAD documents' and 'Documents'. This general document type is differed from technical documents module. In general document type create different document types mainly used to attach the documents in each module especially in Program Management (PM) module in attach options add the documents types such as word, excel, solid work file etc.

4.4 Documents in ARAS

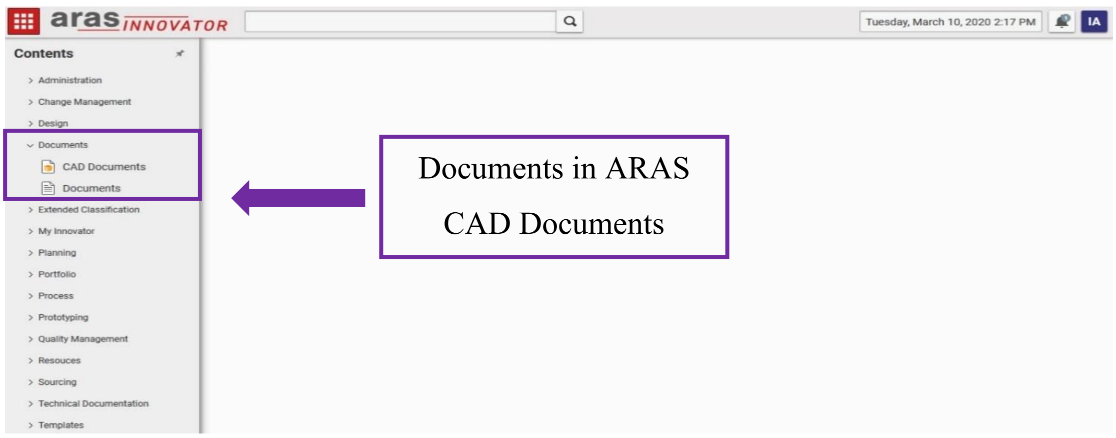


Fig 59: Overview of Documents

For both Document types CAD and documents type need to mention reference document number, name, types, authoring tools such as word, excel etc. short description of documents will added.

For the product Sliding door trolley, I added all CAD documents with native file of original documents and Viewable file of CAD document. In the below fig 60 & 61 attach all the documents of parts and products which can be used for various module of ARAS module in Process Plan, design also.

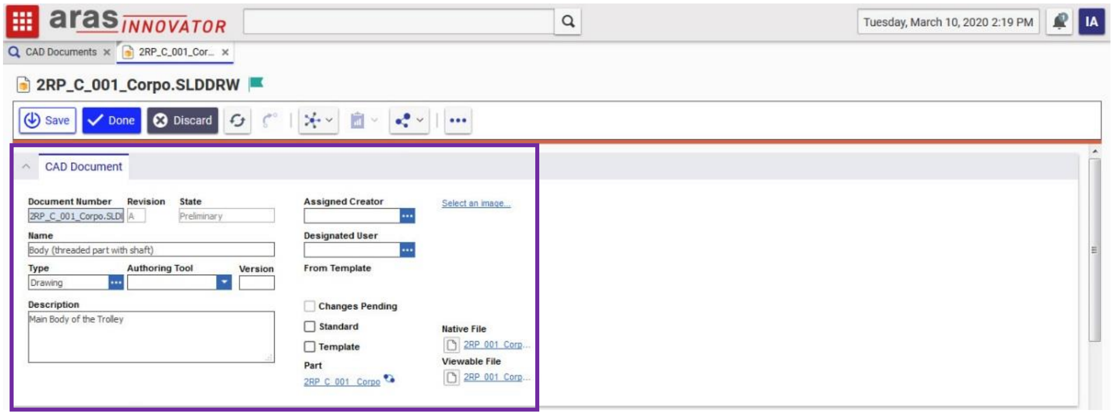


Fig 60: CAD Document general view

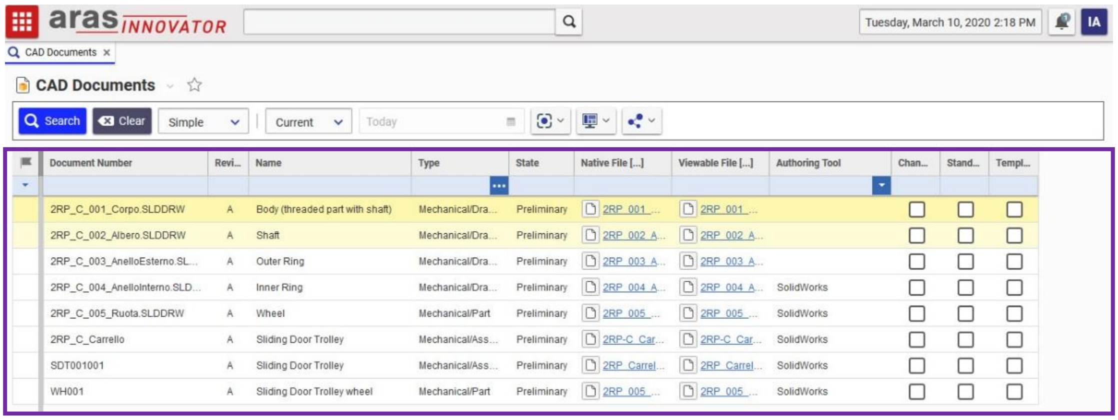


Fig 61: Different CAD documents attachments

The main difference between CAD documents and Documents is that possible to add only CAD file, but in documents add all types of documents in any general format mainly in word, excel documents type.

