DEN 429

Class Notes

9/10/19

Updated 9/4/2022

1. Introduction to the Mechanical Design Process

Key Questions

1. What is the stage-gate design process?

2. What are the phases?

3. What are the gates?

4. What is the “Fuzzy Front End” of the design process?

5. What are the stages of the Product Life Cycle?

6. What makes design hard?

7. What is the design process paradox?

8. What are the Hannover Principles.

9. Who decides what the quality of a product should be?

10. Who was Dr. Edward deBono? What is the meaning of concept of lateral thinking?

11. Should you file for a patent to protect your design?

12. How will the design process change in the future? What are the main driving forces of this change?

- The design process is the organization and management of people and the information they develop in the evolution of a product.
- The success of the design process can be measured in the cost of the design effort, the cost of the final product, the quality of the final product, and the time needed to develop the product.
- Cost is committed in the design process, so it is important to pay attention to early phases.
- Cross-functional engineering integrates all the stakeholders from the beginning of the design process and emphasizes both the design of the product and concern for all processes-the design process, the manufacturing process, the assembly process, and the distribution process.
- All products have a life cycle beginning with establishing a need and ending with retirement.
- The mechanical design process is a problem-solving process that transforms an ill-defined problem into a final product. Design problem have more than one satisfactory solution.
- In problem solving there are seven actions to be taken: establish need, plan, understand, evaluate, decide, and communicate.
- Design Paradox: as knowledge is gained design freedom is diminished.
- The design process includes project definition, product definition, conceptual design, and product development.
- Design for sustainability is the necessary component of every design process.

- The Hannover Principles are:

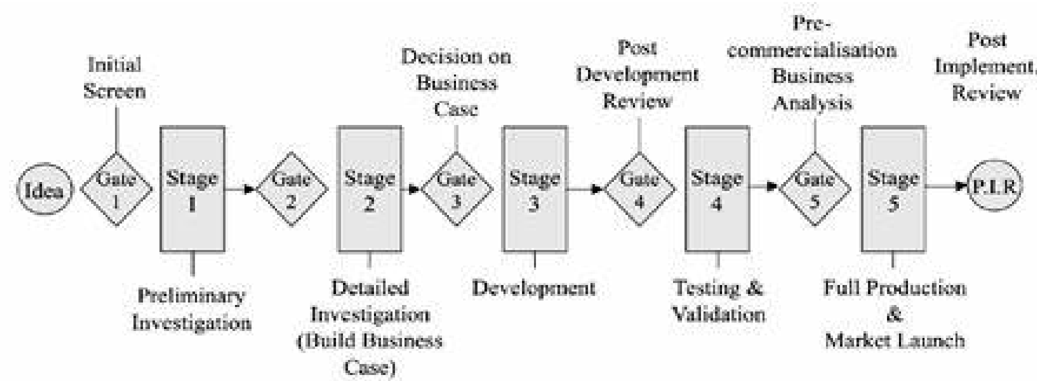
  1. Insist on rights of humanity and nature to coexist
  2. Recognize interdependence between the elements of human design and the natural world
  3. Accept responsibility for the consequences of design
  4. Create safe objects of-long term value
  5. Eliminate the concept of waste
  6. Rely on natural energy flows
  7. Understand the limitations of design
  8. Seek constant improvement by the sharing of knowledge
  9. Respect relationships between spirit and matter

  and, in summary

  You are responsible for the impact of your products on others

- What makes design hard?
  1. Design problems have multiple possible answers
  2. As knowledge is gained design freedom is lost
  3. Decisions are made throughout the design process based on uncertain, incomplete, and conflicting information. Designers will never have perfect information.
- Customers are the ultimate deciders what the quality of a product should be. Do not overdesign just because you can. There may be no willingness or ability to pay for the higher level of quality. The concept of Six Sigma is very often misunderstood and misapplied. It does not mean that the output of the production should be always perfect (3.4 defects over 1 million units produced). The important variable is what is the range of tolerances in performance and characteristics that customers expect. The narrower the interval between the Upper Control Limit and the Lower Control limit then the production project should be more stringent. The wider the interval then the production process would be less stringent. Both would deliver the Six-sigma quality but the quality levels would be different.

