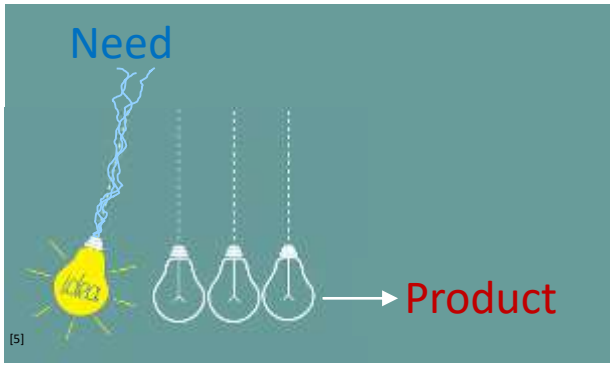
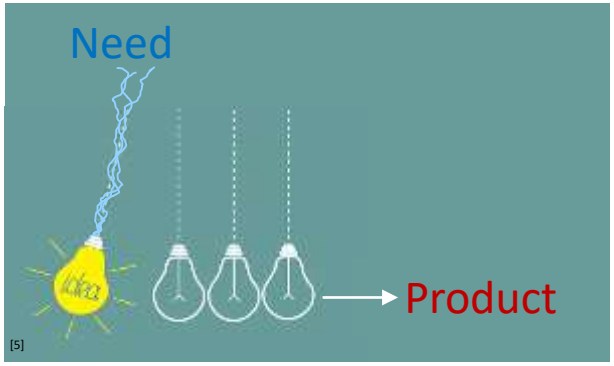
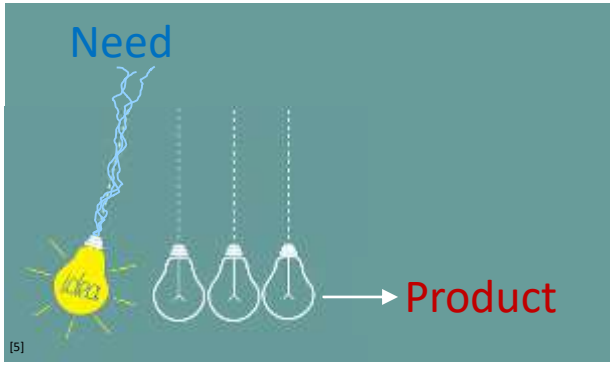
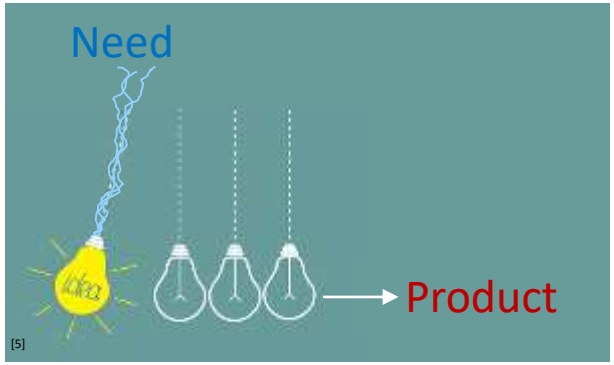


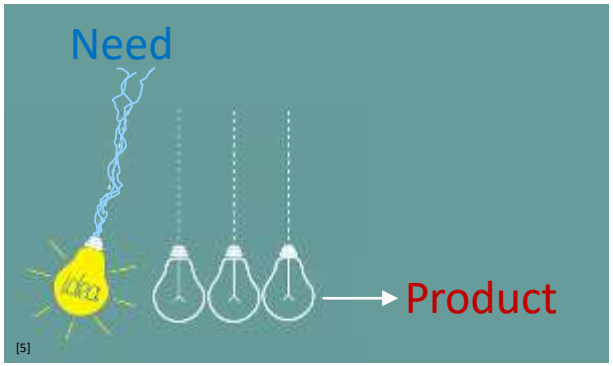
Machine Parts I

Introduction









Łukasz Jedliński

Definitions

Engineering design is a flexible process of thinking and selecting the innovative and creative ideas to fulfill the perceived need [Jadon 15].

Mechanical design have the same goals that engineering design but do not concern about electric and electronics aspects of products.

Machine elements (parts) its an integral part of mechanical design and focus on a single parts of machines and their collaboration.

Need, form a marketing point of view, it is a product (thing or service) that someone wants, which is necessary for life or to fulfill desires.

Introduction

Types of design according to the knowledge about products:

Adaptive design
Minor modification of existing product to adapt parameters or some functions to required task.

Volkswagen Passat B5 pre-facelift
[htthttps://pl.wikipedia.org/wiki/Volkswagen_Passat]

Volkswagen Passat B5 post-facelift
[htthttps://pl.wikipedia.org/wiki/Volkswagen_Passat

Development design
Major modification of existing product to achieve parameters or functions which where not available

Toyota RAV4 IV
[https://www.motortrend.com/news/2019-toyota-rav4-hybrid-why-id-buy-it/]

Toyota RAV4 V **Hybrid**
[https://www.motortrend.com/news/2019-toyota-rav4-hybrid-why-id-buy-it/]

New design
Innovative process based on scientific principles where research is the standard step. The final product is unique.

Buckboard Wagon
[https://blog.newspapers.com/horse-and-buggy-the-primary-means-of-transportation-in-the-19th-century/]

Nicolas-Joseph Cugnot - French inventor
1769 (small version) - First self-propelled mechanical land-vehicle, steam engine
[https://pl.wikipedia.org/wiki/Nicolas-Joseph_Cugnot]

Karl Benz – German automotive designer
1885 - First car with an internal combustion engine
[https://en.wikipedia.org/wiki/Benz_Patent-Motorwagen]

Mechanical design process

Why mechanical design process is important?

Main function is not meet. Most of the light is aimed at the sky.
This is the cause of:

- low efficiency because more power is needed to achieve the same level of light near the ground,
- it will always be not very bright under the lantern,
- light pollution.

The proverb „the darkest place is under the candlestick” in true for this lantern.

Fig. Popular old type of street lamp

Fig. Example of modern lamp

Mechanical design process

Why mechanical design process is important?

„BMW hit by $10 million fine in South Korea over engine fires crisis", 172,000 affected vehicles [https://edition.cnn.com/2018/12/24/business/bmw-south-korea-fine/index.html]

Fig. „A BMW 520d (2015) catches fire on road in Hanam, Gyeonggi-do, South Korea, August 12, 2018.[Photo/VCG]" [http://www.chinadaily.com.cn/a/201808/14/WS5b727df6a310add14f385b23.html]

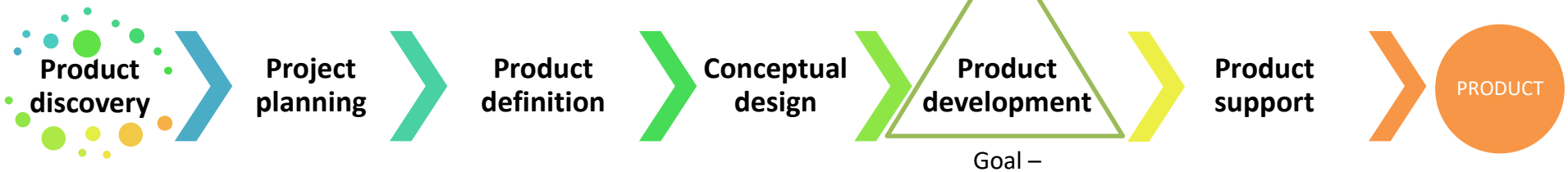
Fig. The Elephant with Horse's legs and the offset column [https://interestingengineering.com/21-engineering-and-design-failures]

Cause: defect in exhaust gas recirculation unit (EGR). „But the transport ministry said the problem was the result of a design deficiency, which BMW denies." [https://edition.cnn.com/2018/12/24/business/bmw-south-korea-fine/index.html]

Fig. Saint Francis Dam Disaster [https://thehill.com/opinion/energy-environment/360712-worst-engineering-failure-in-us-history-made-us-safer]

Fig. [https://en.wikipedia.org/wiki/St._Francis_Dam]

Mechanical design process



- **Key factors:**
- Market pull.
- Technology push.
- Product change.

Goal – plan of product development in a timely and cost-effective manner

- Goal – identify the customer group and their needs.
- Develop specification and requirements.

Goal – develop a concepts that will fulfil and confirm the functions

Machine elements (parts) is a fragment of

Goal – develop a concept into optimal product

- Final documentation.
- Support productions and vendors.
- Maintain product changes.
- Apply for patents.
- Design for end of life the product.

The order of the steps can be different and this is iterative process

Based on Ullman 2010

Mechanical design process

Product discovery

Discovery of a **need** for a product

- Market pull
- Technology push
- Product change

Market pull – customers wants buy a certain product (80% of cases). Knowledge about need is recognized by e.g. marketing department

Technology push – advance in technology enable to produce better or new product. Demand must be created e.g. sticky notes, graphene.

Product change – improvement of product based on experience gained during realization of project

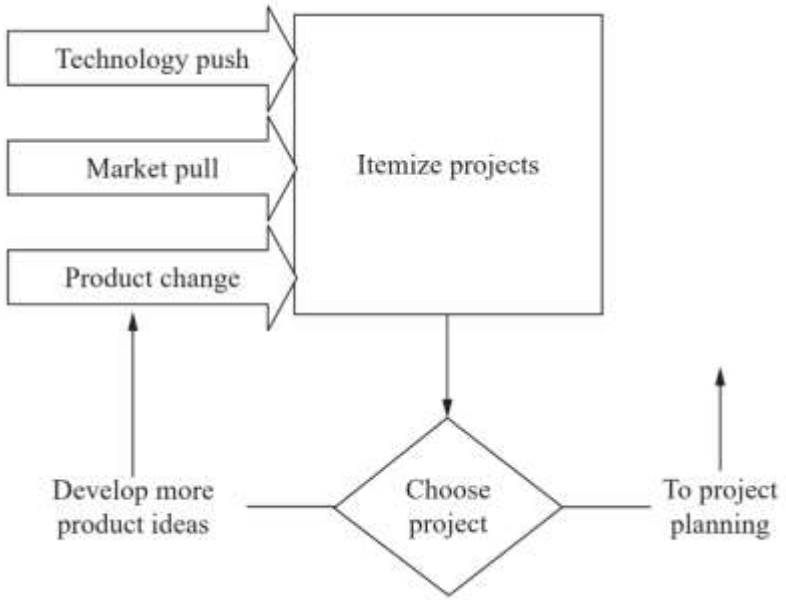


Fig. [Ullman 2010]

Based on Ullman 2010

Mechanical design process

Project planning

Project planning its a process of identification of tasks that are essential to complete a design process and formulate design project plan.

Design project plan - it is a plan of designing a product divided into a tasks. Design team is responsible for its creation and realization.

Design team – group of specialist that represent different fields like designing, manufacturing and marketing.

Goal of project planning:

- product on time and in cost-effective manner,
- assessment of resources: time, money and people,
- assessment of cost needed to design a new product.

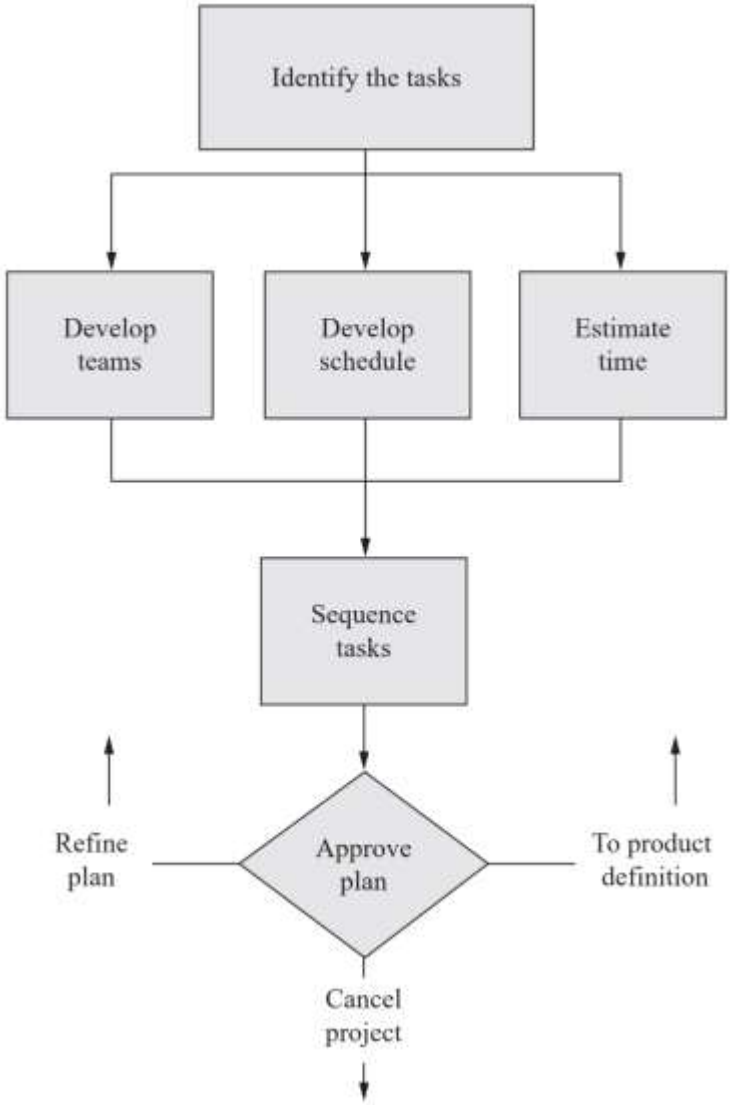


Fig. [Ullman 2010]

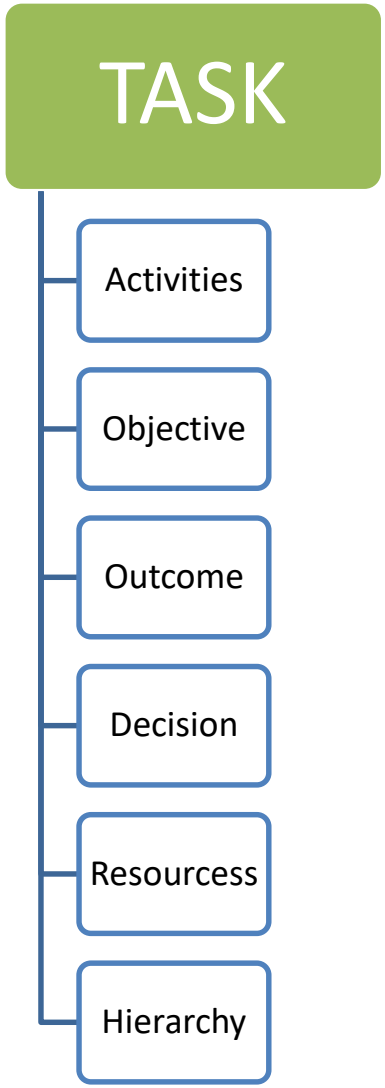
Based on Ullman 2010

Mechanical design process

The first step is to clarify general goal and split into tasks.

Correctly defined task should provide information about:

- activities to be carried out,
- objective like making a drawing or performing numerical analysis,
- outcome like detailed drawing, assembly drawing, information about max. displacement under the max. load, range of motion,
- decision that should be taken based on results like choosing the final material or shape of part,
- resources needed for implementation: people, time and equipment, which enables to estimate a cost,
- place in the schedule (based on task information – parent-children relationship) – which task must be realized before that and which later.



Based on Ullman 2010

Mechanical design process

Project planning

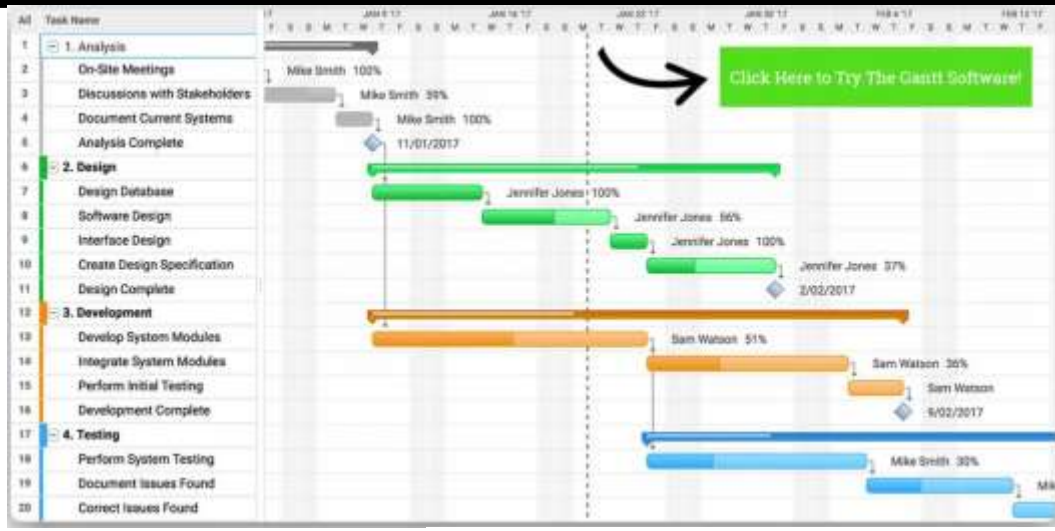


Fig. Gantt chart [https://www.projectmanager.com/gantt-chart]

Types of project management methodologies [Wood M.]:

- waterfall project (stage-gate) – each step is dependent on the one before. After each step there is a decision to make. Several task could be in one step (Gantt chart),
- Agile project (Scrum, Kanban) – focus on small scope which enables to be more elastic,
- Lean project – according to Lean philosophy (more value and less waste),
- Six Sigma project – according to Six Sigma philosophy (eliminate defect and reduce variation),
- etc.