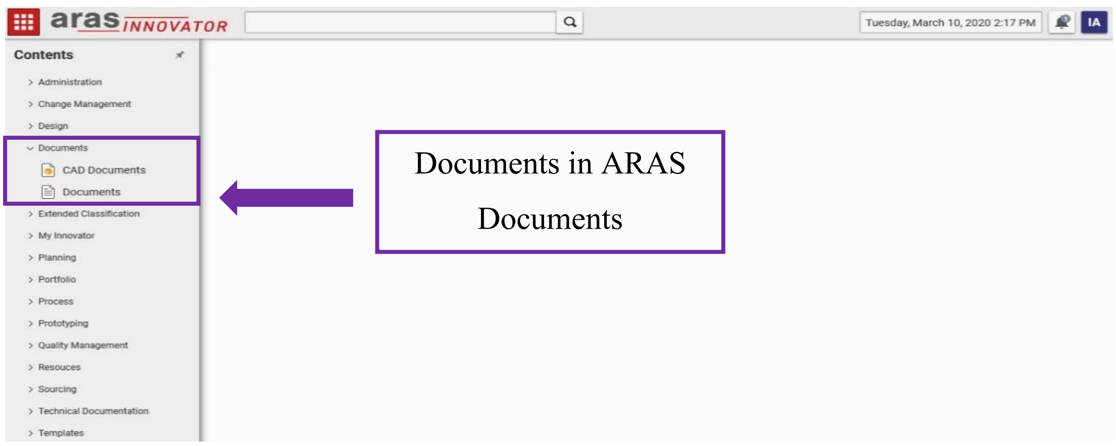


Fig 62: General Documents TOC view

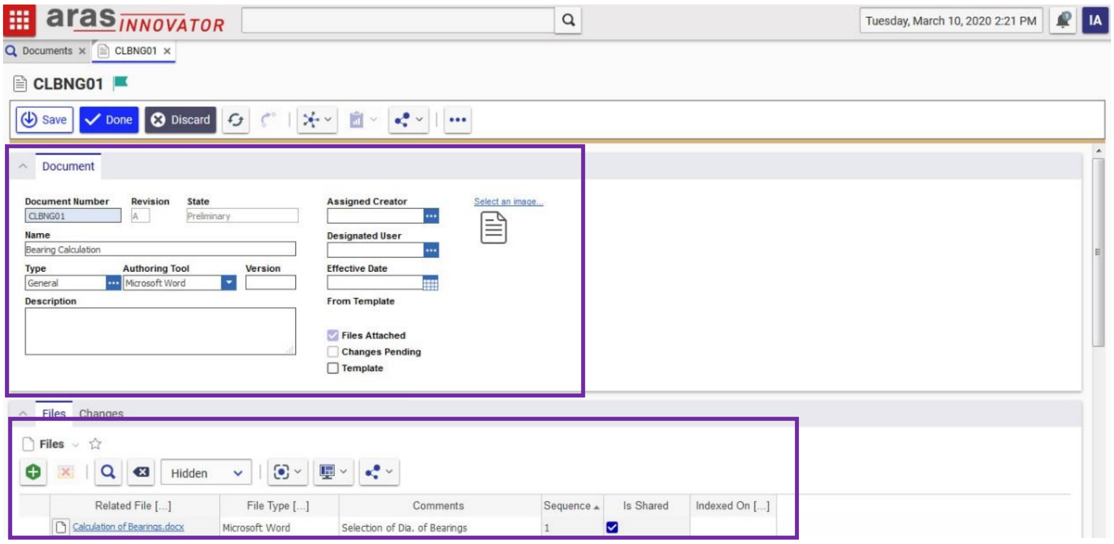


Fig 63: General documents overview

From the below fig 64 shows some of documents type that I used and upload in ARAS for reference.

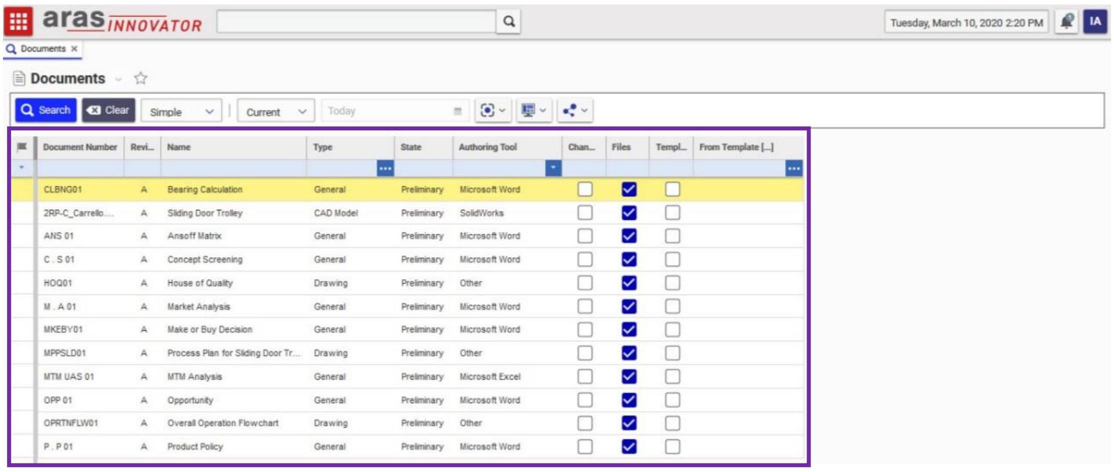


Fig 64: Attachment of different documents

4.5 Design in ARAS

In Design contents there are parts design and product design. From below fig 65 shows parts design.

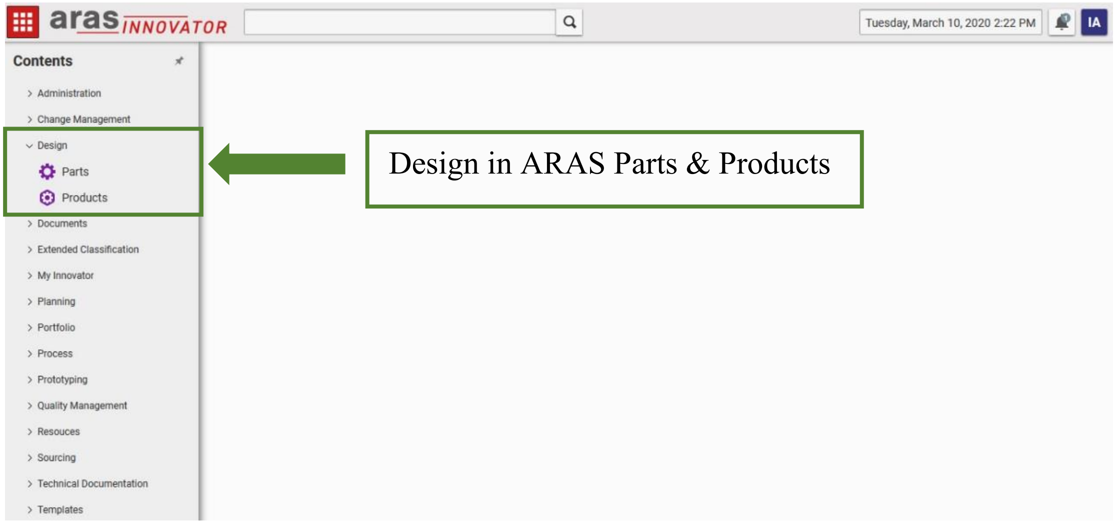


Fig 65: General design TOC view

From the below fig 66 the green box shows all the details of the parts for product "Sliding Door Trolley".

- Part Number – 2RP_C_000_ Carrello is one part of the "Sliding Door Trolley".
- Name - Part Name of the product.
- Type – defining type of part. i.e., component part or assembly part.
- Units – In pcs or EA.
- Make or Buy – Whether the part be Making or Buying the parts.

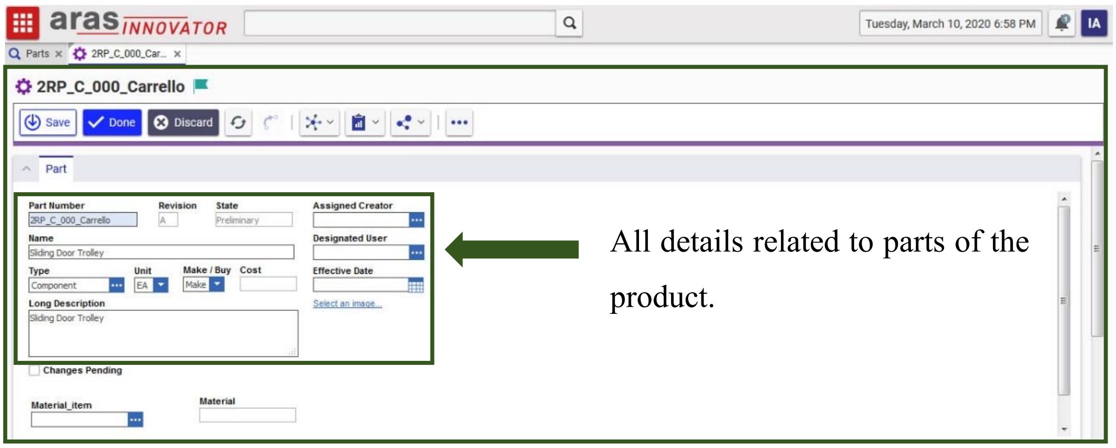


Fig 66: Part design detailed view

- The above same procedure has followed to add different parts of the products "Sliding Door Trolley".