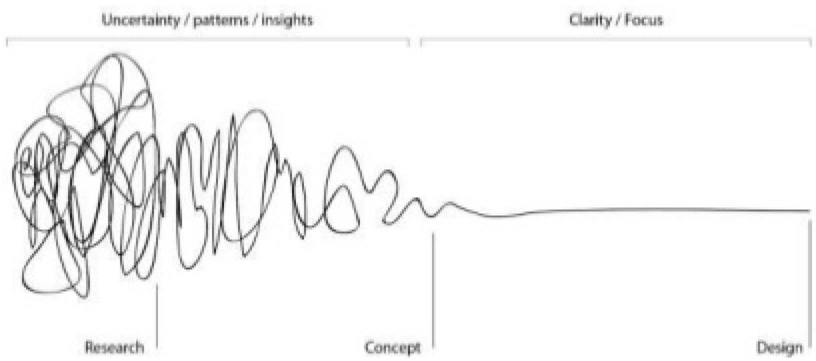
- The Stage-Gate systematic, design process enables senior management maintain control of the process by requiring a review after each major milestone (Gates). Further funding is allocated after each successful gate review.



- The "Fuzzy Front End" is the time period were ideas are freely generated (The Idea step shown on the chart above). Below it is another illustration of that part of the process:

Guiding Concept

The Fuzzy Front-End



- The initial phase before the actual start of the project is ill-defined, random and mysterious (Smith & Reinertsen, 1991; Rhea, 2003).
- Improving the initial phase may have an impact on the entire project. (Reid & De Brentani, 2004)
- Corresponds to the “phase of unfreezing“ (Lewin, 1963)

- Creativity can be learned. The “out-of-the box”-lateral thinking is his recommended approach for designers (Edward deBono).
- The “Fuzzy Front End” of the process is based on creative thinking-seeing something that nobody else can see.
- Patents give you bragging rights and a license to litigate. They are expensive and do not provide the necessary protection to inventors.

- The influencers that will change the design process include”
- Design for sustainability, additive manufacturing, and design for the connected world

2. Understanding Mechanical Design

Key Questions

1. What is the relationship between the form and the function?

2. What can you learn from reversed engineering?

3. Who determines product quality? Should six-sigma always be the key objective?

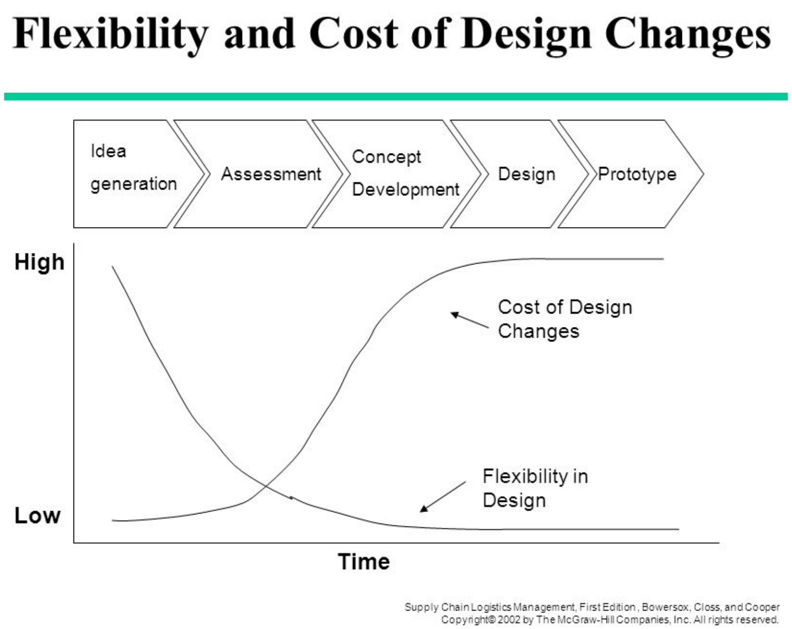
4. Is the lowest cost always the design requirement? Should it be?

5. Is the quickest time to market always the key objective? Should it be?

6. The trade-offs of design changes.

- A product can be divided into functionally oriented elements. These are made-up of mechanical assemblies, electronic circuits, and computer programs. Mechanical assemblies are built of various components.
- The important form and function aspects of mechanical devices are called features.
- Function and behavior tell what a device does; form describes how it is accomplished.
- Function relates desired behavior.
- One component may play a role in many functions, and a single function may require many different components.
- There are many different types of mechanical design problems: selection, configuration, parametric, original, redesign, routine, and mature.
- Mechanical objects can be described semantically, graphically, analytically, or physically.