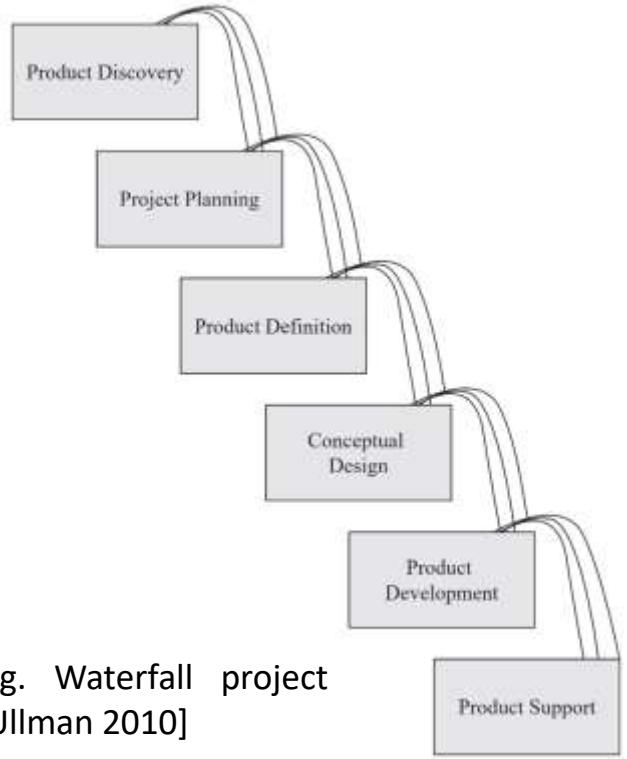


Fig. Waterfall project [Ullman 2010]

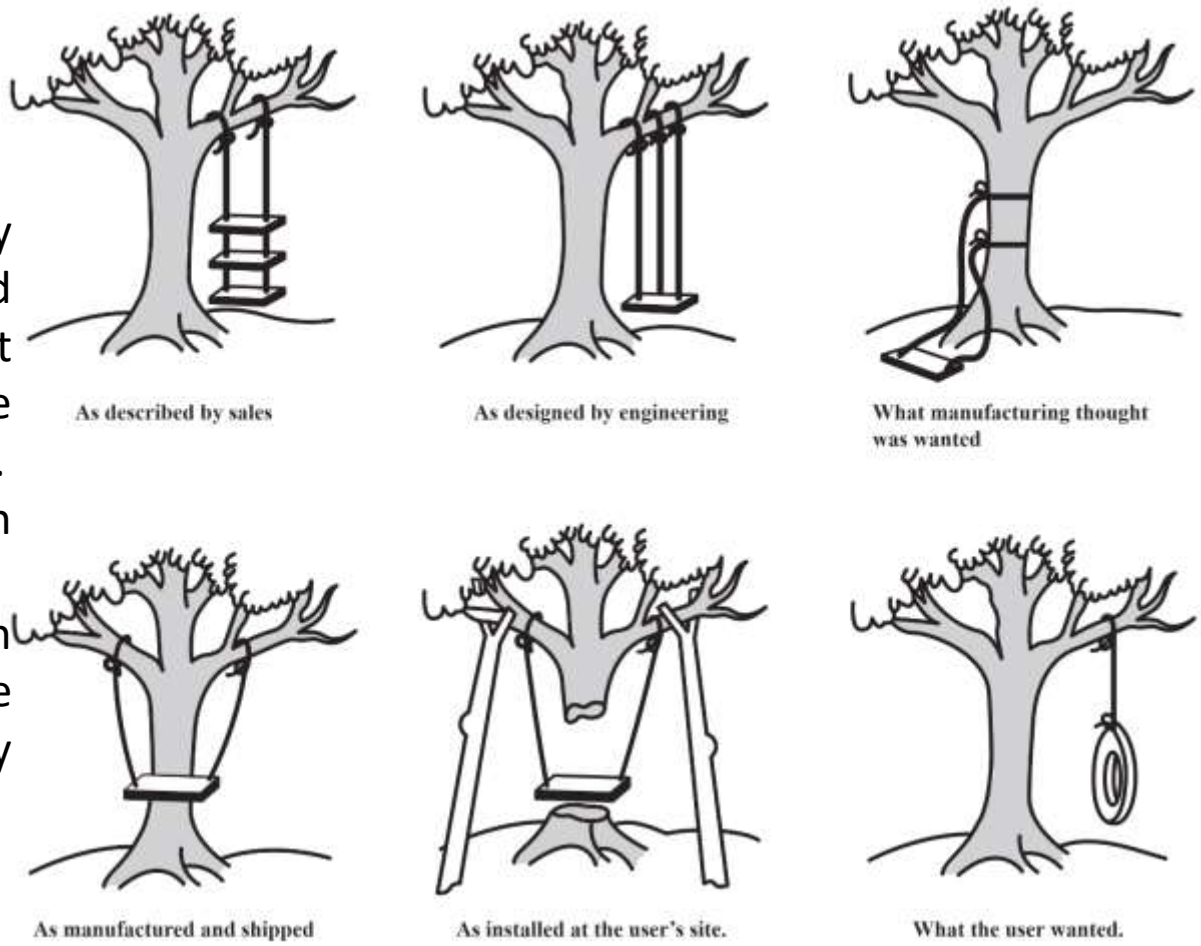
Mechanical design process

Product definition

Need that product is going to satisfy should be fully recognized and understood. Requirements that product must meet are finally write in form of engineering specification. This step is essential to achieve high quality product.

Time spend on product definition save time on further steps because changes in design are significantly reduced

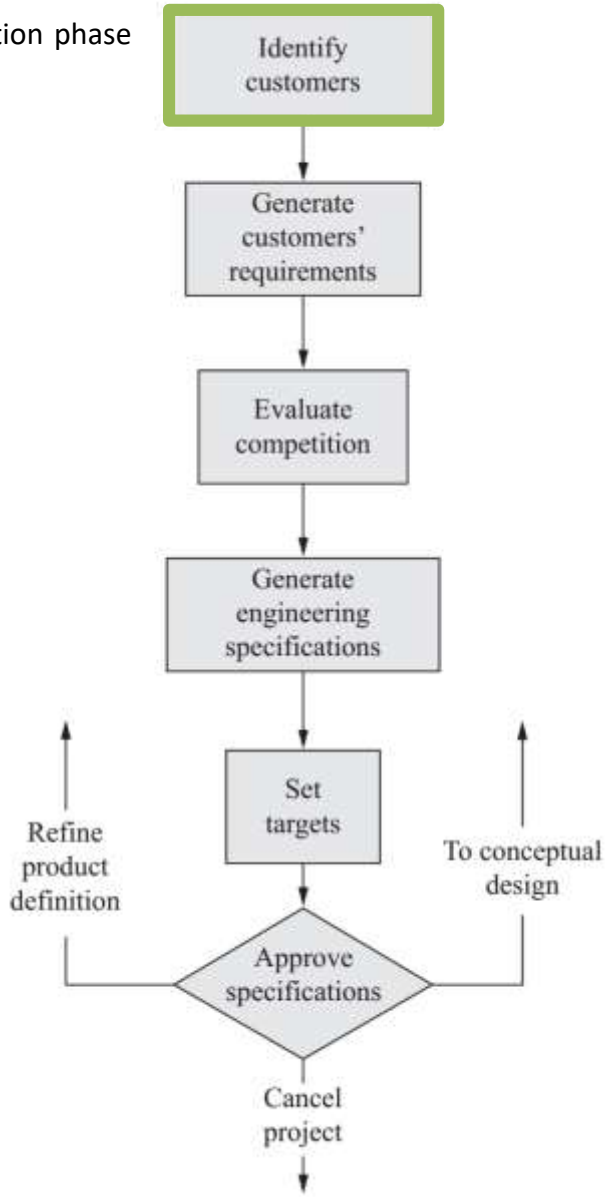
Fig. Misunderstanding of need [Ullman 2010]



Mechanical design process

Product definition

Fig. Steps in definition phase [Ullman 2010]



Target market – it is a group of people that have the same need. In the other words this is a group of people that are the potential buyers of certain product (thing or service).

Market research identify customers and based on that information it is possible to define target market.

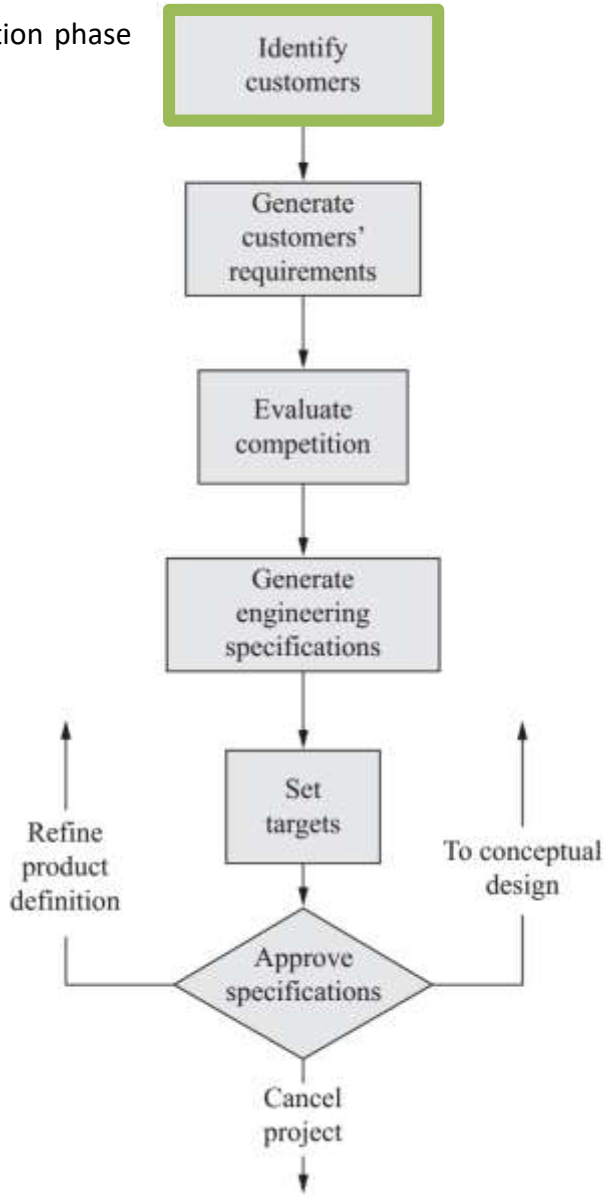
Mechanical design process

Product definition

Identify customers (customer profile):

- age,
- gender,
- income level
- material status,
- education,
- province or state,
- occupation,
- race,
- religion,
- …,

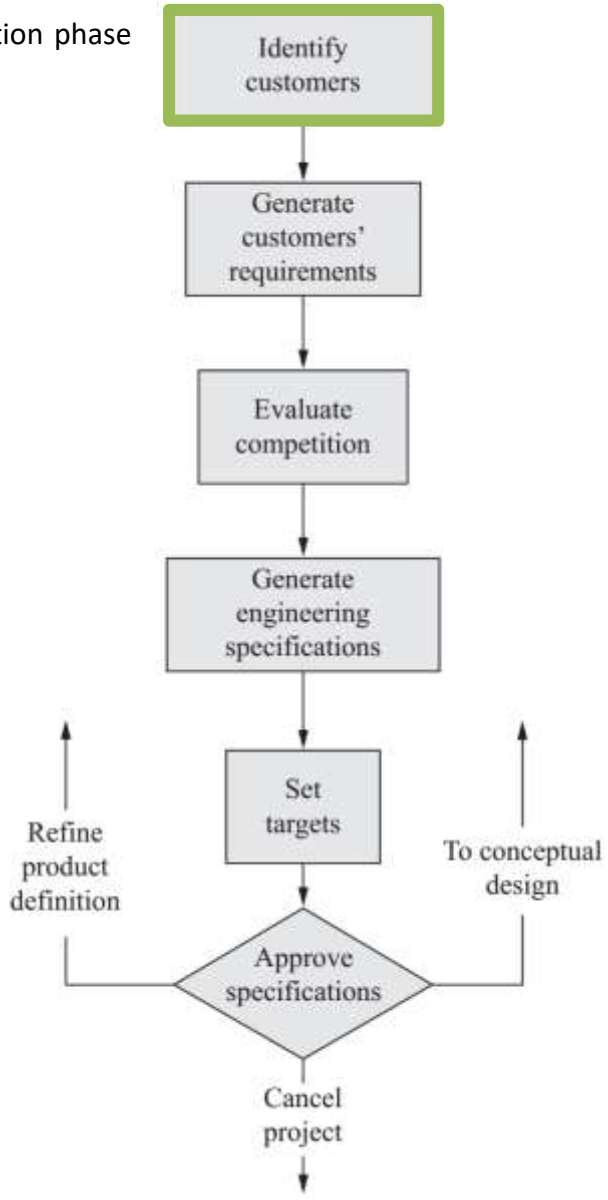
Fig. Steps in definition phase [Ullman 2010]



Mechanical design process

Product definition

Fig. Steps in definition phase [Ullman 2010]



Different strategy to market research:

Steve Jobs: „Some people say give the customers what they want, but that's not my approach. Our job is to figure out what they're going to want before they do. I think Henry Ford once said, 'If I'd ask customers what they wanted, they would've told me a faster horse.' People don't know what they want until you show it to them. That's why I never rely on market research. Our task is to read things that are not yet on the page."

[https://www.businessinsider.com/steve-jobs-quote-misunderstood-katie-dill-2019-4?IR=T]

Does this mean that Apple do not make market research?

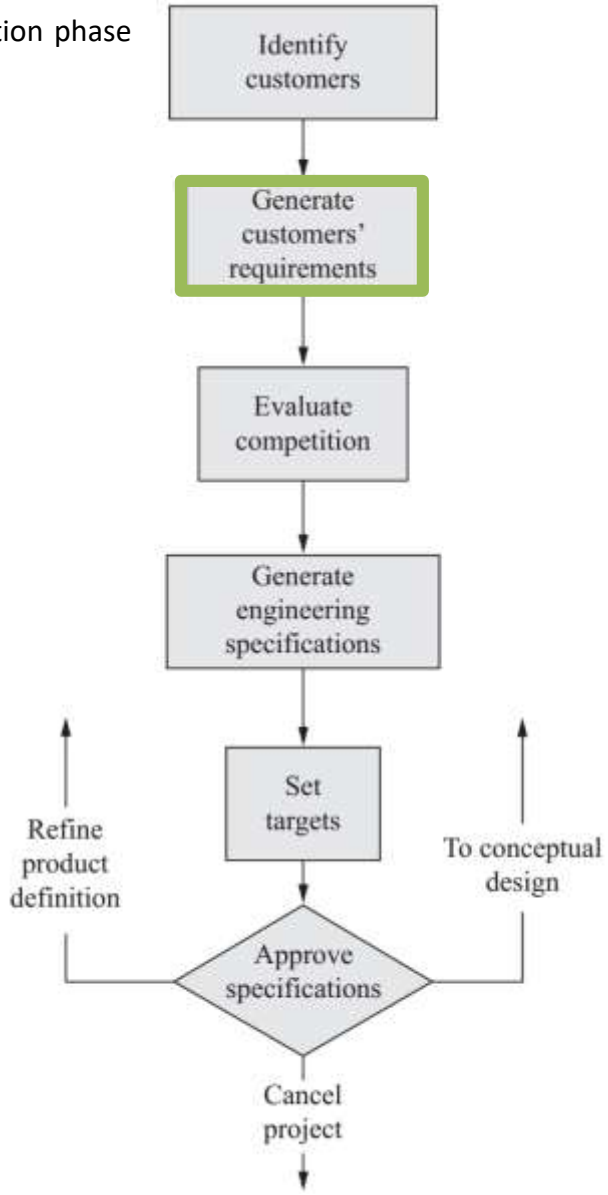
Mechanical design process

Product definition

There are several popular method to gathering information about requirements:

- interview – meeting with (potential) customers,
- focus group – selected group of people that provide feedback by testing (demo, older version of) product,
- survey – answering to carefully prepared questions,
- observation – watching person when he uses a product,
- Internet – social media, keywords and other data that could be analyzed.

Fig. Steps in definition phase [Ullman 2010]

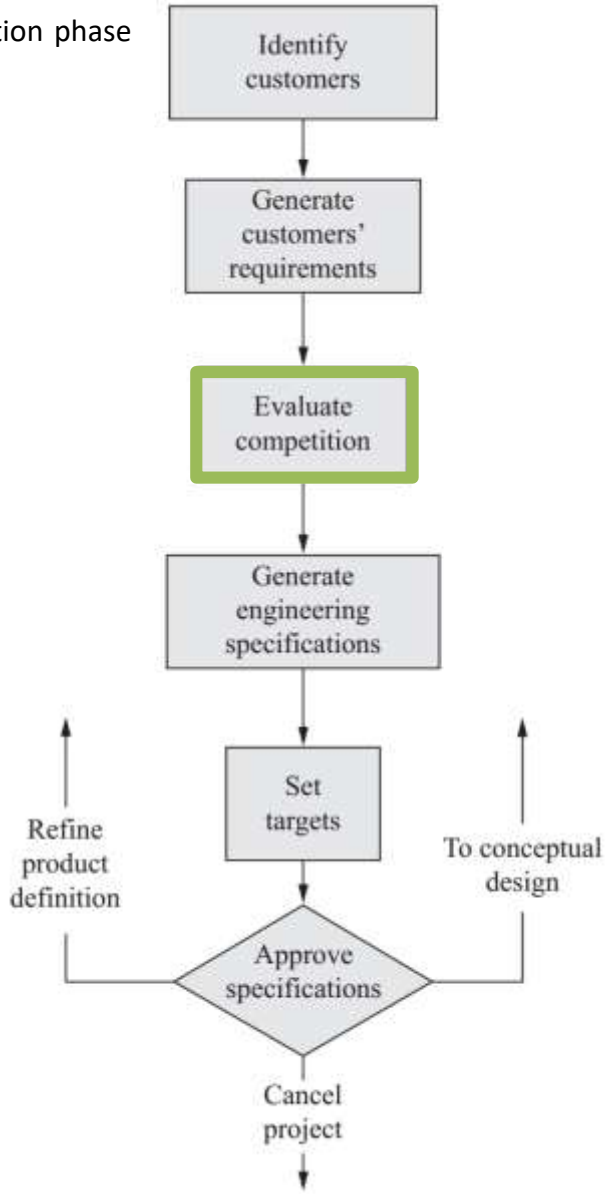


Mechanical design process

Product definition

It is important to analyze competitors product that meet the needs or is similar to our product. Based on that current solutions are clear and potential opportunities are revealed. This is the basis for creating a superior product.