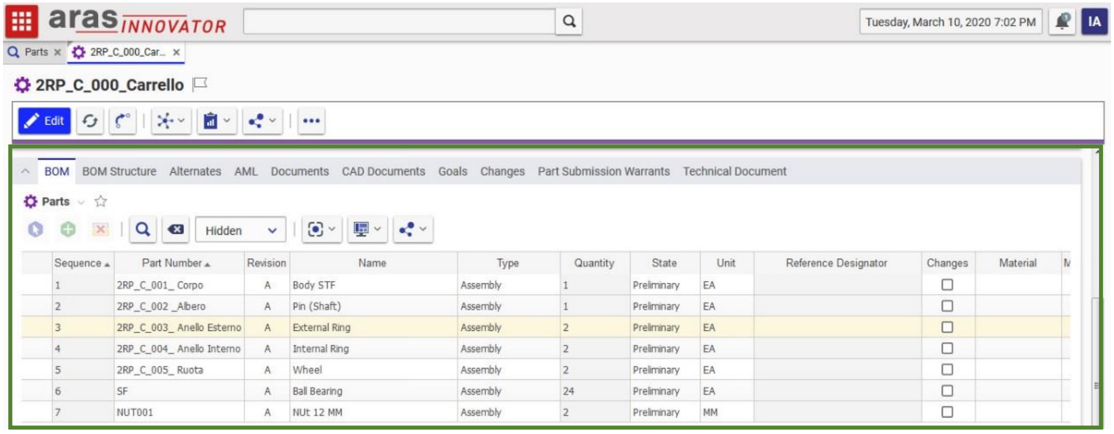


Fig 67: Different parts view

- In product design, defining the product variants. Since the product and parts has varied from different configurations for example 2 wheels or 4 wheels configuration product has different design and part number has increases or decreases based on product design.

Fig 68: Product design TOC view

- Product ID – SLD001001 for 2-wheel configuration model type.
- Name – Actual name of product "Sliding Door Trolley".
- Description – Short description of the product.
- Model number – SLD001001 is belonging to 2 wheels configuration models of "Sliding Door Trolley".

Finally, other options are available attachments – to attach product related documents and Design FMEA to attach quality related documents of the product.

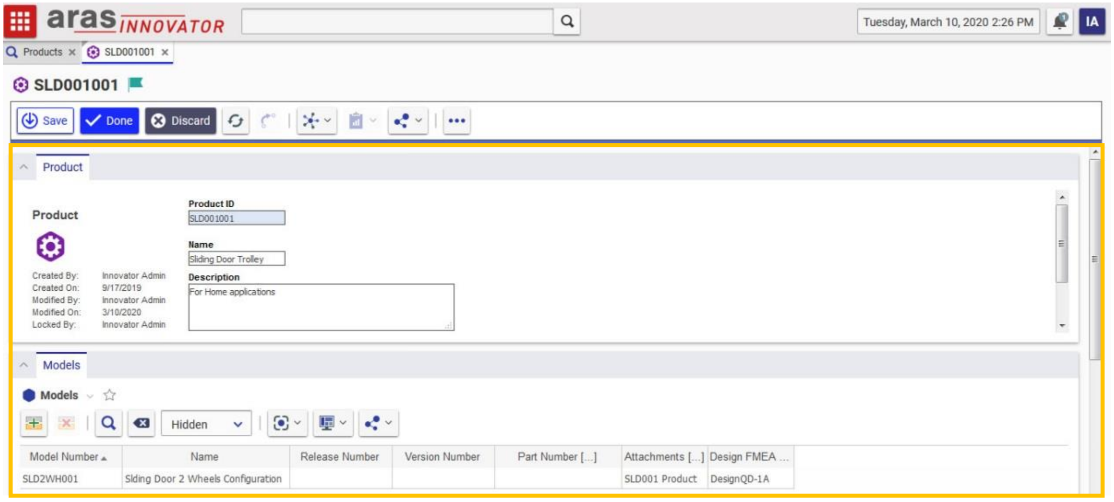


Fig 69: Product design detailed view

4.6 Technical Documentation

In Technical documentation module, adding details related to parts and products of "Sliding door trolley". In the below fig 70 shows the sub contents of Technical documents such as

- Document Types – Standard Documents or MPP Standard.
- Graphics – Add the Images of parts and products.
- Technical Documents – add all details images, Item info, name, ID etc.

Fig 70: Technical documents TOC view

- In below fig 71 shows the parts of "Sliding Door Trolley" graphics name, number and related images. For example – 2RP_C_001_Corpo.

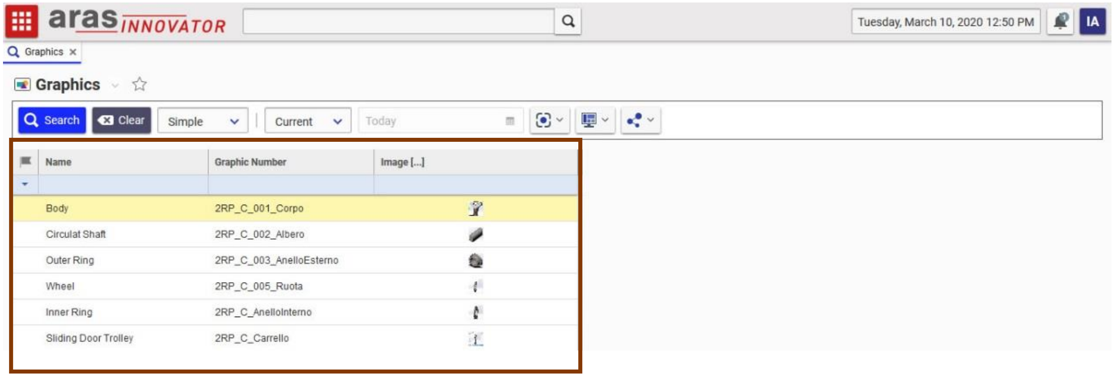


Fig 71: Various technical documents

Here some of the fig 72 show an overall view of technical documents with detailed one.