- The design process is a continuous constraining of the potential product designs until one product finally evolves. This constraining of the design space is made through repeated comparison with the design requirements.
- Mechanical design is the refinement from abstract representation to a final physical artifact.
- The most valuable information is the decisions that are communicated to others.
- Product decomposition (reversed) engineering is a useful and legal way to understand the structure and the architecture of a product. It can be applied to study the design of competitive products.
- The concept of " Six-sigma" is applied to the production process control. It should not be the key objective of a product design effort.
- The "design to cost" considerations should be based on the target customers " willingness and ability to pay.
- The appropriate level of quality should be built-in not tested out.
- The "time-to-market" is important but not in all cases. It is better to design a more reliable product than incur the cost of recall, warranty service, and the market cost of negative publicity.
- The costs and trade-offs of design changes are shown below:



3. Designers and Design Teams

Key Questions

1. What are the key cognitive characteristics of designers?

2. Can creativity be learned?

3. Are engineers creative?

4. Who makes better decisions: a team or an individual?

5. Is a process design a problem-design process?

6. What is the purpose of cross-functional integration?

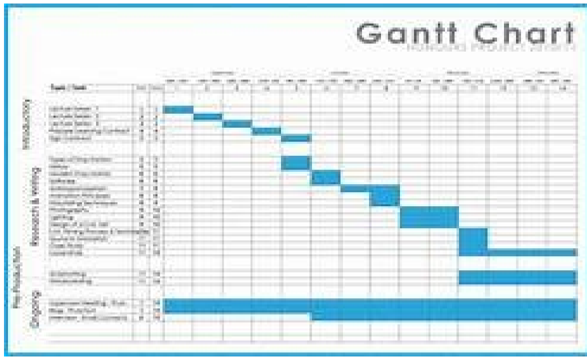
7. When would you implement each of these team structures: light, medium, heavy, or stealth?

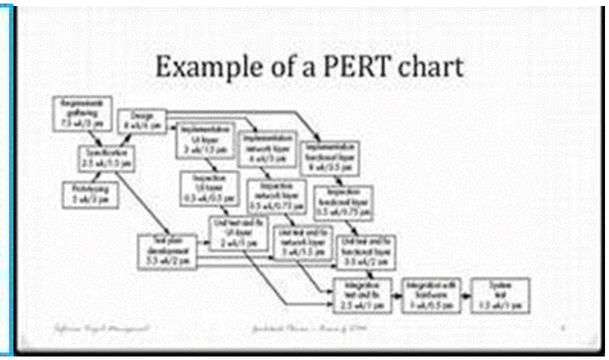
8. Should projects have their project plans?

- The human mind uses the long-term memory, the short- term memory, and a controller in the internal environment in problem solving.
- Knowledge can be considered composed of chunks of information that are general, domain-specific, or procedural in content.
- The short-term memory is a small and fast processor. Its properties determine how we solve problems. We use the external environment to augment the size of the short-term memory.
- The long-term memory is the permanent storage facility in the brain. IT is slow to remember, it is fast to recall, and it never gets full.
- Creative designers are people of average intelligence, they are visualizers, hard workers, constructive nonconformists with knowledge about the problem domain. Creativity takes hard work and van be aided by a good environment, practice, and design procedures.
- Because of the size and complexity of most products, design work is usually accomplished by teams rather than individuals.
- Working in teams requires attention to every team member's problem-solving style-introvert or extrovert, fact or possibility oriented, objective or subjective, decisive or flexible.
- Teams make better decisions than individuals. The most effective are the cross-functional, multi-disciplinary teams.

- There is a relationship between the reporting structure, level of responsibility and authority delegated to a team, and the strategic significance of a project: light structure: repositioning and small adjustments, mid weight structure: more significant product changes. heavy: aimed at new product/new market effort, stealth: the most significant impact of the future of the company.
- Functional “Silos” are detrimental to the successful product development process.
- The cross-functional integration mitigates this problem (as also illustrated in the text):

- It is of extreme importance that project teams develop a project plan at the very beginning of the design cycle.
- There are two types of project plans: Gantt(deterministic) and PERT(probabilistic). More in the Power Point presentation.