Fig. Steps in definition phase [Ullman 2010]



Mechanical design process

Product definition

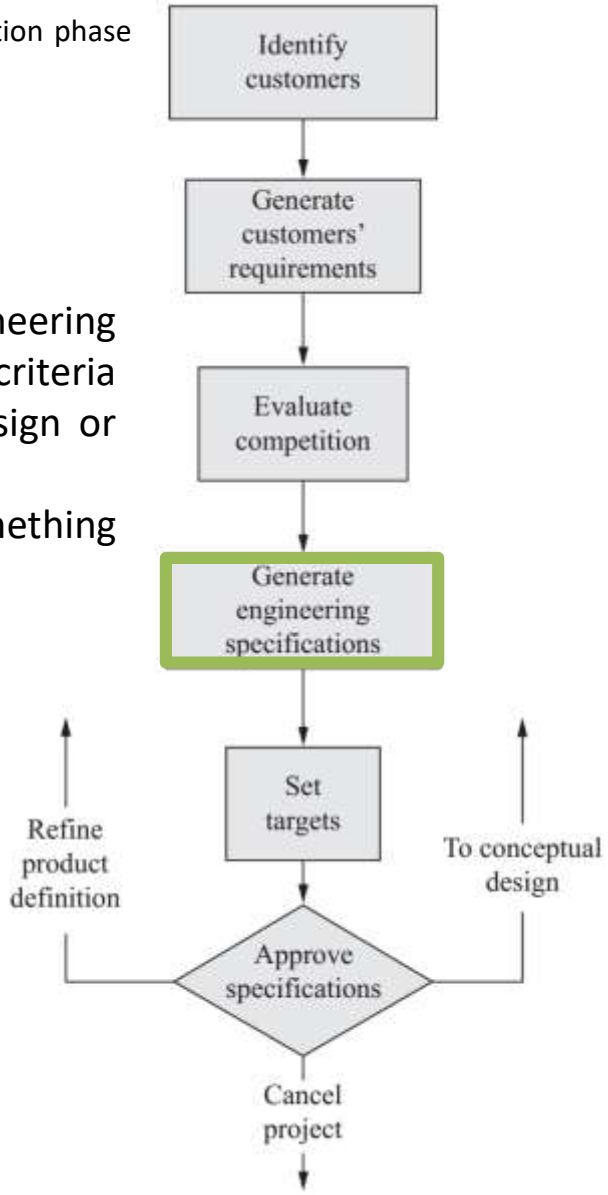
In this step customers needs must be translated to engineering specification(s). This document(s) is composed of measurable criteria (parameters) that describe a design and are used to assess the design or product.

Created parameters in specification must have unit of measure. If something is not measurable it cannot be assessed.

Table 6.1 Types of engineering specifications [Ullman 2010]

Functional performance	Life-cycle concerns (continued)
Flow of energy	Diagnosability
Flow of information	Testability
Flow of materials	Reparability
Operational steps	Cleanability
Operation sequence	Installability
Human factors	Retirement
Appearance	Resource concerns
Force and motion control	Time
Ease of controlling and sensing state	Cost
Physical requirements	Capital
Physical properties	Unit
Available spatial envelope	Equipment
Reliability	Standards
Mean time between failures	Environment
Safety (hazard assessment)	Manufacturing/assembly requirements
Life-cycle concerns	Materials
Distribution (shipping)	Quantity
Maintainability	Company capabilities

Fig. Steps in definition phase [Ullman 2010]

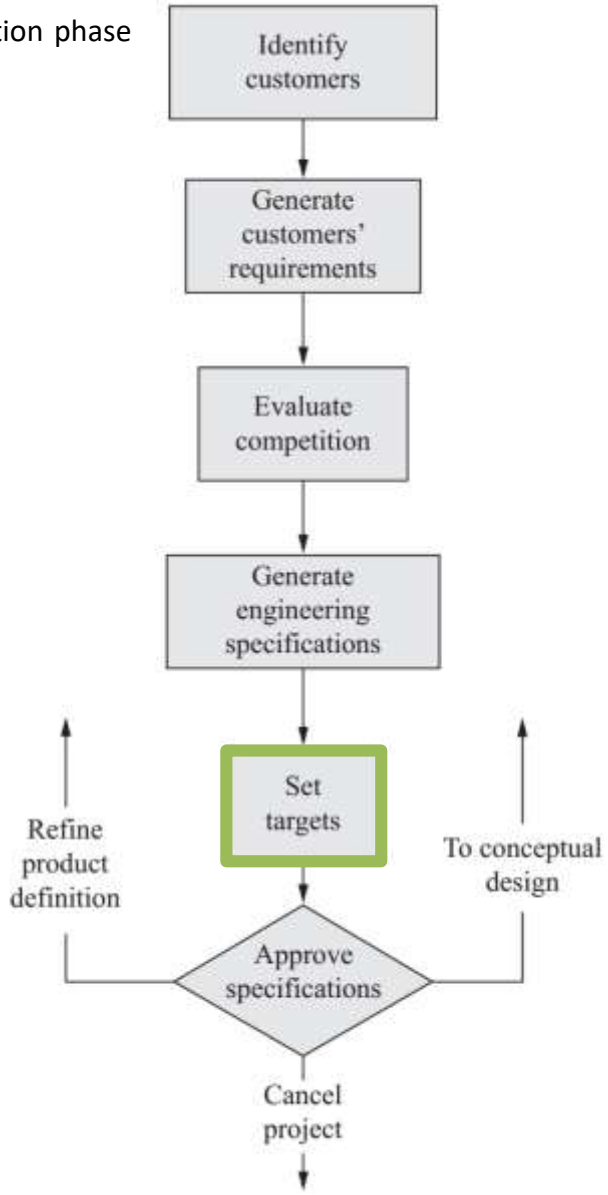


Mechanical design process

Product definition

Parameters have different importance so it is necessary to establish its weights. Also thresholds must be determine e.g. min. value of parameter and optimum one.
It can be done based on analysis of competitors products.

Fig. Steps in definition phase [Ullman 2010]

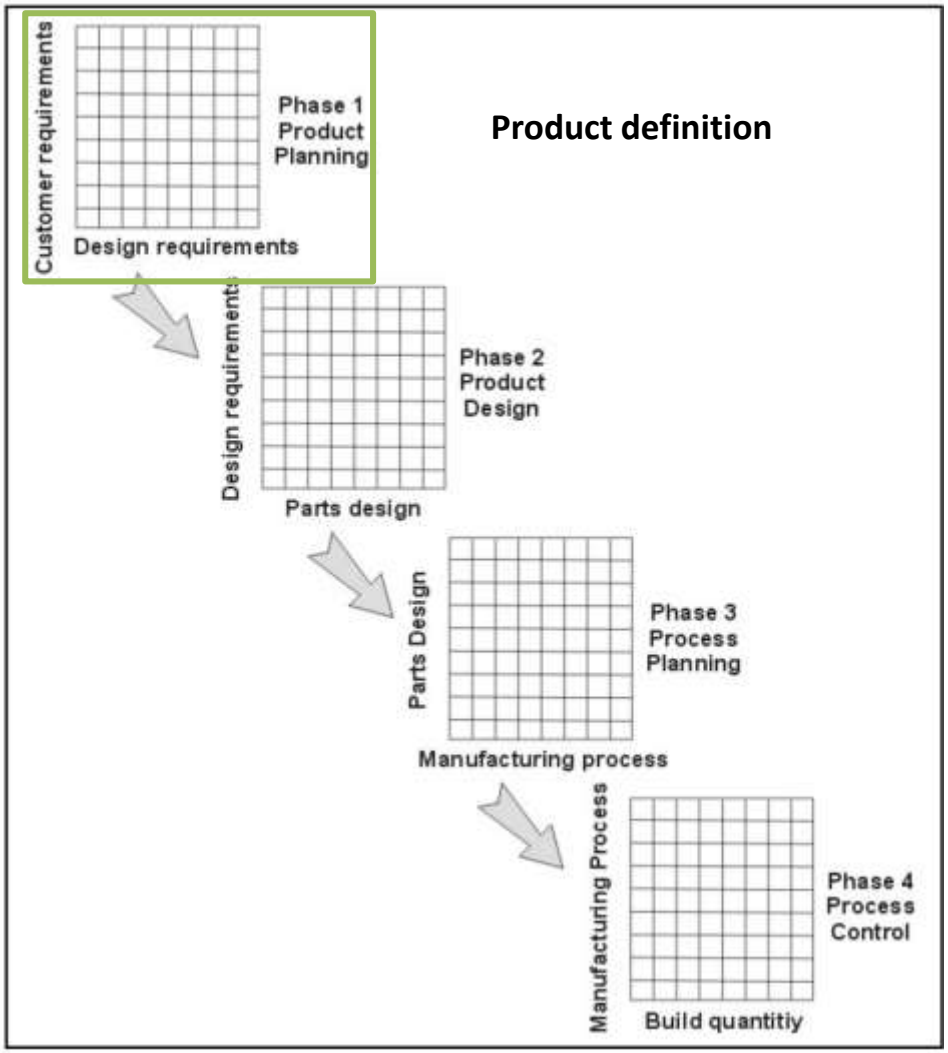


Mechanical design process

Product definition

One of the method that is used for product definition is Quality Function Deployment (QFD). It was developed in Japan. Many companies succeed using it and that contributed to QFD popularity. The main principle is to listen to the „voice of customer" and deliver a high quality product that is the response of it needs or requirements.
QFD also applied to conceptual design and product development.

Fig. QFD phases [http://www.fme.aegean.gr/sites/default/files/cn/quality_function_deployment.pdf]



Mechanical design process

Product definition

The House of Quality is a matrix that is used in QFD method. In unambiguous manner translate needs to technical requirements with assessment of competition and clear set goals.

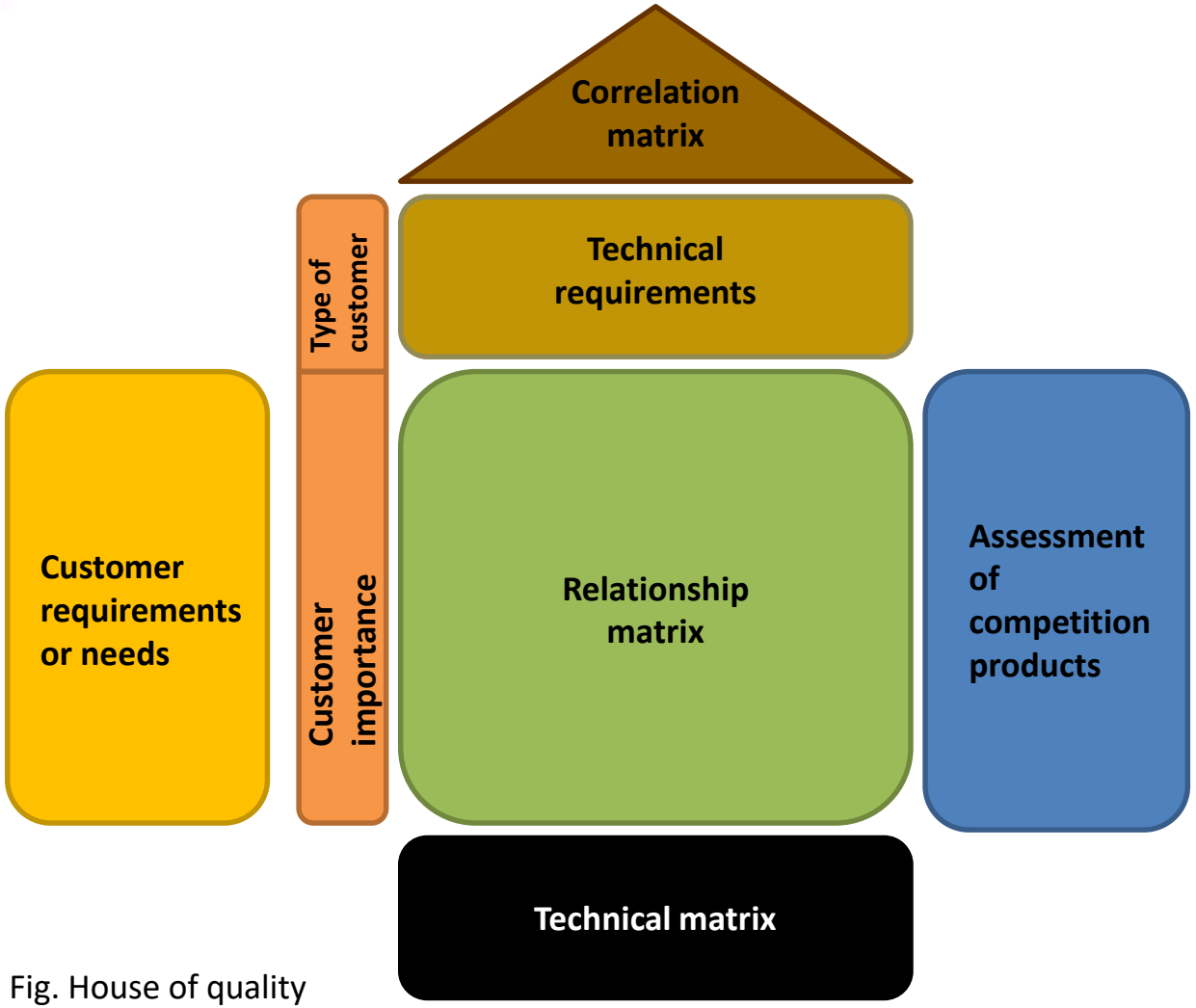


Fig. House of quality

Mechanical design process

Product definition

Fig. Aisle chair [Ullman 2010]

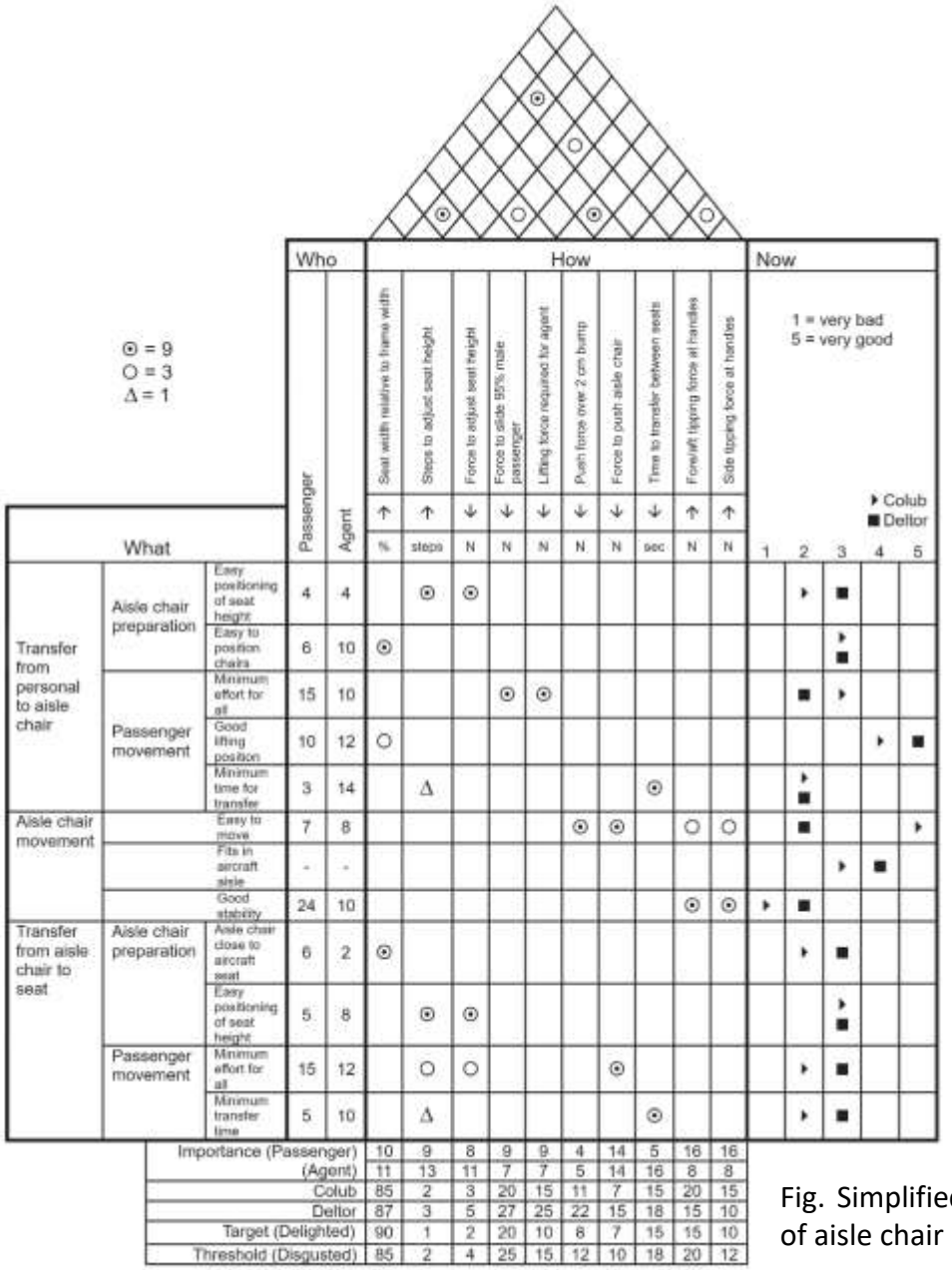


Fig. Simplified house of quality of aisle chair [Ullman 2010]

Mechanical design process

Conceptual design

The goal of this step is to generate many concepts that increases chances of finding optimal solution and choosing the best one.

Concept is *„an idea that is sufficiently developed to evaluate the physical principles that govern its behavior”* [Ullman 2010].