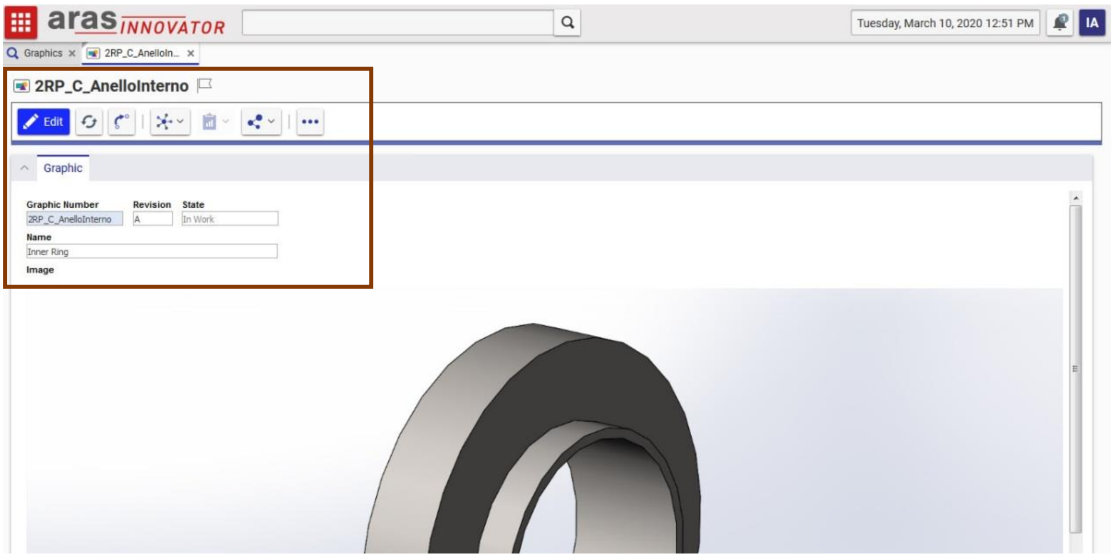


Fig 72: Detailed view of Technical documents

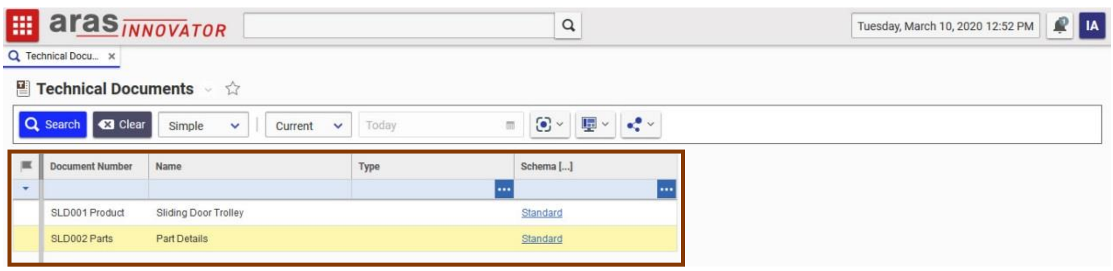


Fig 73: Product & Parts technical documents

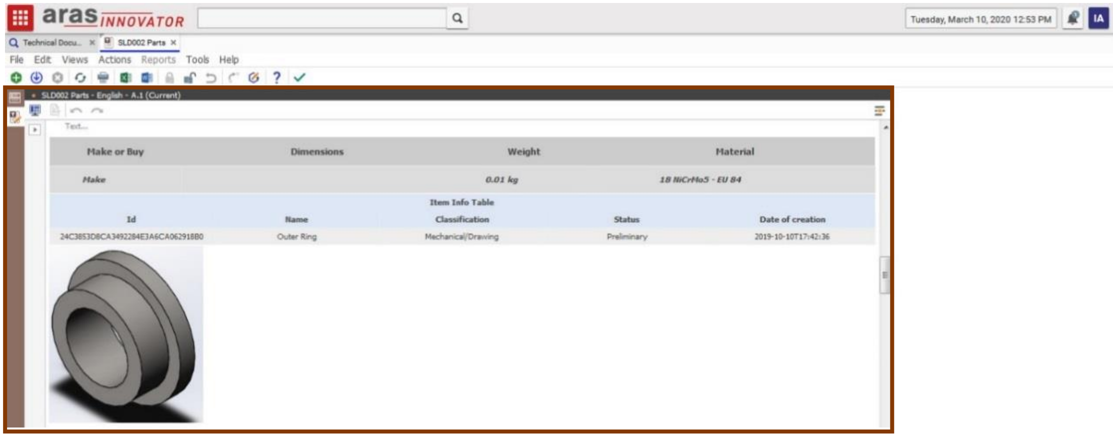


Fig 74: Parts technical documents

As a result, in technical documents module, I added standard document type for both parts and product of "Sliding door trolley" includes part dimensions, weight, material types and document ID.

4.6 Quality Management System

In Quality Management System (QMS) adding quality documents such as Failure Mode Effective Analysis for design i.e., design quality documents in ARAS. Creating the DFMEA documents in ARAS, for all parts such as wheel, internal ring and external ring to identify the potential failure mode, effects and cause with predefined selection table in ARAS.

Fig 75: Quality Documents

- Design Quality Documents – Design QD-1A for parts
- Design Quality Documents – DSGNQD – 1B for complete product.