4. The Design Process

<u>Key Questions</u>

1. What are the phases of the mechanical process design?

2. What is needed for a successful design review?

3. Having a standard design process necessary?

4. Should quality be designed-in or tested out of a product?

5. What is a product definition phase?

6. What is a project definition phase?

7. What is a conceptual design phase?

8. What is a product development phase?

9. What is the product support phase?

- There are specific design process techniques to support the planning, specification development, conceptual design, and product design phases of the design cycle.
- The techniques help to design effort in its earliest stages, where the major decisions are made. Additionally, the techniques encourage communication, force documentation, and encourage data gathering to support creativity.
- Communication is an integral part of the design process.
- The design process consists of a series of decisions.
- The design process focuses effort on early stages, when the major decisions are made and quality benchmarks are defined.
- The project definition phase of the design process includes activities to discover, choose, and plan design projects.
- The conceptual design phase of the design process focuses on concept generation, evaluation, and decision making.
- The product development phase of the design process includes activities that help refine a concept into a product.
- The product support phase includes activities that occur after the product is in production and includes its support, changes, and retirement.
- The quality, as defined by customers should be designed in and not tested out.

5. Project Definition

Key Questions

1. Does one type of plan fit all design projects?

2.What is a difference between a waterfall and a spiral plan?

3. How can a plan be developed when the future is so uncertain?

4.What are the sources of new concept ideas?

5. What does it mean for product to be mature?

6. What is a decision tree approach to project planning?

- Planning is an important engineering activity
- Progressive companies have a generic product development process that serves as a basis for planning each product development activity.
- Design projects commonly fall into one of four types: variation of an existing product. Improvement of an existing product, development of a new product for low volume production, and development of new products for high volume production.
- Design teams may have representatives from many different disciplines, and they may be organized in one of five different structures.
- The use of prototypes and models is important to consider during planning.
- There are five planning steps: identify the task, state their objectives, estimate the resources needed, develop a sequence, and estimate costs.
- Design projects originate from market pull, technology push, or product design
- Choosing which projects to undertake is critical to the efficient use of resources.
- The goal is to design a plan to meet the needs of the project.
- There are six basic decision-making activities: clarify the issue, generate alternatives, develop criteria, identify criteria importance, evaluate the value of the alternatives, and decide what to do next.

6. Product Definition

Key Questions

1. How can you identify the “customers” for a product?

2. Why is it so important to understand the voice of the customer and work to translate this into engineering specifications?

3. How can you best benchmark the competition to understand design and business opportunities?

4. How can you justify taking time at the beginning of a project to do specification development instead of developing concepts immediately?

- Understanding the design problem is best accomplished through a technique called quality function deployment (QFD). This method transforms consumers requirements into targets for measurable engineering requirements.
- Important information to be developed at the beginning of the problem includes consumers’ requirements, competition benchmarks, and engineering specifications complete with measurable benchmarks.
- Time spent completing the QFD is more than recovered later in the design process.
- There are many customers for most design problems.
- All design problems are poorly defined
- Your decisions, good or bad, affect everyone downstream.

8. Concept Evaluation and Selection

Key Questions

1. How can rough conceptual ideas be evaluated without refining them?

2. What is technology readiness?

3. What is the decision matrix?

4. How can I manage risk?

5. How can I make robust decisions?

- The feasibility of a concept is based on the design engineer's knowledge. Often it is necessary to augment this knowledge with the development of a simple models.
- For the technology to be used in a product, it must be ready. Six measures of technology readiness can be applied.
- Product safety implies concern for injury to humans and for damage to the device itself, other equipment, or the environment.
- Safety can be designed into a product , added on, or warned against. The first of these is best.
- A mishap assessment is easy to accomplish and gives good guidance.
- The decision-matrix method provides means of comparing and evaluating concepts. The comparison is between each concept and a datum relative to the customers' requirements. The matrix gives insight into strong and weak areas of concepts. The decision-matrix method can be used for subsystems of the original problem.
- An advanced decision matrix method leads to robust decisions by including the effects of uncertainty in the decision-making process.
- Belief maps are simple yet powerful way to evaluate alternatives and work to gain team consensus.

9. Product Generation

Key Questions

1. What are the steps to turn an abstract concept into a quality product?

2. What is a BOM?

3. In what order should we consider constraints, configuration, connections, and component during the design of parts and assemblies?