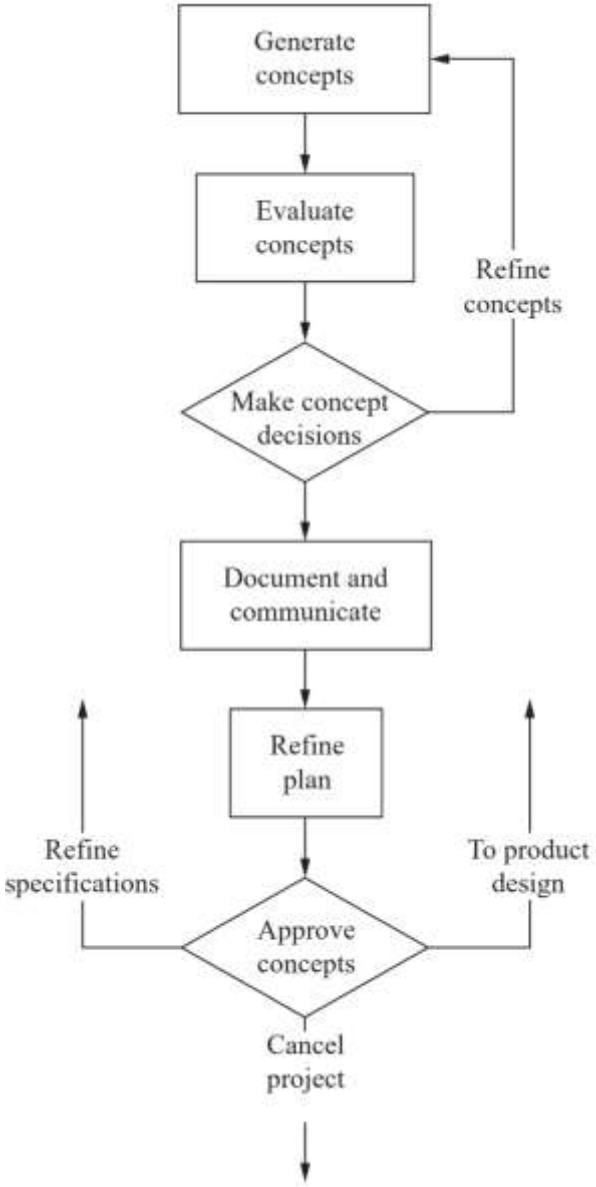


Fig. Conceptual design phase [Ullman 2010]

Mechanical design process

Conceptual design

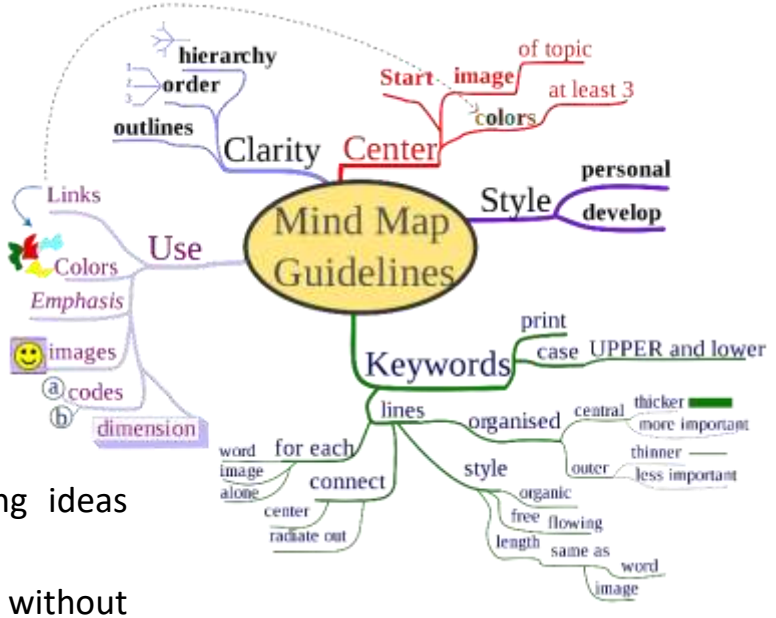


Fig. Mind map [https://en.wikipedia.org/wiki/Mind_map#/media/File:MindMapGuidlines.svg]

Selected methods for concepts generation:

- ***mind mapping*** – graphical technique of writing and organizing ideas on paper,
- ***brainstorming*** – most often group of people generates ideas without assessment in first stage. After that ideas are filtered,
- ***find ideas in book, journals, patents, the Web or consult with an expert,***
- ***TRIZ*** (the theory of inventive machines - created by Russia engineer, inventor and writer Genrich Altshuller) – it is a method with tools and knowledge base used to meet the needs by developing products. One of the finding is that many problems have been already solved but it could be in different industry, situation and technology. Products developed by using this method could be innovative and often patents are obtained. World-wide companies use this method. According to Forbes Samsung achieve many success with TRIZ. The drawback of the method is complexity (training could be required) and also access to knowledge base.

Fig. Idea of TRIZ solution [https://en.wikipedia.org/wiki/TRIZ]

https://www.forbes.com/sites/haydnshaughnessy/2013/03/07/why-is-samsung-such-an-innovative-company/?sh=cd068ff2ad7e

Mechanical design process

Conceptual design

Selected methods for concepts generation:

- ***morphological chart*** (analysis) – the method foster generating concepts based on functions. The first step is to define general and detailed (sub)functions of device. Next, for each of them in a table row, are putted concepts that realized this function. The last step is to choose individual concepts and create conceptual designs,
- ***questioning, reverse thinking, SCAMPER …***

Fig. Morphological chart [http://edge.rit.edu/edge/P17221/public/Systems%20Design]

	Solutions				
Move X axis	 Belt Drive	 Chain Drive	 Ball Screw	 Linear Actuatuor	
Move Y axis	 Belt Drive	 Chain Drive	 Ball Screw	 Linear Actuatuor	
Drive Carriage	 Stepper Motor	 Servo	 Small I.C. Engine		
Retain Carriage	 Wheeled carriage	 Linear Slide	 Casters	 Air Bearing	
Measure position	 Linear Poteniometer	 Rotary Poteniometer	 Motion Sensor	 Laser Sensor	 Stepper Motor

Fig. Morphology chart [Ullman 2010]

Morphology

Product: One-handed bar clamp — **Organization Name:** Irwin Tools

Subfunctions	Concept 1	Concept 2	Concept 3	Concept 4
Collect grip force and motion from user	One trigger	Two triggers		
Transform grip force and motion to bar	Jam plate	Ratchet	Rack and pinion	Linkage
Move bar	Free sliding	2 speed system	> 2 speed system	
Amplify force	Short stroke	Long stroke		

Team Member: DVP	Team Member:	Prepared by: DVP	
Team Member: AKO	Team Member:	Checked by: AKO	Approved by:

The Mechanical Design Process

Designed by Professor David G. Ullman
Form #15.0

Mechanical design process

Conceptual design

After generating a concepts one of presented strategies can be applied to choose the best one:

1. In the case there is only one concept, it is developed into a product.
2. Evaluate most promising concepts or all concepts and select the best one.
3. Develop most promising concepts or all concepts parallel, and when the knowledge enables more accurate evaluation, gradually eliminate weakest and in the end only one will remain.

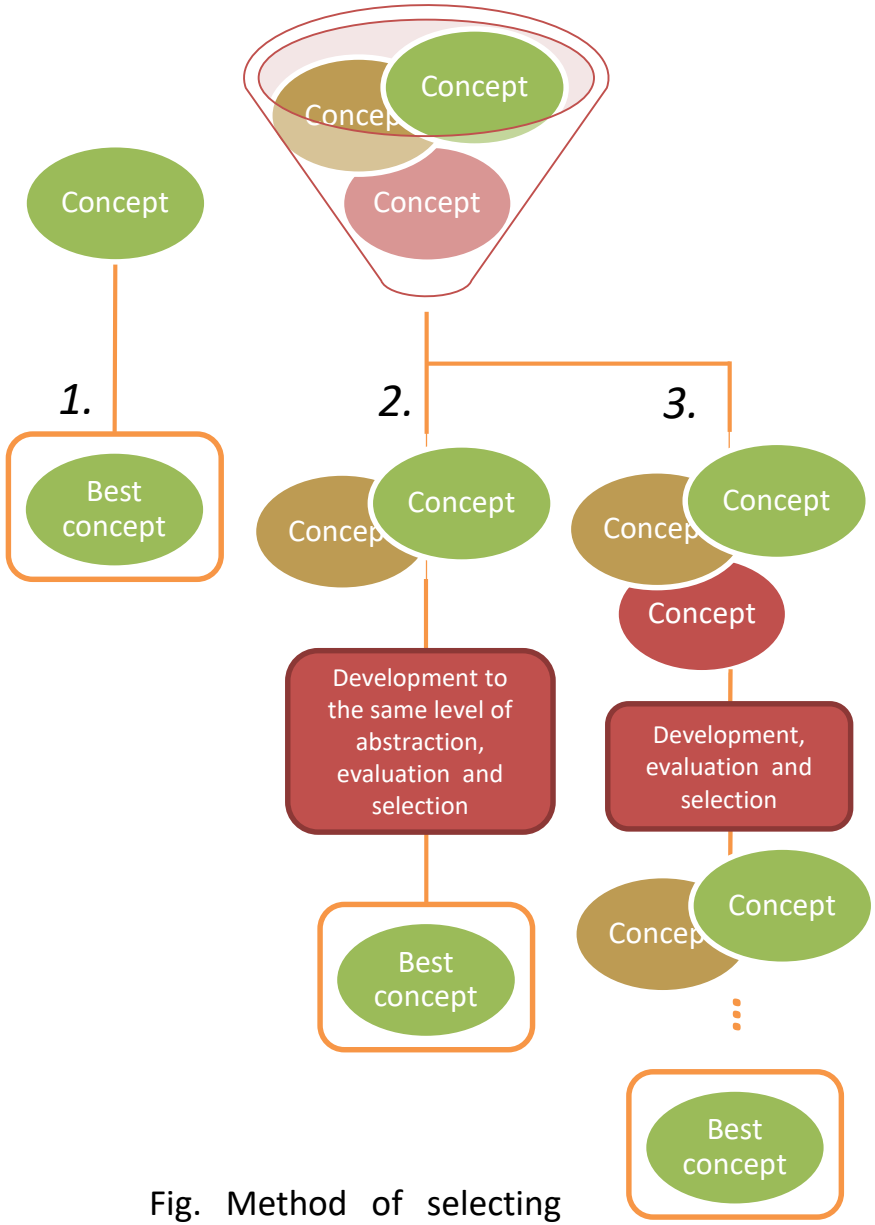


Fig. Method of selecting the best concept

Based on Ullman 2010

Mechanical design process

Conceptual design

Each of the methods can lead to successful product and there is no one right answer.

Comments about methods

1. Creating only one concept and developing into product could be successful in the case of non innovative product. This method is also used when resources of company do not allow to more extensive process.
2. Having several concepts leads to the problem of selecting the best one. Comparison is possible if concepts are on the same level of abstraction. If current level is not enough to make the right evaluation more development must be done. The tricky thing is to find compromise on invested resources and assurance that the best concept was selected.
3. Last method is similar to second but in here concepts are evaluated during development and that with least chance to be successful are gradually rejected during process.

Based on Ullman 2010

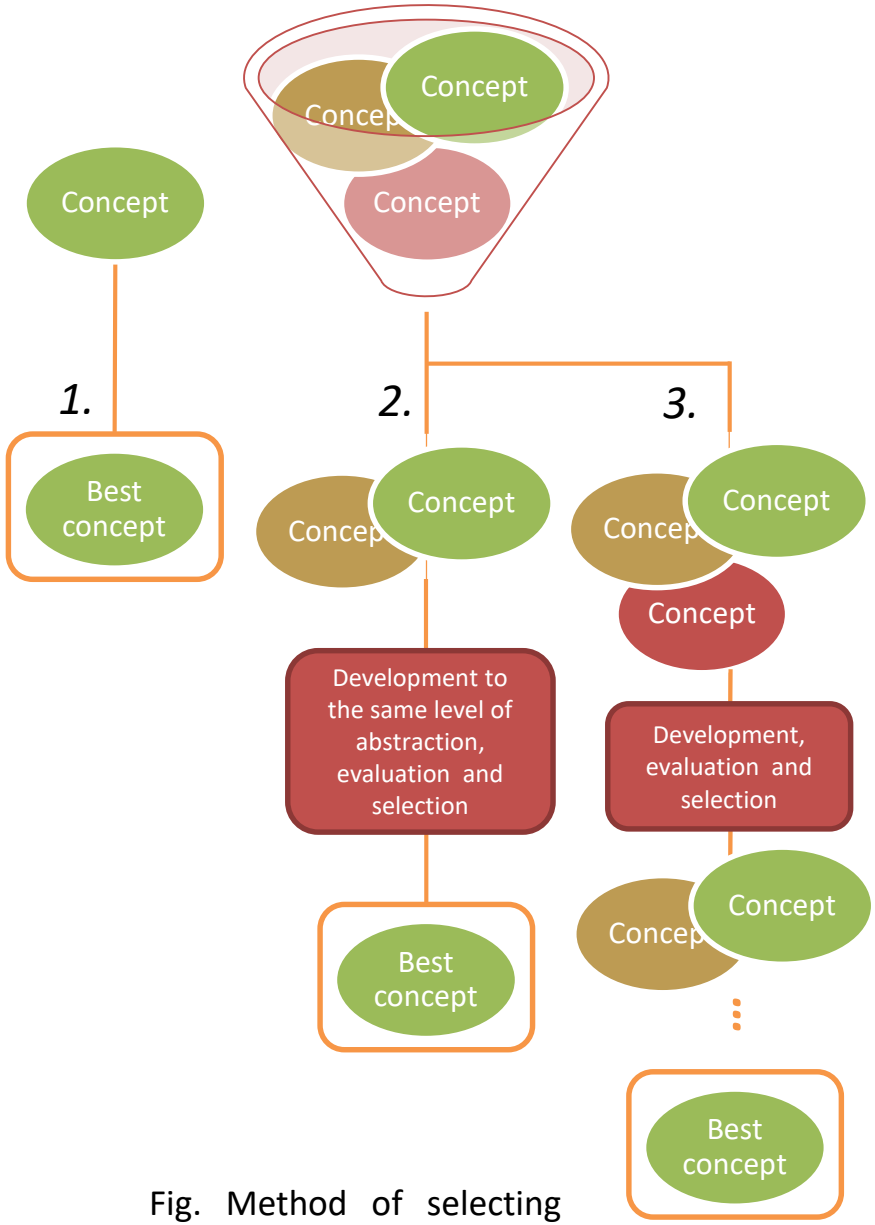


Fig. Method of selecting the best concept

Mechanical design process

To make decision more objective and robust systematic approach should be used. Two method will be presented:

1. Decision-matrix method (Pugh method).
2. Belief map.

Based on Ullman 2010

Mechanical design process

Conceptual design

1. Decision-matrix method (Pugh method)

It is a method to solve decision task in broad spectrum of fields. In mechanical design to make correct evaluation of alternative concepts, their level of abstraction must be the same.

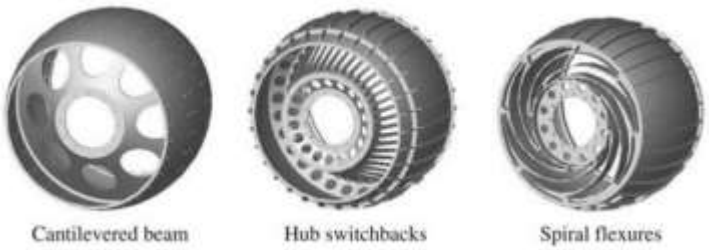


Fig. MER wheels [Ullman 2010]

Fig. General plan of decision-matrix table [Ullman 2010]

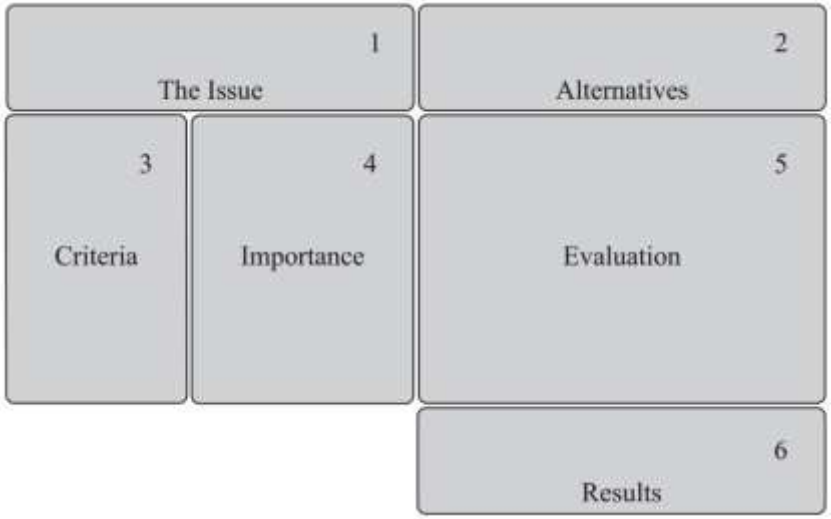


Fig. Example of decision-matrix table [Ullman 2010]

Issue: Choose a MER wheel configuration		Baseline	Cantilevered Beam	Hub Switchbacks	Spiral Flexures	Multipiece
Mass efficiency	35	Datum	0	0	1	?
Manufacturability	10		0	−1	−1	?
Available internal wheel volume	20		1	1	1	?
Stiffness	35		1	1	1	?
	Total		2	1	2	?
	Weighted total		55	45	80	?