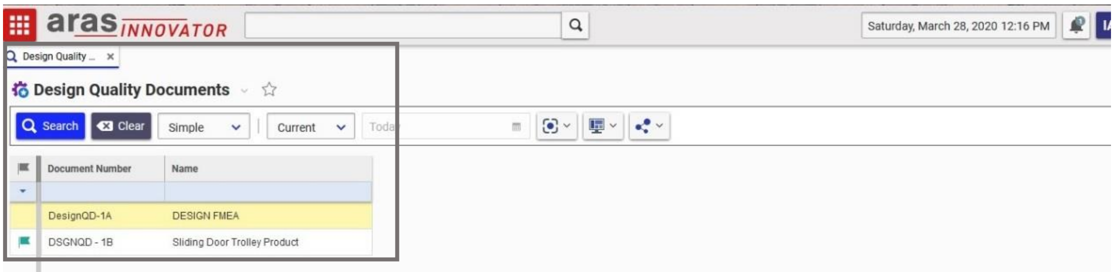


Fig 76: Design Quality Documents

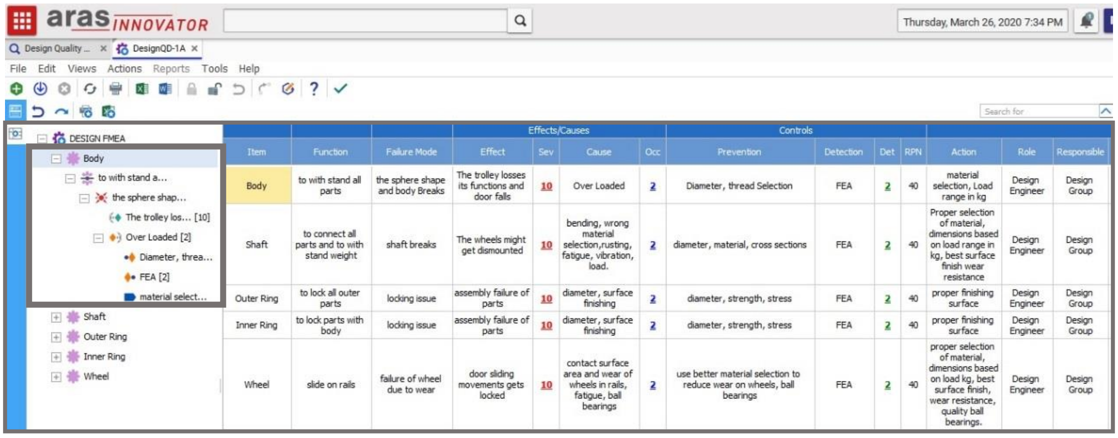


Fig 77: Design Failure Mode Effective Analysis for Parts

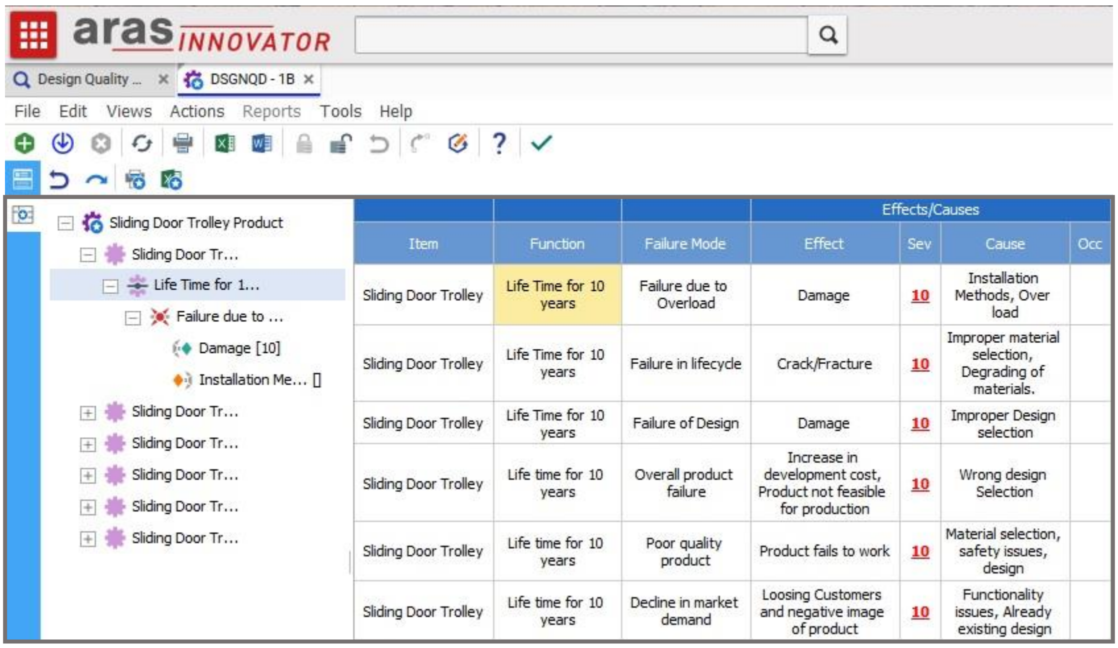


Fig 78: Design Failure Mode Effective Analysis for Complete Product.

From fig 76,77,78 shows the overall view of quality documents by using predefined options adding ‘item’, ‘function’, ‘Failure mode’ and ‘severity rank range’ by predefined selection table.

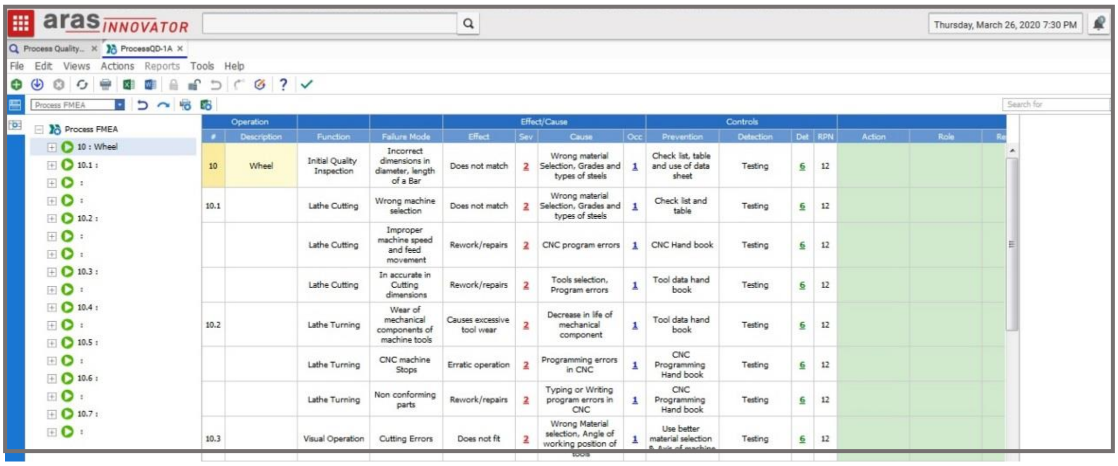


Fig 79: Process Failure Mode Effective Analysis

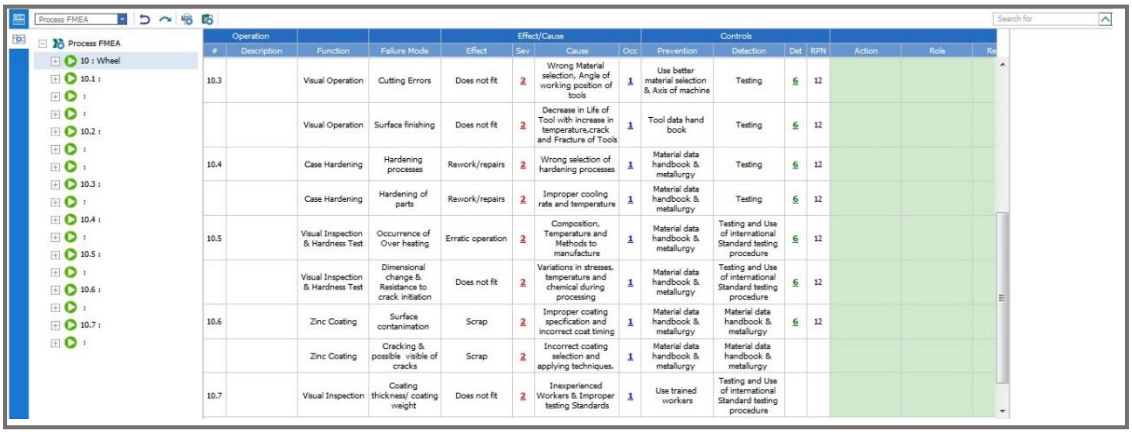


Fig 80: Process Failure Mode Effective Analysis

In this thesis, I similarly created Process failure mode effective analysis for manufacturing the complete product “Sliding Door Trolley”, “operation number’, ‘description’, ‘function’, ‘failure mode’ etc. that are clearly mentioned in fig: 1.80,1.81.