4. How can force flow help in the design of components?

5. Who should make the parts you design?

- A bill of material in a parts list-an index to the product.
- Products must be developed from concepts through concurrent development of form, material, and production methods. This process is driven by the functional decomposition.
- Form is bound by the geometric constraints and defined by the configuration and connected components.
- The development of most components and assemblies starts at their interfaces, or connections, since for the most part functions occur at the interfaces between components.
- Product development is an iterative loop that requires the development of new concepts, the decomposition of the product into subassemblies and components, the refinement of the product toward a final configuration, and the patching of features to help find a good product design.
- Vendor selection in an important part of the design process.

10. Product Evaluation for Performance and the Effects of Variation

Key Questions

1. What is best to evaluate the product performance, analytical models or physical testing?

2. What is a P-diagram and how does it help identify noise?

3. How are trade-offs made?

4. What are the three types of noises and how do they affect product quality?

5. Why is tolerance stacking important during assembly?

6. How is robust design used to ensure quality?

- Product evaluation should be focused on comparison with engineering requirements and also on the evolution of the function of the project.
- Product should be refined to the degree that their performance can be represented as numerical values in order to be compared with engineering requirements.
- P-diagrams are useful for identifying and representing the input signals, control parameters, noises, and output response.
- Physical and analytical models allow for comparison with the engineering requirements.
- Concerns must be shown for both the accuracy and variation of the model.
- Parameters are stochastic, not deterministic. They are subject to three types of noises: the effects of aging, the environment change, and of manufacturing variation.
- Robust design takes noise into account during the determination of the parameters that represent the product. Robust design implies minimization the variation of the critical parameters.
- Tolerance stacking can be evaluated both by the additive method and by statistical means.
- Both analytical and experimental methods exist for finding the most robust design.

11. Product Evaluation: Design for Cost, Manufacture, Assembly, and Other Measures

Key Questions

1. What is the cost (DFC) and how can cost be estimated?

2. How can a product be easy to manufacture (DFM) and assemble (DFA)?

3. How do failure modes and effects analysis (FMEA), fault tree analysis (FTA), and design for reliability (DFR) help eliminate failures?

4. Can products be designed that are easy to test (DFT) and measure (DFM)?

5. What can a designer do to protect the environment through design for sustainability (DFS)?

- Cost estimation is an important part of the product evaluation process.
- Features should be judged on their value-the cost of the function
- Design for manufacture focuses on the production of components
- Design for assembly is a method for evaluating the ease of assembly of a product. It is most useful for high-volume products that have molded components. Thirteen guidelines are given for this evaluation technique. Also this best practice leads to design for disassembly, a consideration in sustainability.
- Functional development gives insight into potential failure modes. The identification of these modes can lead to design of more reliable and easier-to maintain products.
- Design for sustainability emphasizes concern for energy, pollution, and resource conservation in processing raw materials for products. It also emphasizes concern for recycling, reuse, or disposal of the product after its useful life is over.
- Avoid component characteristics that complicate retrieval
- Design components for a specific type of retrieval handling and mating
- A single part always costs something to manufacture
- It is beneficial to be consistent in the use of manufacturing methods
- All additively-manufactured parts cost the same to make.

- Every fastener adds costs and reduces strength
- Specify the smoothest surface the machine can make no matter what
- Design a part to be easy to hold
- Use generous fillets and chamfers
- Design so that whole part can be created on one machine
- When designing a part consider the disposal of a part, transportation of the product, energy consumed during its production, energy consumed during its design
- When designing a product consider: the probability of failure, the impact on the user, the MTBF, production materials, production process, transportation and logistics cost and requirements,
- Design your tooling and operations to be simple.
- Designers multiply their calculated stresses on a part by a " factor of safety" to anticipate all ways that a product will be used
- There is no such thing as a perfect design
- Ergonomics should not be ignored during the design process if they add to the cost point of a product.
- Design that part so it is easy to pull out and replace by a customer
- A plastic part that has extensive internal structure (structure not visible from any place outside the part) should be made using the injection molding process.
- There is no such a thing as a perfect product.
- TRL levels 8 or 9 technologies should be used for when designing for public.
- The cost of assembly is a significant component of the overall cost of production.
- 3D printing is best for prototyping small parts.
- Injection-molded parts should not have walls of varying thickness
- Cast-iron products are best produced by the use of a sand-casting method.
- Components that tangle add the most labor to an assemble process.
- A company should not make all the parts that it uses in its products.
- To do a dimensional analysis, we should reduce each term to: mass, length, and time
- If a part has a manufacturing tolerance of +/- 0.05, this does not mean that all such parts have the diameter of 0.05mm.
- 3D printed parts are created one layer at a time
- Design for Assembly guidelines include; end-to-end symmetry, symmetry around the axis of insertion, non-symmetrical components should be identified.
- A design with the fewest possible parts is easiest to assemble.
- A failure mode analysis should consider only the prescribed uses.