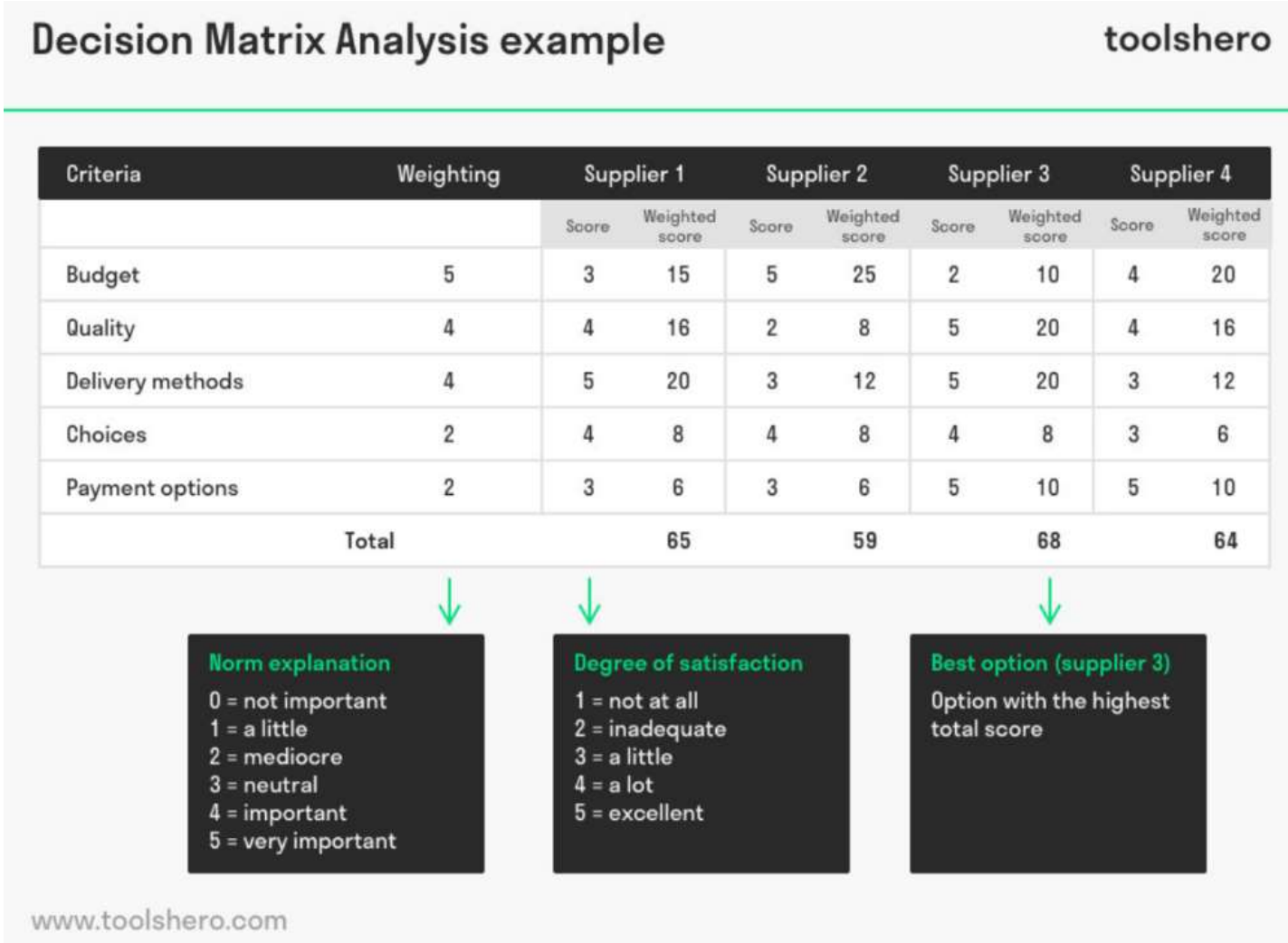
Based on Ullman 2010

Mechanical design process

Fig. [https://www.toolshero.com/decision-making/decision-matrix-analysis/]

Conceptual design

1. Decision-matrix method (Pugh method)



Criteria	Weighting	Supplier 1		Supplier 2		Supplier 3		Supplier 4	
		Score	Weighted score	Score	Weighted score	Score	Weighted score	Score	Weighted score
Budget	5	3	15	5	25	2	10	4	20
Quality	4	4	16	2	8	5	20	4	16
Delivery methods	4	5	20	3	12	5	20	3	12
Choices	2	4	8	4	8	4	8	3	6
Payment options	2	3	6	3	6	5	10	5	10
Total			65		59		68		64

Mechanical design process

Conceptual design

2. Belief map

VL – very low
L – low
M – medium
H – high
VH – very high

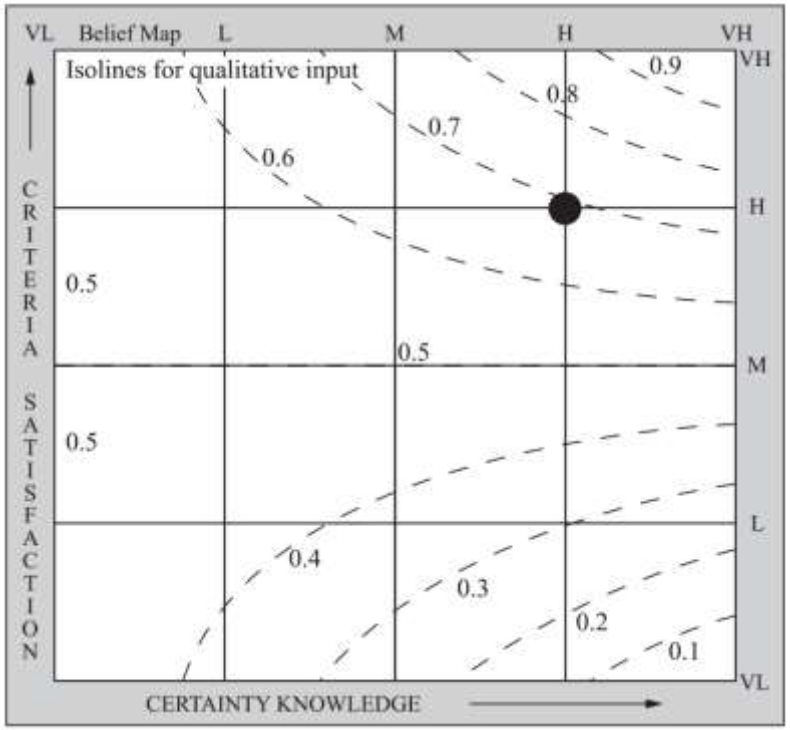
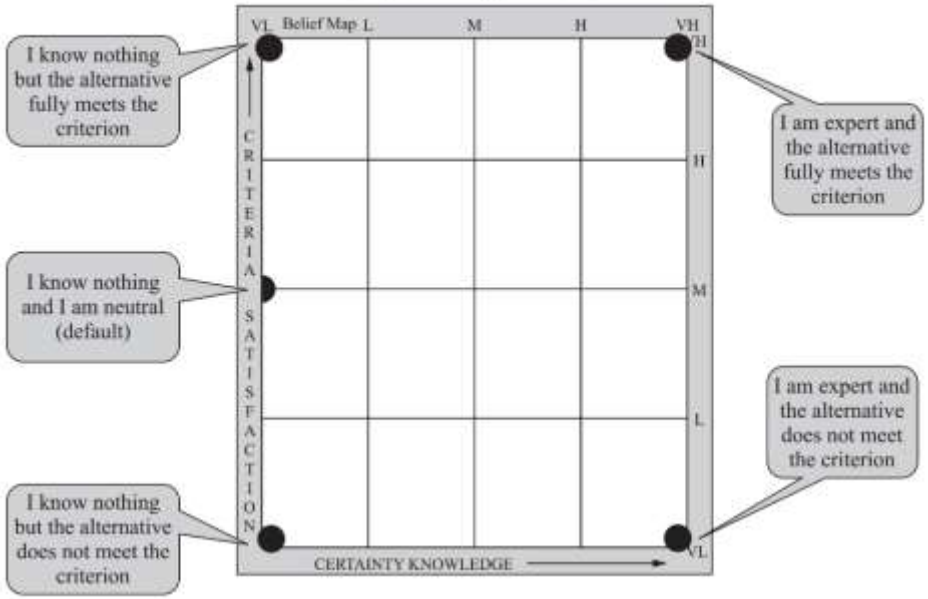


Fig. [Ullman 2010]

Belief map basics Fig. [Ullman 2010]



Even then a level of concepts abstraction is the same, knowledge about specific technical solution could be different. Evaluation of requirements, in this case, have different uncertainty. Belief map is a method that help in decision making when information is not completed or with different uncertainty.

Based on Ullman 2010

Mechanical design process

Conceptual design

2. Belief map

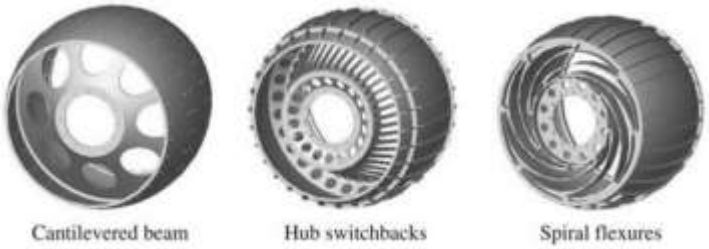


Fig. MER wheels [Ullman 2010]

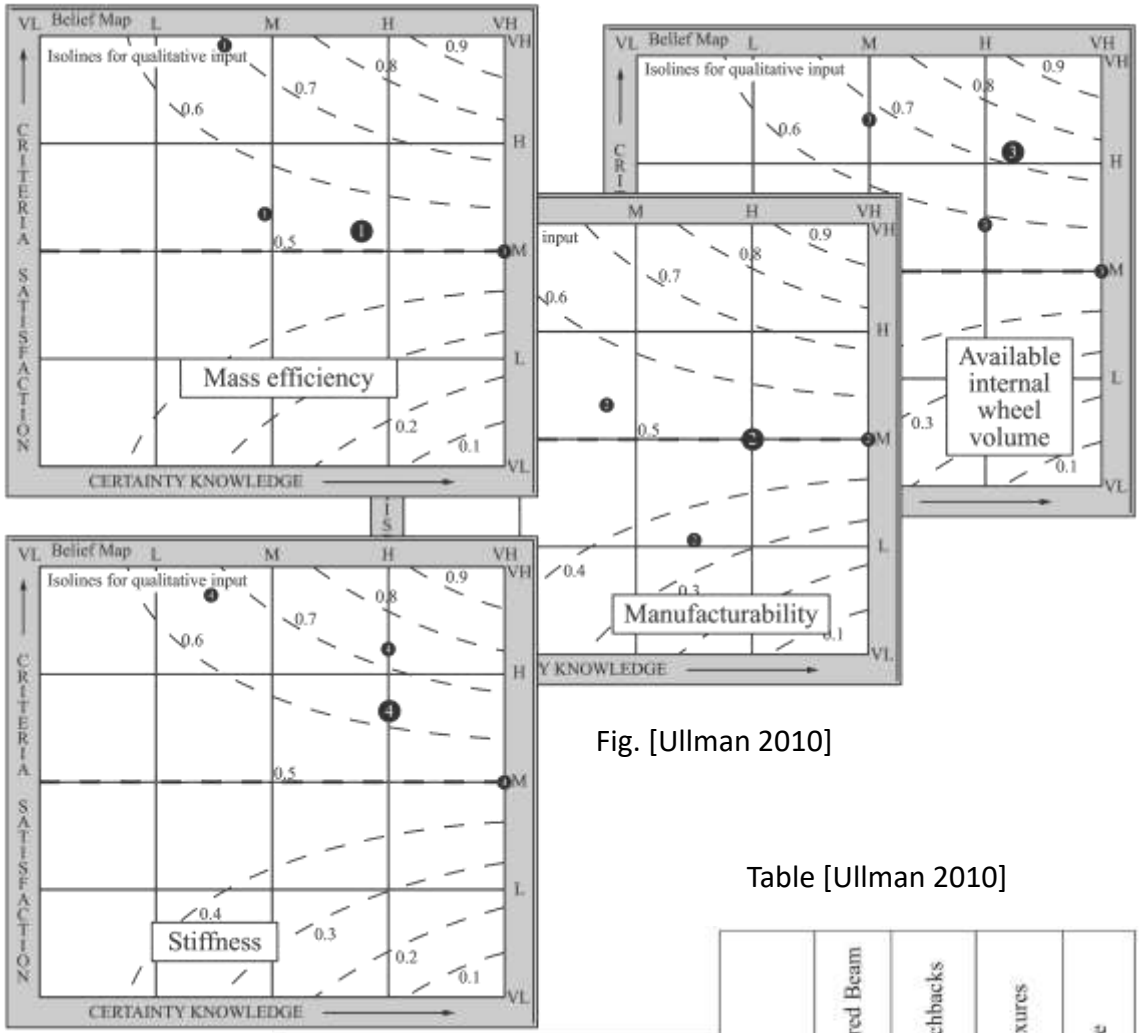


Fig. [Ullman 2010]

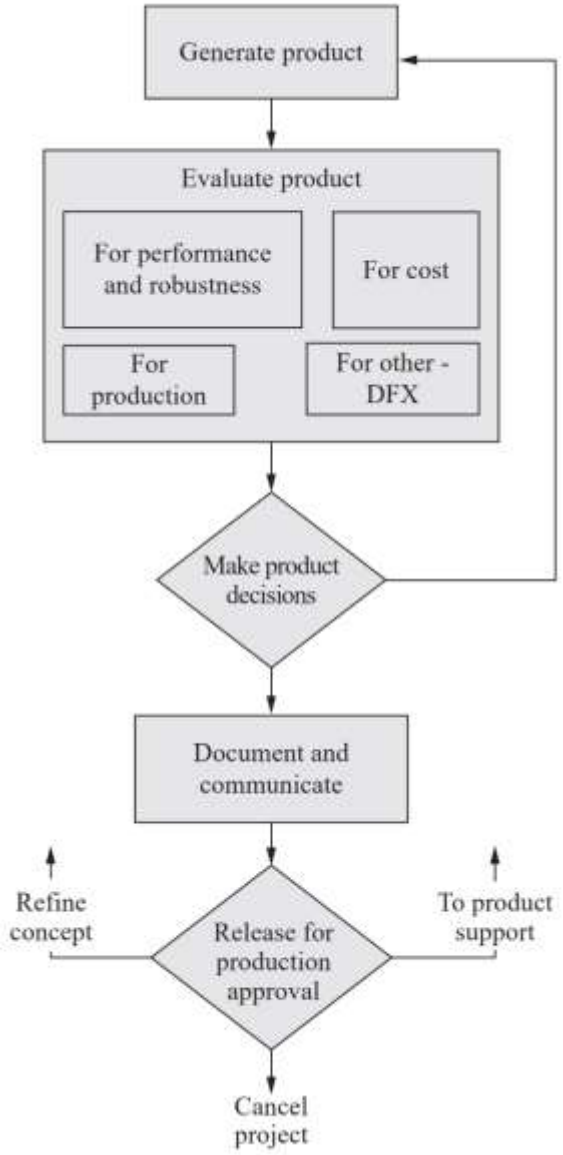
Table [Ullman 2010]

Issue: Choose a MER wheel configuration		Baseline	Cantilevered Beam	Hub Switchbacks	Spiral Flexures	Multipiece
Mass efficiency	35	0.5	0.55	0.55	0.77	0.71
Manufacturability	10	0.5	0.5	0.35	0.4	0.52
Available internal wheel volume	20	0.5	0.72	0.58	0.84	0.67
Stiffness	35	0.5	0.62	0.74	0.86	0.68
	Satisfaction	50	60	60	78	67

Based on Ullman 2010

Mechanical design process

Design process is stepping to final phase. Concept will be developed into product. During that period product will be optimized for different criterion like performance, robustness, cost, production and others.



Based on Ullman 2010

Fig. Product design phase [Ullman 2010]

Mechanical design process

The key idea that should be used in product development is that all starts with functions that product must meet. Based on that three things are set:

- form,
- material,
- production.

This is a simultaneous and iterative process.

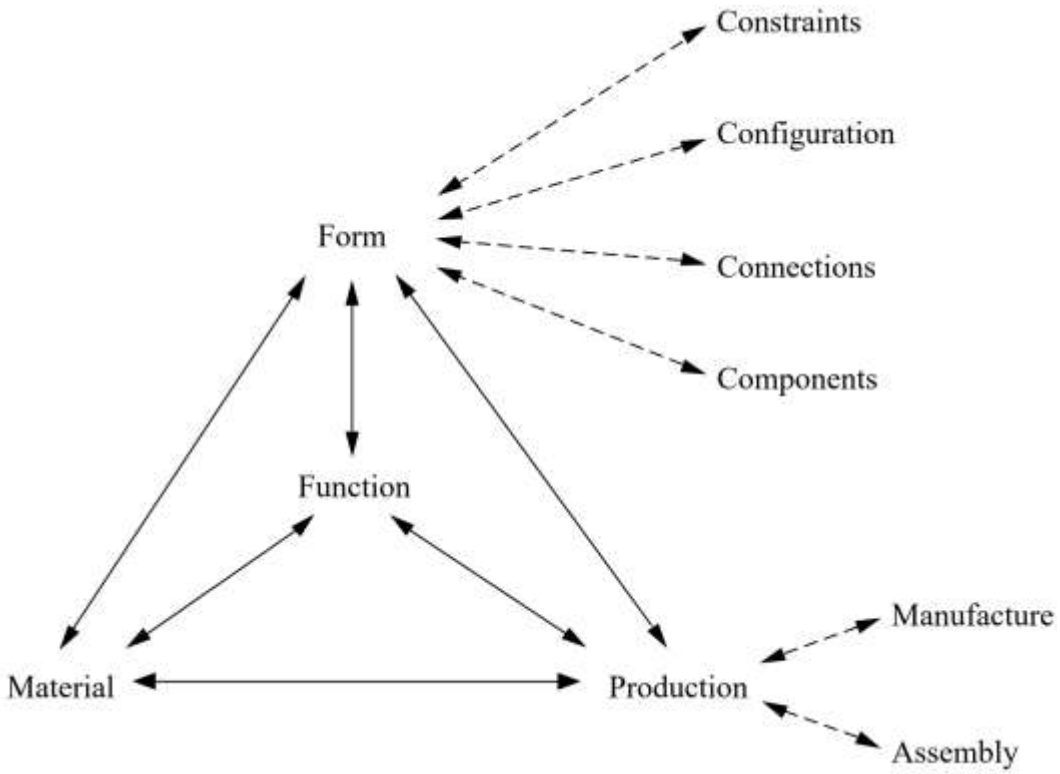


Fig. Product design phase [Ullman 2010]

Based on Ullman 2010

Mechanical design process

Function and is some degree material, technology of manufacturing and assembly put boundaries on possibly **form** of component or assembly. This can be seen as: constraints, configuration and connections that are limiting possible form.