4.7 Manufacturing Process Plan in ARAS

Manufacturing process plan (MPP) module helps to create Manufacturing Bill of material (MBOM) means to make up “end item” and Engineering Bill of material (EBOM) driven from CAD tools, I created the Process Plan (PP) by defining machines, tools, skills that are needed for producing the product. From the below fig 81 it shows the basic details need to add while creating new process plan.

Fig 81: Process Plan Creation

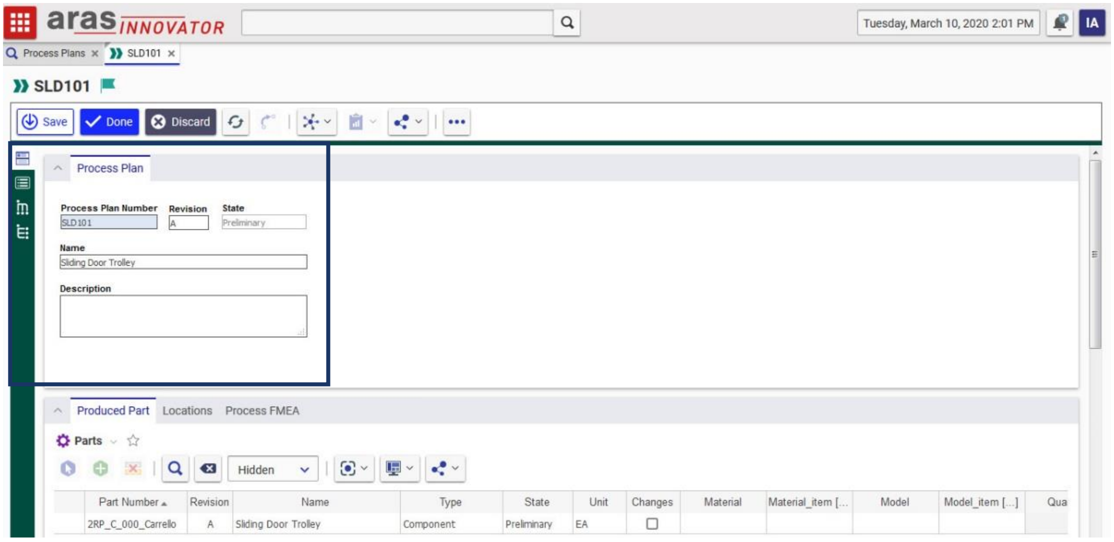


Fig 82: Process Plan SLD001 "Sliding Door Trolley".

In this thesis I created Process Plan with, each part operation. Product which I defined is "Sliding door trolley", which have 7 parts out of which 3 parts must produce internally such as wheels, internal ring and external ring these are make products.

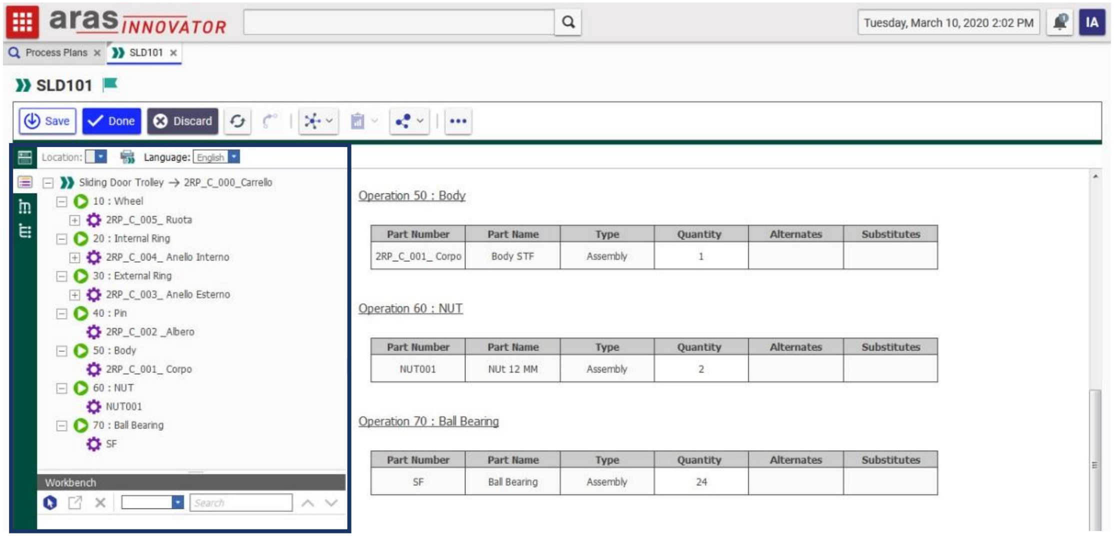


Fig 83: Process Plan SLD001 for Product Operation

From the below fig 84 shows the Manufacturing Bill of Materials for product "Sliding Door Trolley", defining the parts of various which item types like assembly, component or phantom and also quantity of parts, consumables and work instructions (W.I) for each operation types are required for manufacturing. In my thesis of Product development process, defining the operations for example: 2RP_C_005_Ruota.

- BAR_AVP is a component operation name is Lathe Cutting, required quantity is 2 and used in Operation 10.

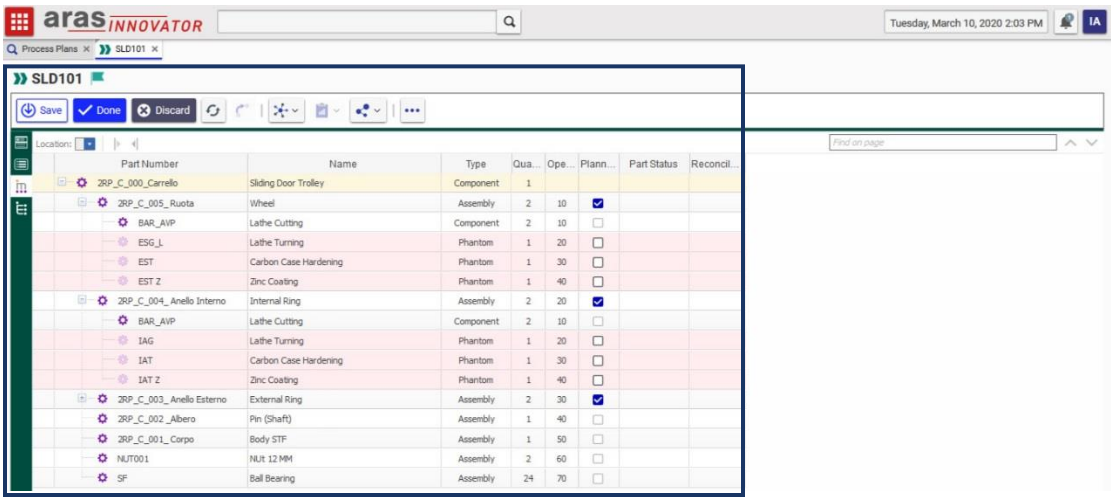


Fig 84: Manufacturing Bill of Materials (MBOM)

- Engineering Bill of materials (EBOM), which is directly driven from CAD tools, it also contains list of parts, components must need for make up the design. Both MBOM and EBOM are to help increase in engineering productivity and improvement in production.