- Injection molding is manufacturing method that is used in long production runs.
- End-to-end asymmetrical components with small variance add the MOST work to an assembly process.
- Once you have your design finalized it would still be impossible to change it, but at a significantly higher cost.
- The prevailing American manufacturing philosophy is not the "continuous improvement" by eliminating variations.
- End-to-end symmetrical design of components add the LEAST work to an assembly process.
- The Design for Reliability guidelines include: the function affected, specific failure modes, the effects of failures, the causes of failures, the required corrective actions.
- The Design for Assembly guidelines include; avoid machining operations, specify the most liberal surface finish and tolerances,
- Design a component so it can be machined using one tool only, design components to be easy to hold, use generous fillers and chamfers
- The “Red Bead” experiment illustrates the effects of not understanding the methods and principles of SPC.
- The Failure Risk Assessment and Risk Management include the following steps; identify the objectives of analysis, identify failure modes, model the failure logic, compute expected values, decide on the failure and risk mitigation procedures.
- Design perfection is achieved not when there is nothing more to add, but rather when there is nothing more to take away.
- A Bill of Material is a list of all the parts that are needed to make a product.
- The rule of thumb states: Eighty percent of cost is typically incurred by 20% of components.
- Injection molding would be the most appropriate for a long-run manufacturing of small plastic parts.
- You should not design a part in such a way that it must be repositioned often during its assembly process.
- An inaccurate model is inaccurate no matter how small the variation.
- The following are guidelines for evaluation of component mating; Design components to mate through straight-line assembly- all from the same direction, make use if chamfers and leads to facilitate proper insertion and alignment, Maximize component accessibility.
- When designing a bookshelf at the lowest possible cost the following should be under consideration; material Cost vs. material strength, available small run manufacturing techniques, environmental impact.
- Costs generally increase exponentially with tighter tolerances
- T**he Design for Assembly guidelines include;** overall component count should be minimized, use the minimum number of separate fasteners, design the product with a base, do not require the base to be repositioned during assembly, make the assembly sequence efficient.
- **T**he Japanese manufacturing philosophy is “continuous improvement”.
- A single part always costs something to assemble.

12. Wrapping up the Design Process and Supporting the Product

Key Questions

1. What additional documents are needed to launch a product?
2. What is important in supporting of vendor and customer relationship?
3. How are engineering changes managed?
4. How can you apply for a patent?
5. What does it mean to retire a product?

Course Context: Applied Engineering Definitions

Applied engineering deals with the application of management along with design and technical skills required for designing new products. Integrating systems, execution of new product designs, improving the current manufacturing processes while managing and directing the physical or technical functions of a firm are also encompassed in this field.

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Applied Engineering Sub Disciplines

Applied Engineering has been divided into the following:

- Manufacturing execution systems,
- Supply chain management systems,
- Six sigma,
- Lean enterprises,
- Quality control,
- Motorsports management and technology
- Nano engineering technology

Definitions

Optimization means finding an alternative with the most cost effective or highest achievable performance under the given constraints, by maximizing desired factors and minimizing undesired ones.

In comparison, maximization means trying to attain the highest or maximum result or outcome without regard to cost or expense.

Practice of optimization is restricted by the lack of full information, and the lack of time to evaluate what information is available (see bounded reality for details).

In computer simulation (modeling) of business problems, optimization is achieved usually by using linear programming techniques of operations research.

Design means realization of a concept or idea into a configuration, drawing, model, mold, pattern, plan or specification (on which the actual or commercial production of an item is based) and which helps achieve the item's designated objective(s).

Process is a sequence of interdependent and linked procedures which, at every stage, consume one or more resources (employee time, energy, machines, and money) to convert inputs (data, material, parts, etc.) into outputs. These outputs then serve as inputs for the next stage until a known goal or end result is reached.