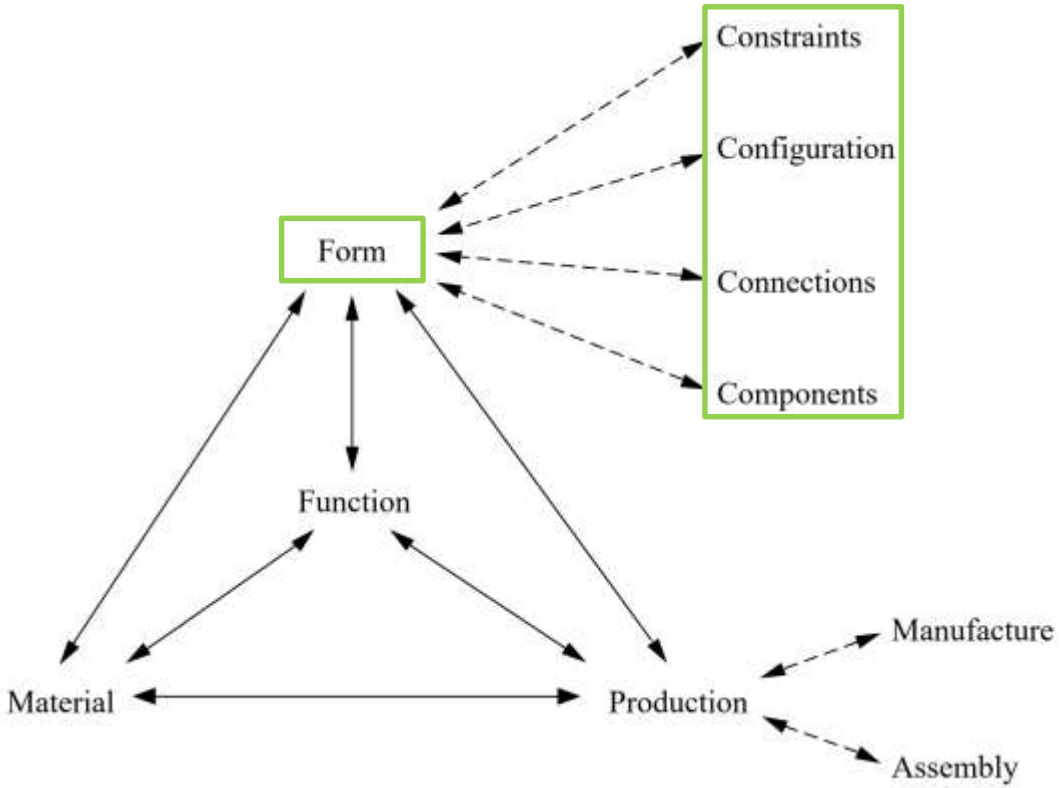


Fig. Product design phase [Ullman 2010]

Constraints are mainly the spatial limitations resulting from the avaible space for product, assembly or component. CAD 3D programs are a great tool in designing products.
Configuration is a composition or arrangements of components in product. It defines position and order of components as well as how many components will be used to perform the function.

Based on Ullman 2010

Mechanical design process

Configuration

Component can be decompose because of [Ullman 2010]:

- use of different material
- required relative motion,
- accessibility for maintenance or recycling,
- manufacturing limitations,
- availability of standard components,
- cost optimization.

Power: 0,4 – 487 kW
Torque: 1140 – 76500 Nm
Ratio: 16 - 315

Fig. Family of gear units [http://www.befared.com.pl/?pid=30]

If subassembly or component perform function or functions that are separate from the others (it is design in this way), there is a possibility of creating product with modular structure. This is beneficial if:

- a product families is needed,
- the design work is carrying out in parallel way (CAD software's support this technique) which is practice in complex product and in reducing time to market,
- to use the same components or modules with different product that company manufacture.

Based on Ullman 2010

Mechanical design process

Configuration

Fig. PC computer
[https://en.wikipedia.org/wiki/Desktop_computer]

Mobility

Fig. Wikipedia co-founder Jimmy Wales using a laptop on a park bench
[https://en.wikipedia.org/wiki/Laptop]

The contrary technique is to integrate parts and reduce its number. This can lead to achieve product with ultimate performance or unique features.
But it is also used to develop cheap products with reduced functionality.

Fig. Soldering tool – about 5 $
[https://www.aliexpress.com/item/32968152006.html?spm=a2g0o.productlist.0.0.233c5bf3Phlfnh&algo_pvid=ec134ae1-99a7-4e69-a3c5-d1ca48cb7f3b&algo_expid=ec134ae1-99a7-4e69-a3c5-d1ca48cb7f3b-55&btsid=0b0a182b16071796302464090e2407&ws_ab_test=searchweb0_0,searchweb201602_,searchweb201603_]

Fig. Soldering station – more than 100 $
[https://www.aliexpress.com/item/4000270265126.html?spm=a2g0o.productlist.0.0.220a3ed57CBgRK&algo_pvid=aa27061e-f5ae-4ba5-bbb2-e2efaa3dff1d&algo_expid=aa27061e-f5ae-4ba5-bbb2-e2efaa3dff1d-1&btsid=2100bb4a16071800471963121e9151&ws_ab_test=searchweb0_0,searchweb201602_,searchweb201603_]

Mechanical design process

Connections

can be stationary or movable (joints). A lot of effort is put in designing connections. They have direct influence on movement and exact positions of components. Connections have direct impact on functions and are transmitting load or other medium.

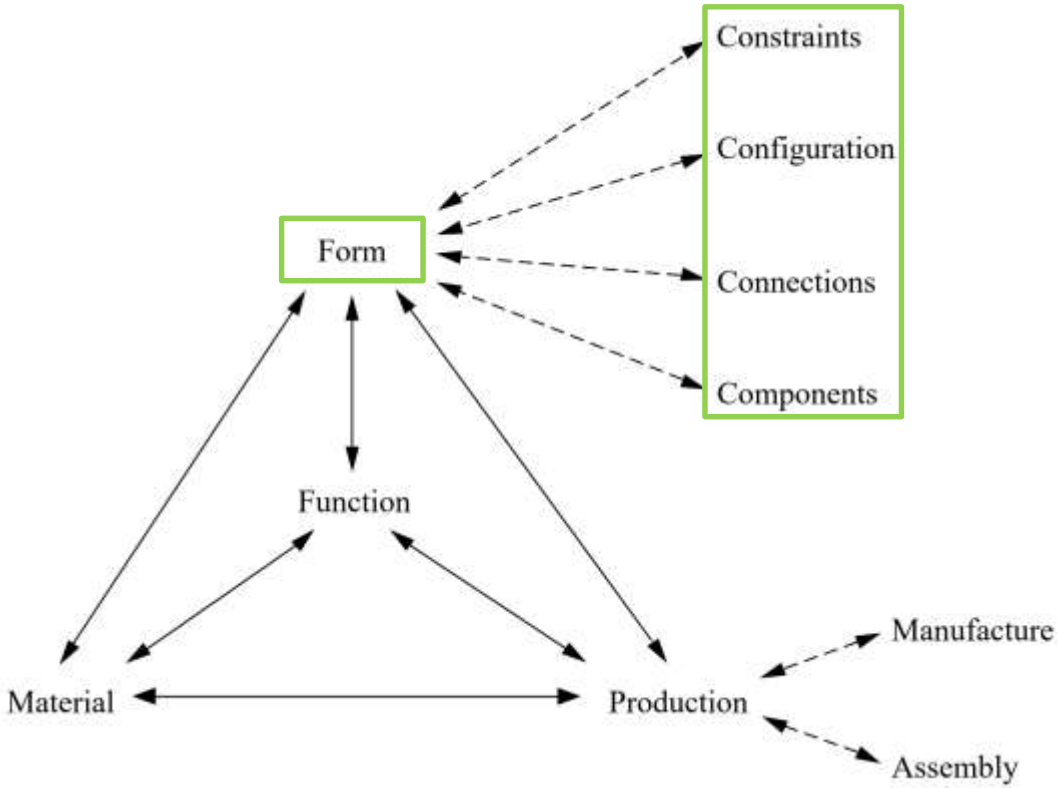


Fig. Product design phase [Ullman 2010]

Components **-** in this step final shape is created. One of not mentioned function of outside components is appearance. Attractive look of product is an important factor deciding on sales figures.

Designing a form of components and assembly based on this four guidelines occurs simultaneously

Based on Ullman 2010

Mechanical design process

Engineers creating final form of components also take into account material and production aspects. Material should be accessible and fit to function of component. But material also determines the possible manufacturing technology.

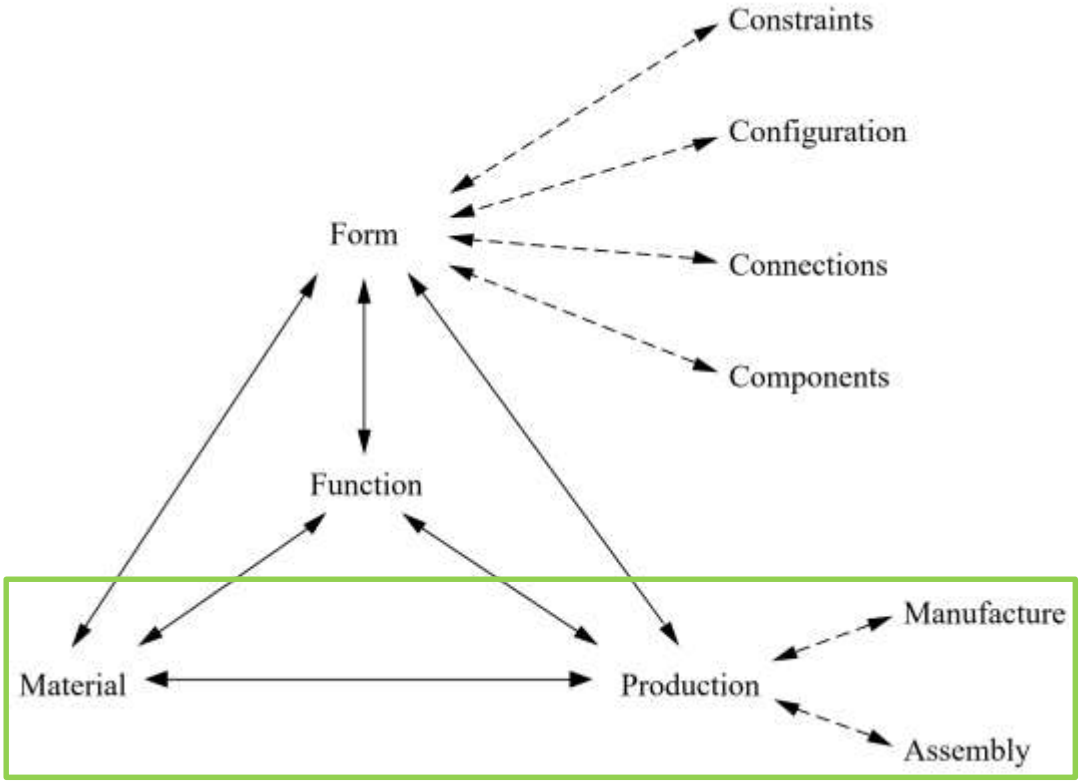


Fig. Product design phase [Ullman 2010]

Based on Ullman 2010

Mechanical design process

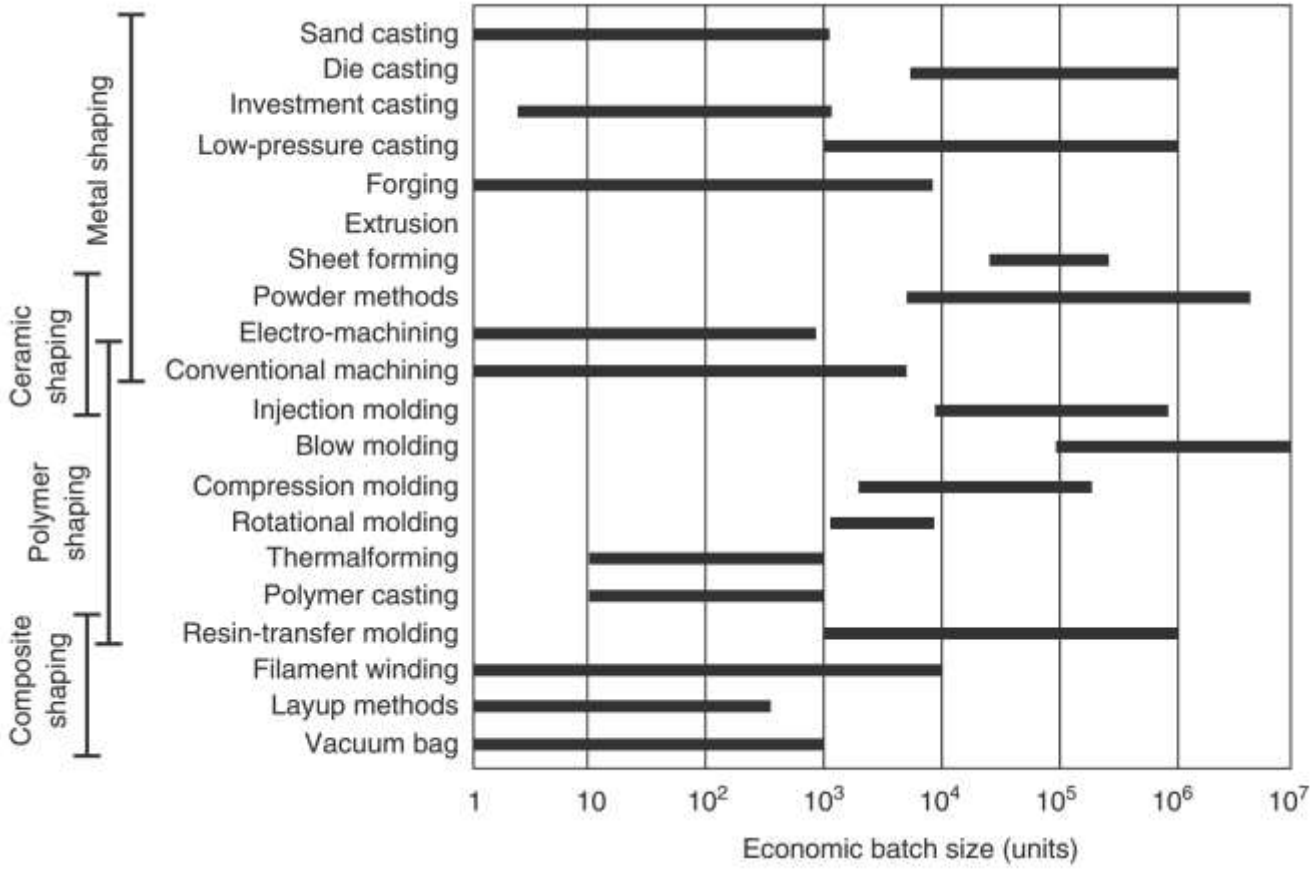


Fig. Cost of production process vs batch size [Dieter 2009]

Plastic injection molding, casting, punching requires expensive tooling. It could be economy justify only then number of pieces is high. More details are presented on Fig.

Another limitation during designing a product is manufacturing capacity of a company. If new technology is needed there are two solution. Company can buy new machines (technology) or order components form subcontractor.

Mechanical design process

Once the project of a product is developed it should be evaluated. **Evaluation** is done, based on model of product, for two main purpose. Firstly to get information if customers requirements and others related to safety, standards, regulations etc. are meet and in what extent. Secondly to improve the product according to the adopted criteria - optimization.

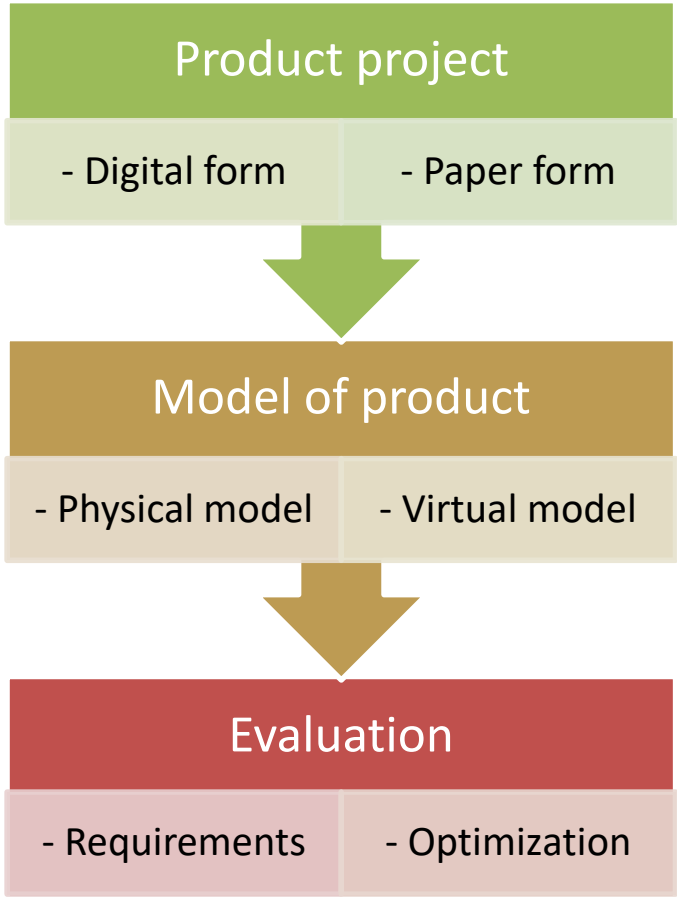


Fig. Evaluation of product

Mechanical design process

Model of product is realized as virtual or physical.

Physical model have the following ***advantages*** (in compare to virtual model):

- can be without any simplification,
- all phenomenas are included during testing,
- results are certain for tested conditions,
- complexity of product is not a barrier.

Disadvantages:

- building physical model is expensive and to analyze the influence of parameters usually several prototypes must be build or prototype with special construction,
- range of analyzed parameter can be lesser,
- smaller capacity of rearranging the product structure,
- building and testing can required more time.