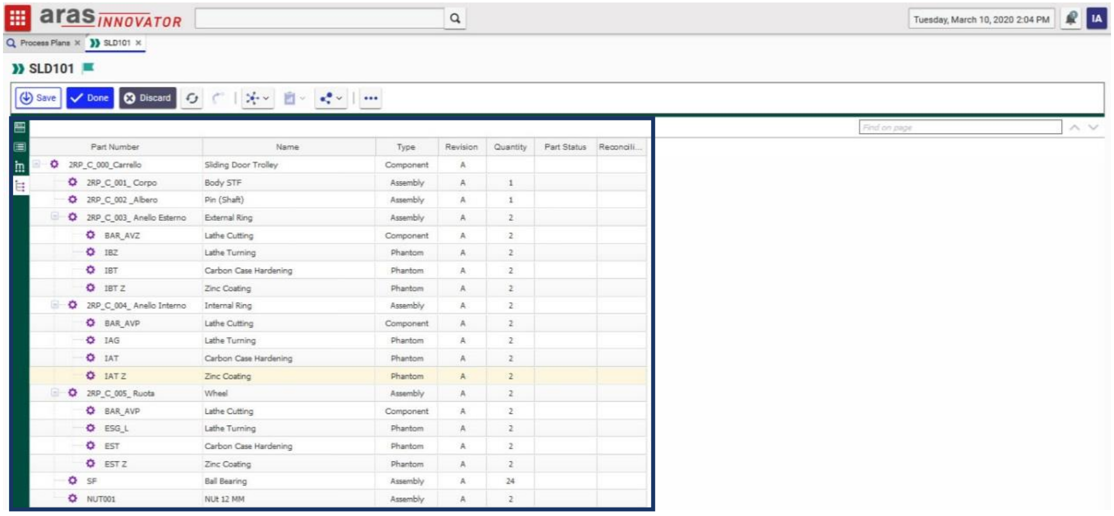


Fig 85: Engineering Bill of Materials (EBOM)

Once I created the MPP for whole product development, here I created process plan (PP) for each part. Defining process plan number INTR01 for wheel manufacturing process in fig 86 process plan for parts.

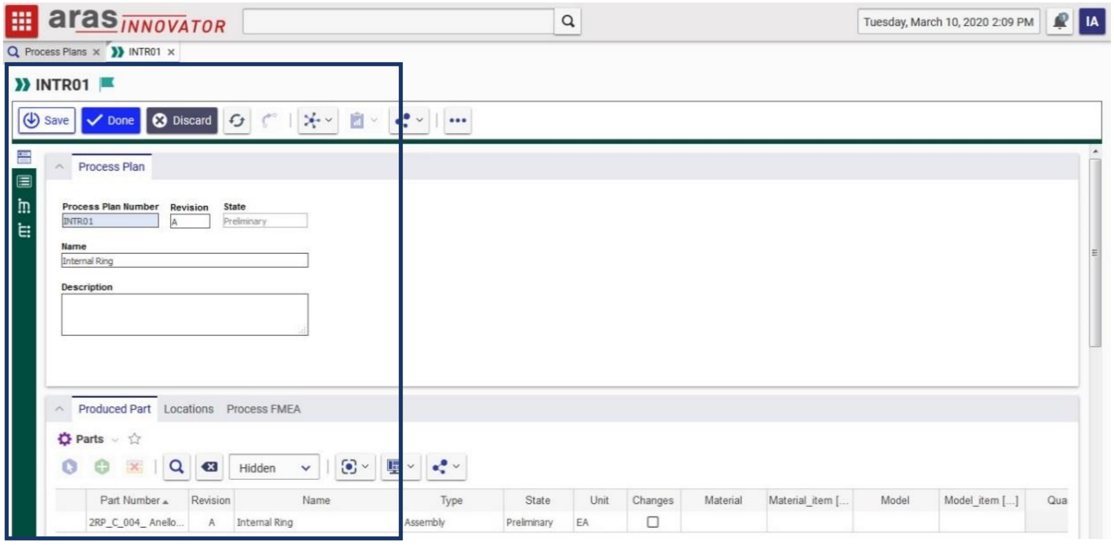


Fig 86: Process Plan for Parts

From the below fig:1.88 Process plan for a part called for wheels operation which includes OP 10 for Lathe cutting process defining parts, tools, machine required to do this operation 10. Parallelly, in right side defining all part details such as part number, part name, type of parts, quantity needed and possible to give all operation details as text helpful for operator who is going to handle this operation.

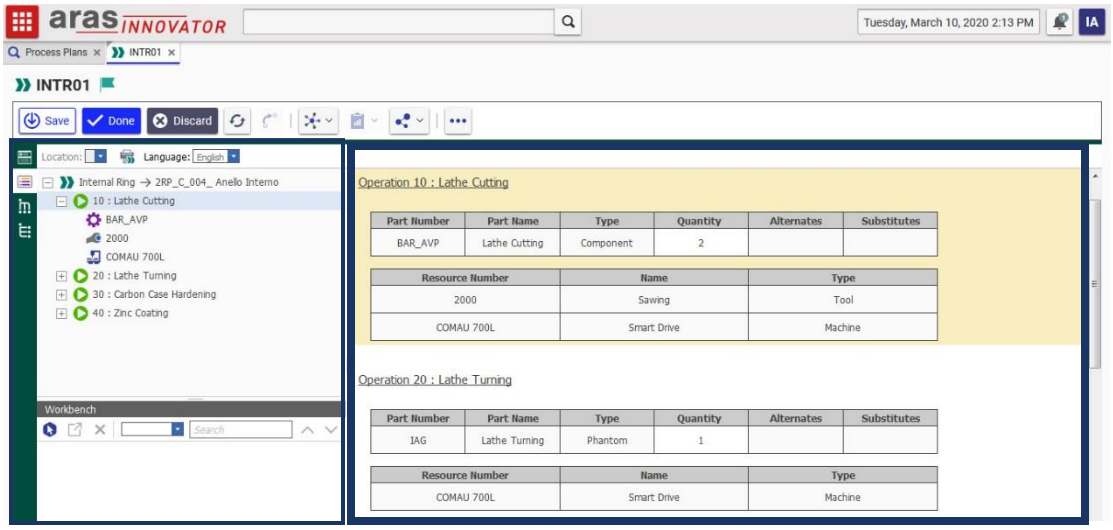


Fig 87: Process Plan for Part Operation

From the below fig 88 Manufacturing bill of materials (MBOM) and fig 89 Engineering bill of materials (EBOM) created for parts in product "Sliding Door Trolley".