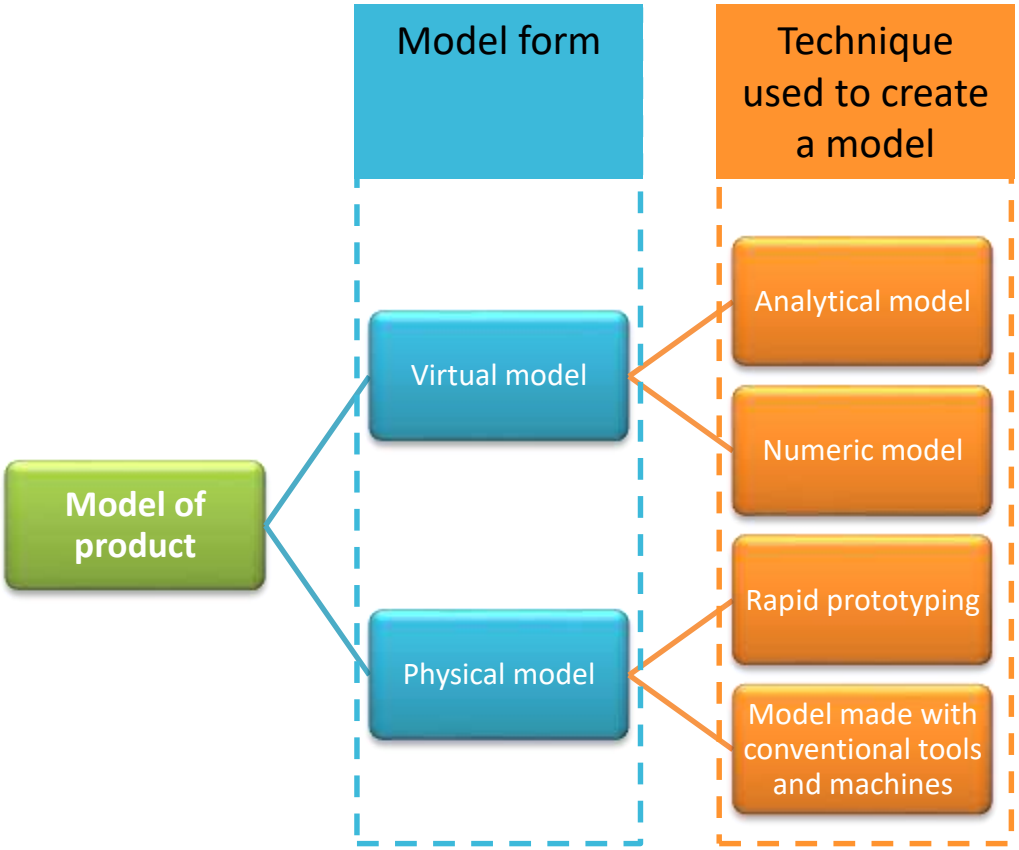


Fig. Realization of product model

Mechanical design process

Virtual model have the following ***advantages*** (in compare to physical model):

- time of building and testing usually can be clearly shorter,
- usually is less expensive,
- results can be obtained for a larger number of parameters and for product with different configuration.
- study of the influence of one or several parameters without changing others is easy.

Disadvantages:

- results can be inaccurate:
  - not all phenomena are included and usually the interactions between them are neglected (e.g. heat and vibration),
  - model is always simplified,
  - greater likelihood of making a mistake,
  - not all data needed for simulation is available or precise,
- the objective of simulation is beyond the scope of knowledge.

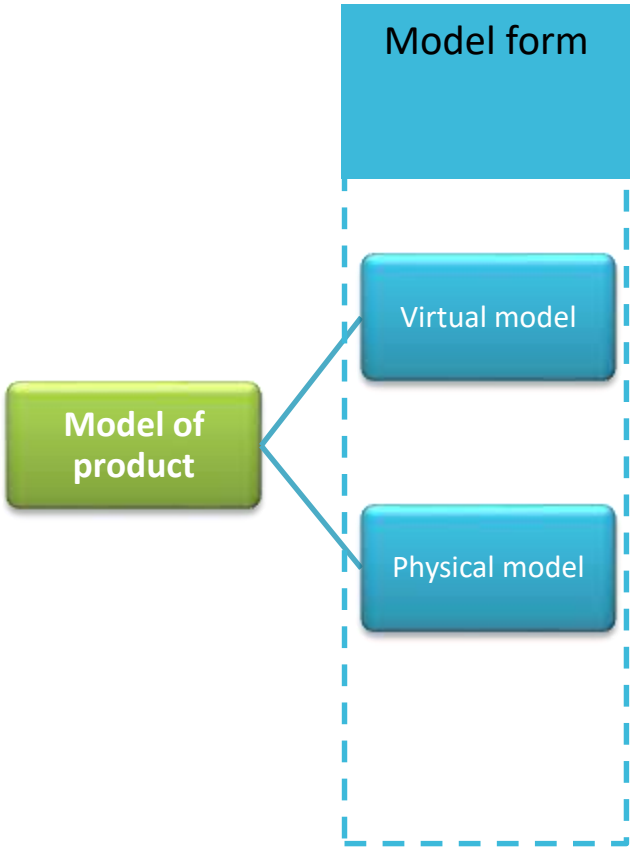


Fig. Realization of product model

Mechanical design process

Virtual model is most often in the form of analytical or numerical model.

Analytical model is represented by equation or equations which form is known and exact solution can be achieved. Usually engineer write them on the paper or in digital form in software. Currently solving this equation(s) is made by numerical methods by two reasons: it is much faster way or there is no (known) exact solution and result can be obtained only by numerical methods (semi-analytical model).

Numerical model is represented by equations that do not have exact solution. Most often this equations are not write by an engineer and there is no possibility to see them. Engineer creates equations indirectly by defining components, type of connections, material, etc. using computer software.

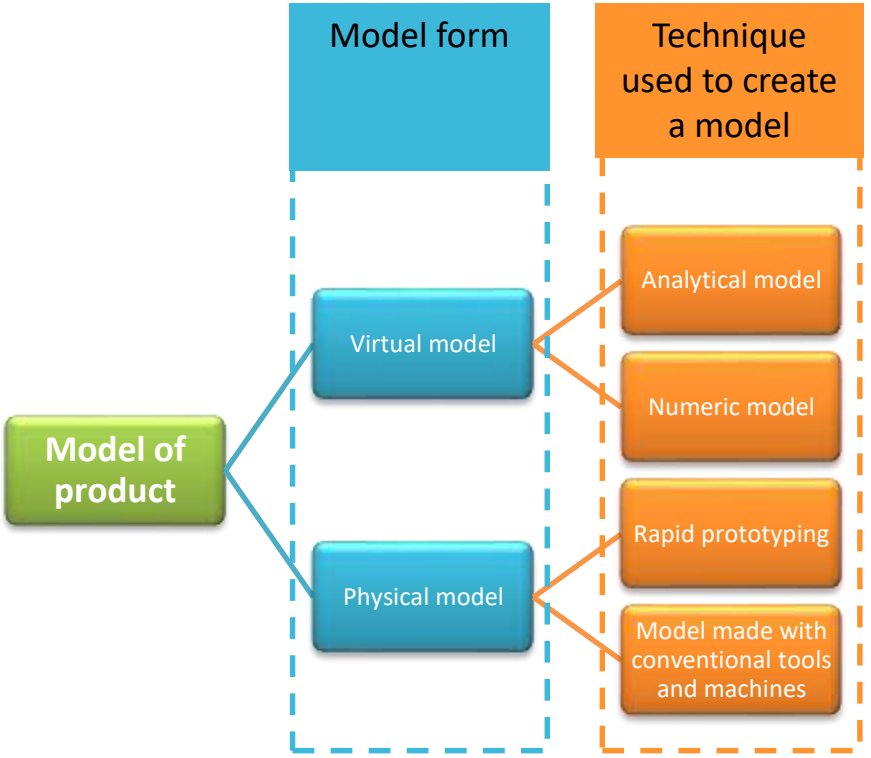


Fig. Realization of product model

Mechanical design process

Physical model is a prototype which could be exact as in the project or it could be modified to study the influence of design changes.
Technique used to create a prototype have influence on time, cost and material that is used to manufacture it. Rapid prototyping is a set of methods that enables quick and relatively cheap production of prototype. The material is usually a plastic. If there is a need of using metal traditional machines are used.

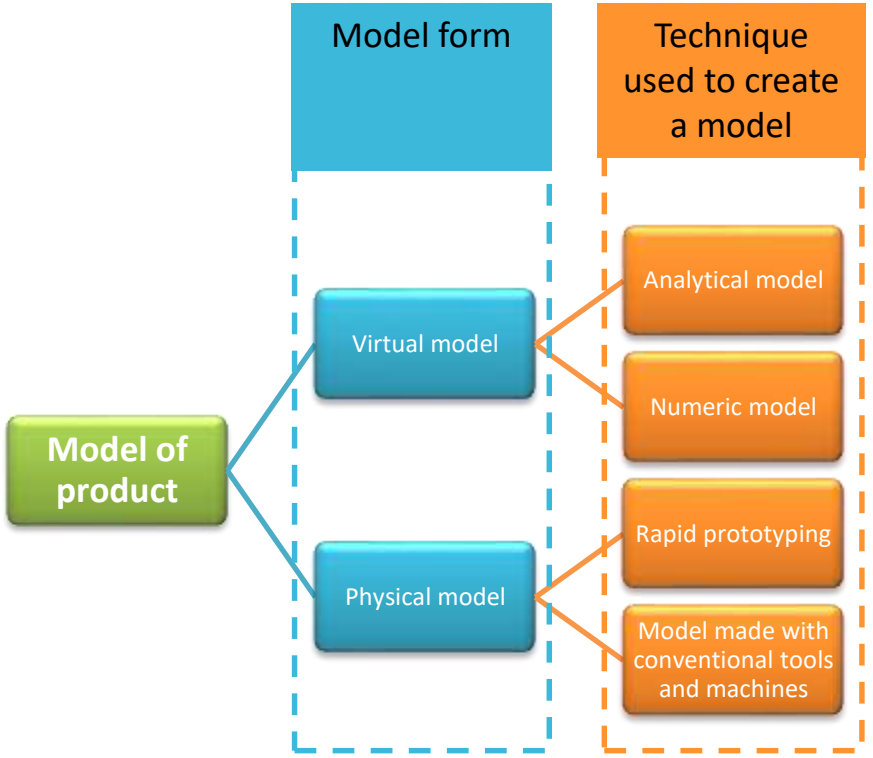
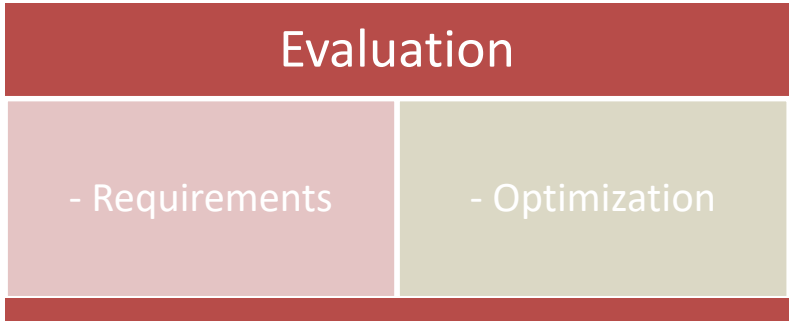


Fig. Realization of product model

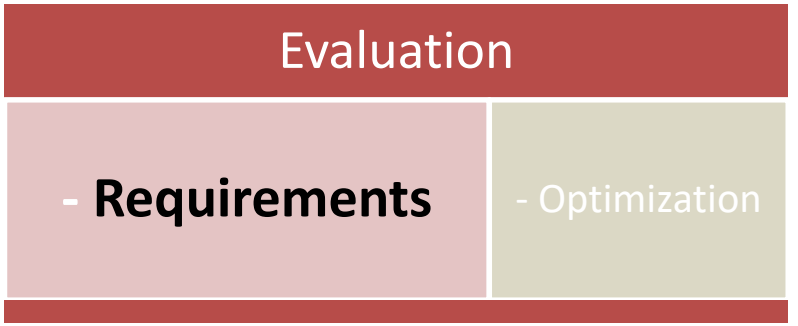
Digital form of a project ease of creating a model of product as physical or numerical. Solid model from CAD software can be used directly in rapid prototyping and also serves as input to generate code on CNC machines in CAM (computer aided manufacturing) software.
Numerical model can be created in CAE (computer aided engineering) software and CAD model is a starting point. Example of numerical analysis are FEM (finite element method) or MBS (multibody simulation).

Mechanical design process



Evaluation of a project based on model is done to retrieve precise information about a future product. Some of his functions, parameters and properties are critical and without their fulfillment on acceptable level product cannot be sell or it wont be profitable. The sources of this ***requirements*** are from legal obligation and customers needs. Other parameters, functions or properties can be ***optimize*** to increase profit and better protect the environment.

Mechanical design process



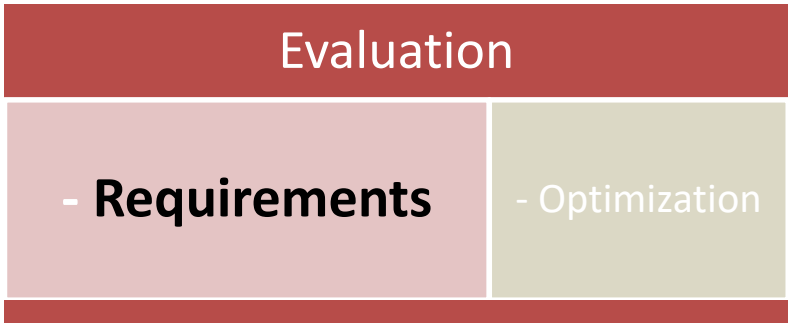
Legal obligations are determined by a destination market and type of product. It could be a level of vibration or sound pressure, size and type of material of parts (e.g. toys for children), emission of CO_2 (e.g. combustion engines), minimal efficiency, etc.

Products have different functions to meet various customers needs. But several needs of customers are the same regardless to the type of product and they are: works as it should, work long, easy to use, safe and with minimal maintenance.

This universal expectations and related to specific product can be ensured by:

- robust design,
- tolerance analysis,
- design for reliability,
- design for maintainability and repair,
- design for safety,
- testing.

Mechanical design process



Robust design (Taguchi method) is a method of development of robust product. Robust means that even manufacturing variation, outside condition like contamination, different temperature, load, speed, wear of components etc. product does it job. The idea is to determined values of design parametrs that lead to small variation of the response. In the other words influence of noise on product performance is minimalized.

It is quite complex method in which information is recieved mainly from experiments.

Mechanical design process

Evaluation

- Requirements

- Optimization

Tolerance analysis is treated as a separate method or as a part of robust design. Manufacturing operations are characterized by specific nominal tolerance. Tighten the tolerance to be smaller then nominal can increase cost of production significantly. It should be analyzed if tighter tolerance is necessary (does it support quality and functions of product?) or maybe redesign is possible and it will be cheaper solution.

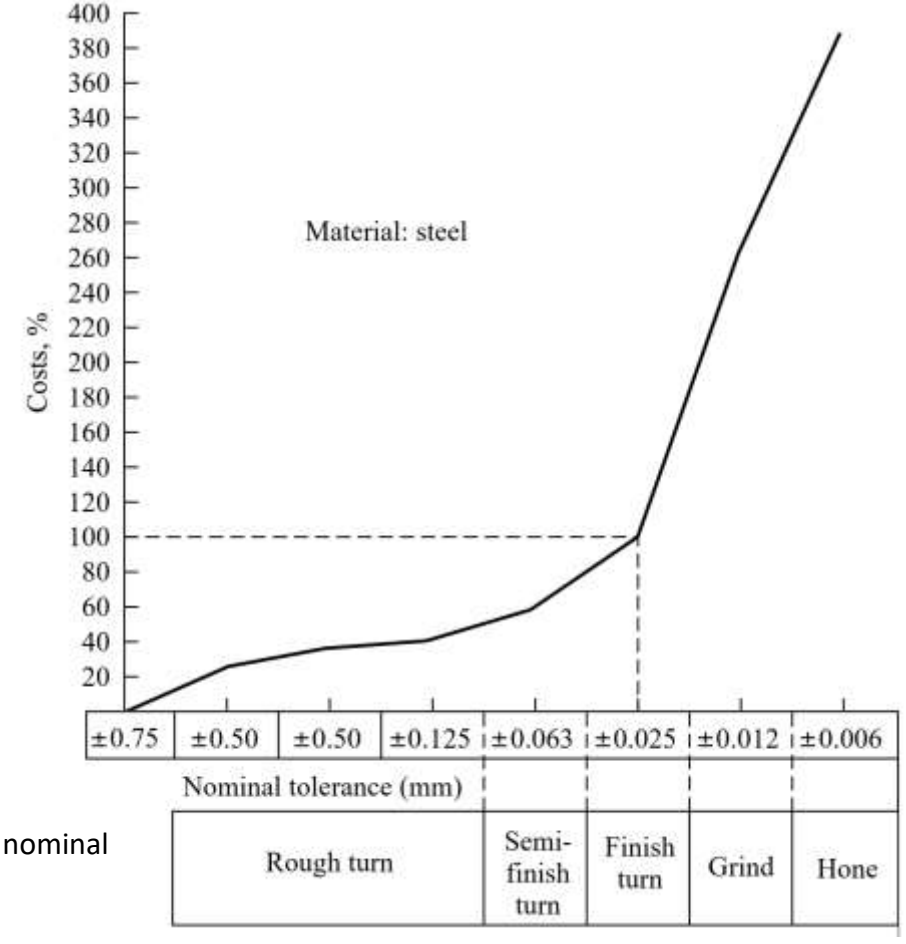
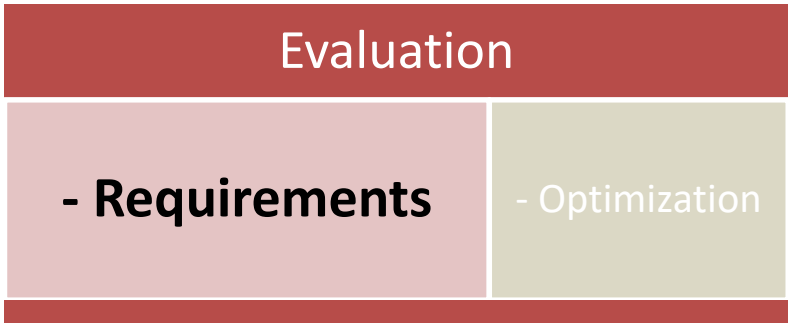


Fig. Production cost vs nominal tolerance [Ullman 2010]

Mechanical design process



Design for reliability

Reliability is a probability measure of capability of product to operate without failure. Failure is understood, in this case, as an inability to perform the function on acceptable level.

Design for reliability means that reliability of a product is analyzed and established goal is achived.