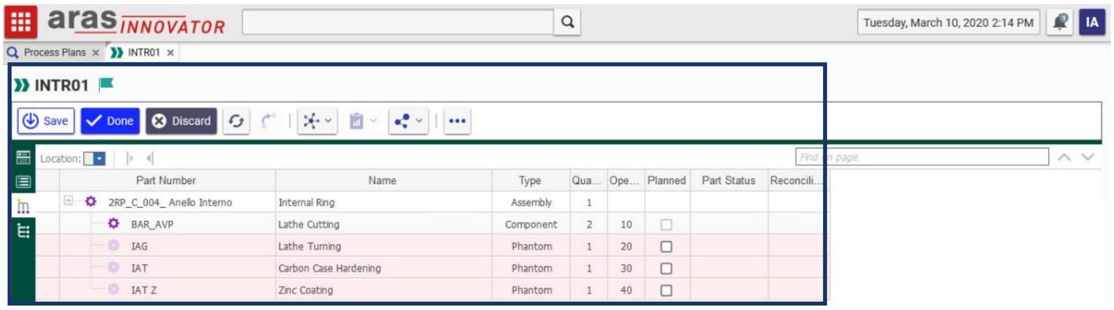


Fig 88: Manufacturing Bill of Materials (MBOM)

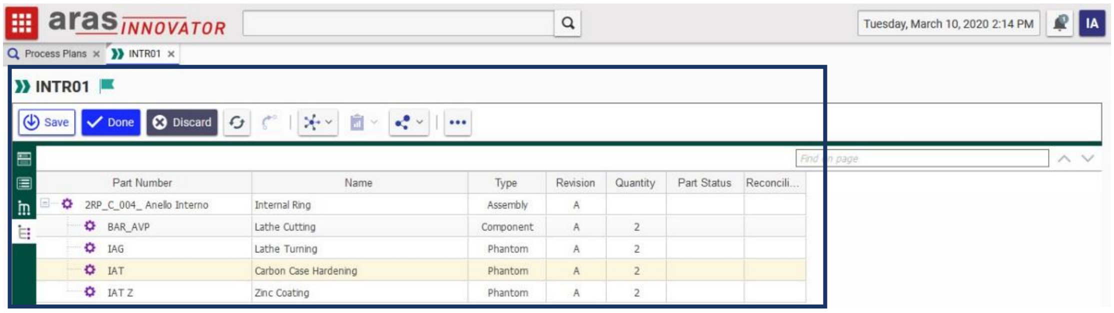


Fig 89: Engineering Bill of Materials (EBOM)

Once implement all data in that module, ARAS platform provides a provision for users who can do login into ARAS by creating Identities and to give permissions to that Identities who can do the work in that module.

Fig 90: Identities Creation

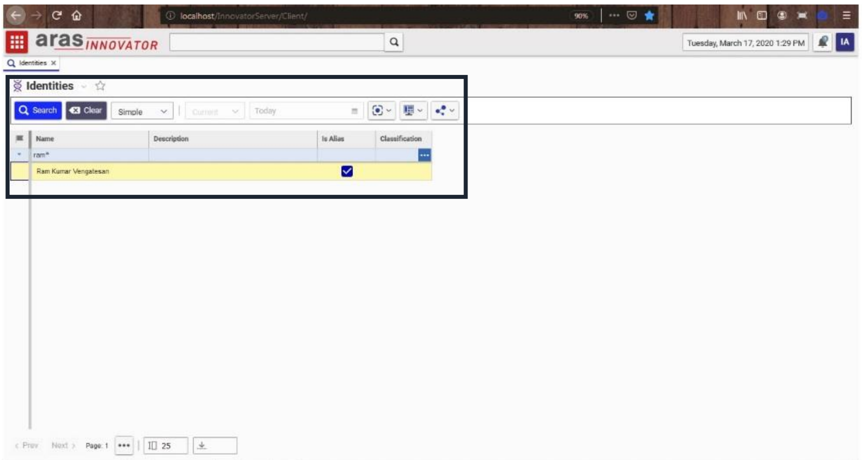


Fig 91: Identities Creation

Fig 92: Identities Creation with Password

For example, in Design, designer can work for long time, and quality departments partially involved in that. Similarly, Manufacturing process designer, quality, production department also involved in that. So, restrict the use of all used and providing users with all permissions by creating “Username & Password” for login.

In Program management module, at the time of creation of each phase providing the lead role options to assign the work for each one. For example, designer can do work at this phase and in next phase process and finally the manager for decision making of overall phase of project.

Chapter 5

Conclusion

As a result of the thesis, understanding the importance of new product development process in both companies and manufacturing industries. Due to increasing in population customer needs are increasing, and introduction of new product in the market at proper time is very important. Parallelly customer needs and expectations are drastically increased, so the industries are giving more and more importance in New product development or Introduction.

In this thesis, I done NPD process for the product "Sliding Door Trolley", creating PLM cycle, selecting best business strategy to analysis the market trends. Designing the product by best design approach by axiomatic design by applying Axioms and design principles to make as a perfect design. Design of different alternatives parts possible to make some design solutions. Supporting the design process by applying Failure mode effective analysis to understand the possible failure mode and effects to avoid overall failure of the product. Creating best manufacturing process plan, material selection process, operation flowchart to support for production.

After obtaining various results from each phase of Product Lifecycle Management (PLM) cycle. All the data and information related to product, that are stored in PLM platform ARAS Innovator, so that possible to update the data if necessary.

My thesis is one of the ways for New product development by applying various methods, models, principles to get an approximate result for the product "Sliding Door Trolley". Moreover, it forms the base for future thesis work who are interested to work in the area of New product development and in PLM platform.

Bibliography

[1] A. a. H. Booz, “New Product Process,” in *New Product Process*, NewYork, 1982.

[2] J. Stark, Product Lifecycle Management 21st Century Paradigm for Product Realisation, Geneva, Switzeland: Springer, 2011.

[3] I. A. Saaksvuori .A, "Product Lifecycle Management", Verlag Berlin, Heidelberg: Springer, 2004.

[4] Z. A. V. G. I. V. Anja ORCIK, “PLM as a Framework for New Product Development,” *ANNALS of Faculty Engineering Hunedoara - International Journal of Engineering,* pp. (373 - 378), 2012.

[5] M. A. &. B. M. Enrico Vezzetti, “New product development (NPD) of "Family Business" dealing in the Luxury Industries,” *International Journal of Fashin Design, Technology and Education,* pp. (219 -229), 2016.

[6] S. D. E. Karl T. Ulrich, Product Design and Development, New York: McGraw Hill Education., 2016.

[7] N. P. Suh, Axiomatic Design Advances and Application, New York: Oxford University Press, 2001.

[8] P. C. o. Technology, Design Data: Data Book for Engineers., INDIA: Kalaikathir Achchagam, 2012.

[9] D. E. Library, “Machine Design Data Book,” McGraw Hill Education, 2004.

[10] P. D. W. A. Geoffery Boothroyd, Product Design for Manufacture and Assembly, New York: CRC Press, 2011.

[11] G. J. S. J. L. S. Harold Bright Maynard, Methods Time Measurement, New York: Mc Graw Hill Book, 1948.

[12] Ford, Failure Mode and Effective Analysis, Ford Motor Company, 2011.

[13] J. B. K.G. Swift, Manufacturing Process Selection Handbook, U.S.A: ELSEVEIR Ltd., 2013.

[14] P. M. Institute., A Guide to the Project Management Body of Knowledge., USA: Project Management Institute., 2000.