There are different techniques and methodologies that help identify the weekest parts of product, assess the reliability and improve product: Failure Mode and Effects Analysis (FMEA), Fault Tree Analysis (FTA) and other mainly for process: Hazard and Operability study (HAZOP), Event Tree Analysis (ETA)

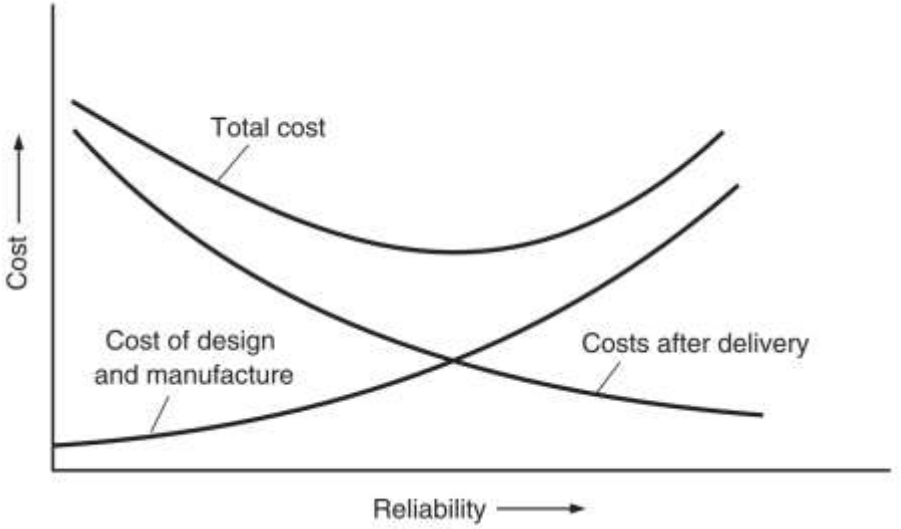
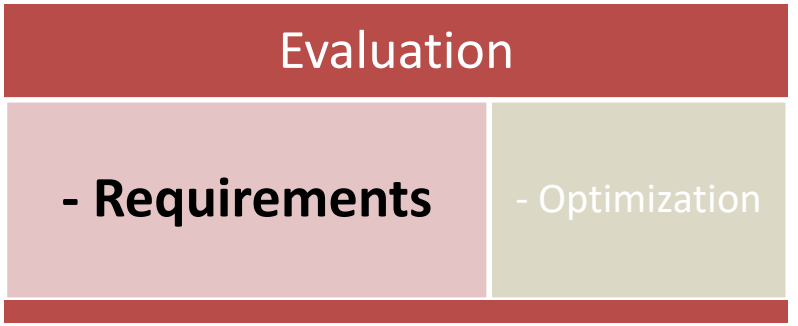


Fig. Cost vs reliability [Dieter 2009]

Mechanical design process



Design for maintainability and repair

According to the goals of this method product is easy to diagnose and repair. It is not only positive aspect for customer but also for the environment.

Design for safety

Safety product is not created by a chance. Engineer is responsible for this issue and if there is a design mistake that causes injury, property loss or environmental damage he can be convicted. Potential hazard must be recognized and solutions should be applied. There are three types of ways to make the product safe:

- design safety directly into product (best method but not always possible),
- add protective devices,
- warning objects like labels etc. (the weakest method).

Testing

For high quality products and those of great importance testing is obligatory. Only by testing prototype (physical model) it could be assured ultimate safety, reliability and performance.

Mechanical design process

Evaluation

- Requirements

- Optimization

Making product in great amount give possibility of optimization especially for:

- manufacturing,
- assembly,
- value,
- environment.

Design for manufacturing

The main purpose of this strategy is to produce components in economic way (the range of the strategy is not broadly accepted).

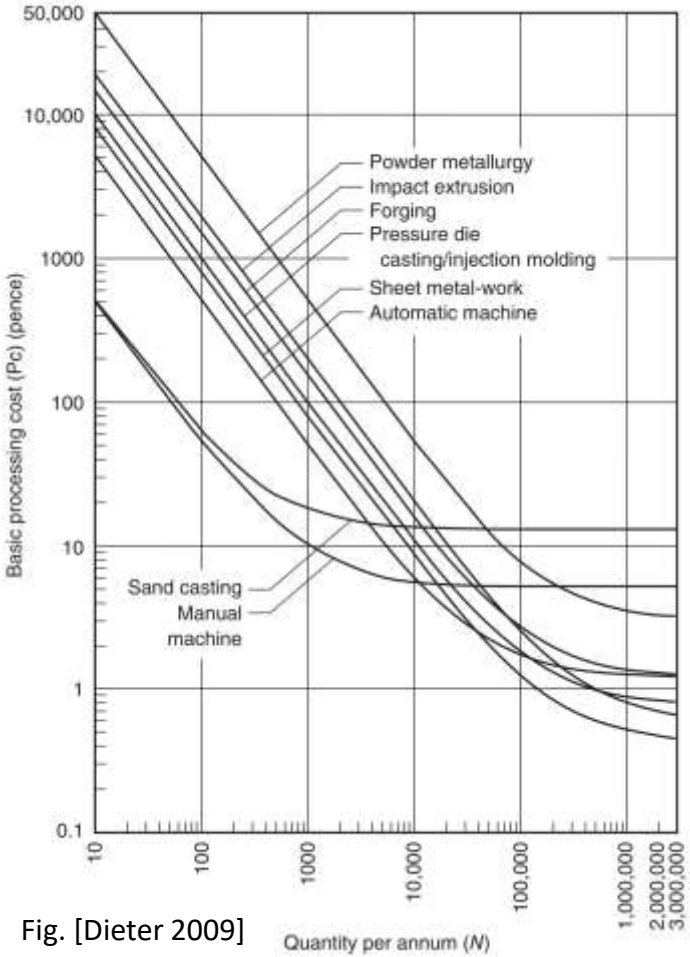


Fig. [Dieter 2009]

Mechanical design process

Evaluation

- Requirements

- Optimization

Design for manufacturing

Decision about material and type of manufacturing process have influence on final price of component.

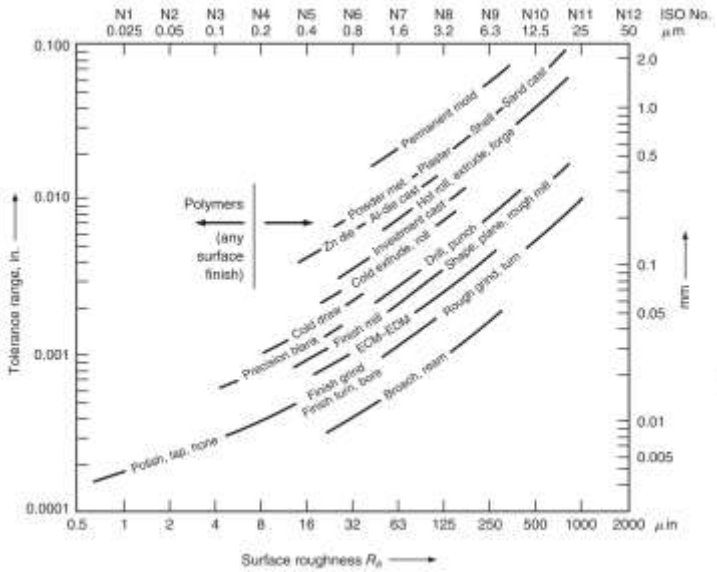
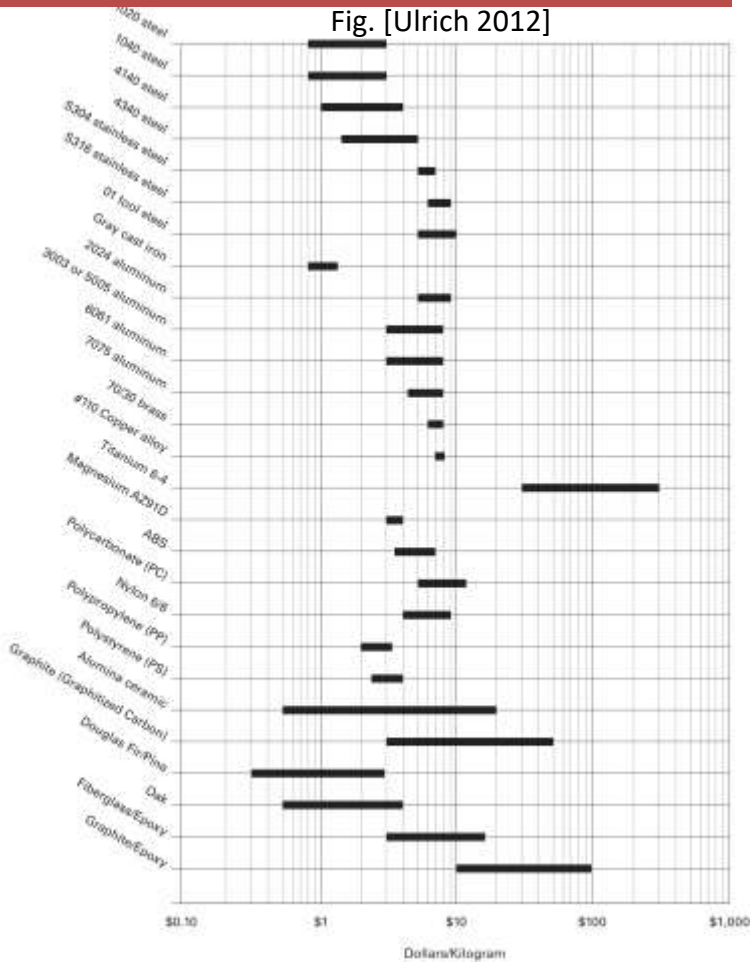


Fig. Tolerance and surface roughness vs material and process [Dieter 2009]

Fig. [Ulrich 2012]



Mechanical design process

Evaluation

- Requirements

- Optimization

Design for assembly

Then cost of assembly is relevant optimization can bring expected savings. There are many guidelines like: min. number of components, min. numbers of separate fasteners (nuts and bolts), components should fit to each other only in one position, use subassembly etc.

This methodology is wrongly use if cost is the only criterion. Dismantling also should be provide in not difficult way. This support replacement of damaged component essential for environment and low cost of exploitation by customer.

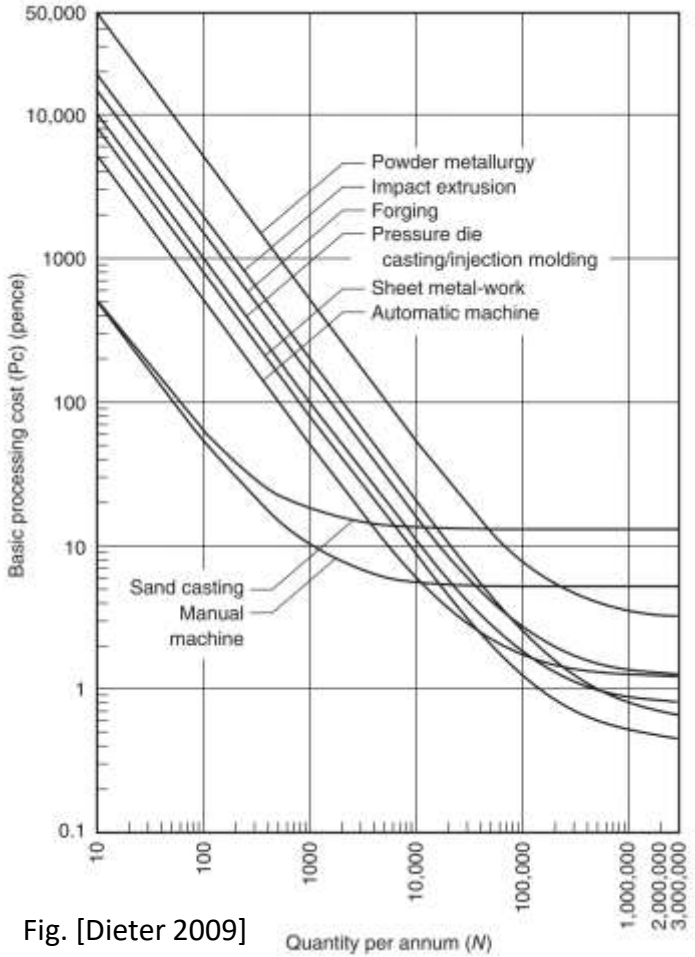
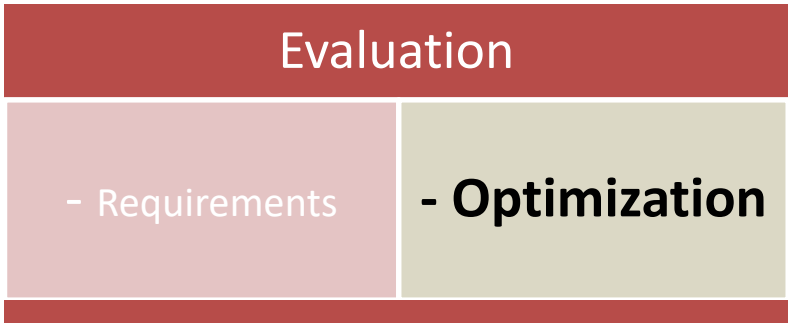


Fig. [Dieter 2009]

Mechanical design process



Design for value

The key point of this methodology is to assess not only the cost of the feature, component and assembly but it's value for customer. Value is defined as worth of a feature, component or assembly to cost. Worth is obtained based on functionality that feature, component or assembly provide to the customer.

If value is low redesign could be a good solution.

Mechanical design process

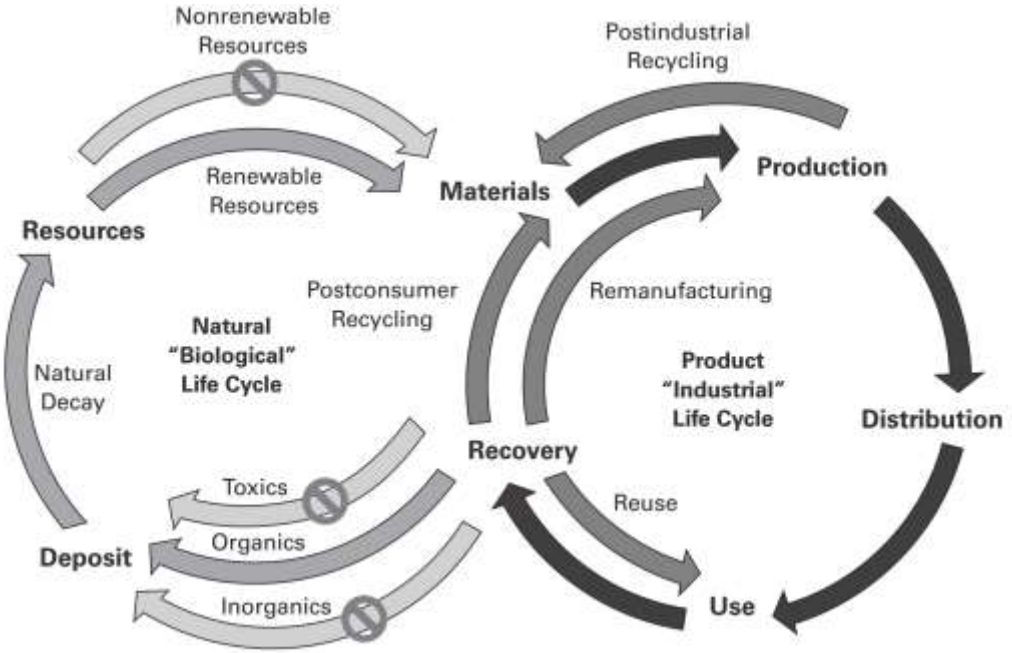
Evaluation	
- Requirements	**- Optimization**

Design for environment

Government laws concerning the environment must be meet but they should be treated as minimal requirements. This ethical behavior favor good public image of company and meets the expectations of customers. Some factors that are good for environment:

- product made of materials that could be recycled,
- high efficiency of product (lower energy consumption),
- long lasting products (lower pollution and energy consumption),
- product easy to dismantling with material markings on components,
- product with low emissions of harmful compounds.

Fig. Natural and product life cycle [Ulrich 2012]



Mechanical design process

Product support

After the final project is accepted designer engineers still have work to do. Documentation concerning: quality control, assembly, installation, operating and maintenance is created by them or with their contribution. Design engineers support subcontractor, customers and in general life of the product form the beginning to end.

Perfect project and product do not exist and sometimes some changes are made in final documentation.

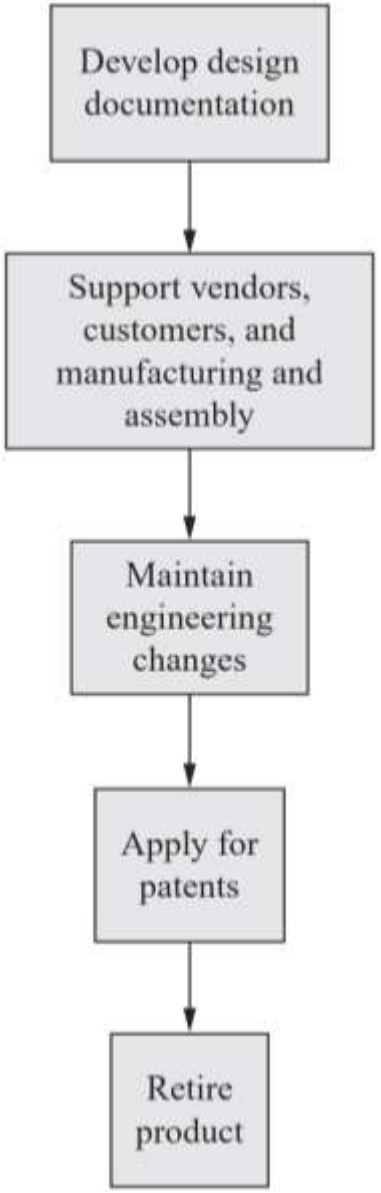


Fig. Product support [Ullman 2010]

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4. Meredith Wood: 7 PROJECT MANAGEMENT TYPES AND WHEN TO USE THEM, https://www.projectsmart.co.uk/7-project-management-types-and-when-to-use-them.php
5. Part of Fig. on first slide is from: https://ied.eu/project-updates/startup-ideas-for-1000-euros/