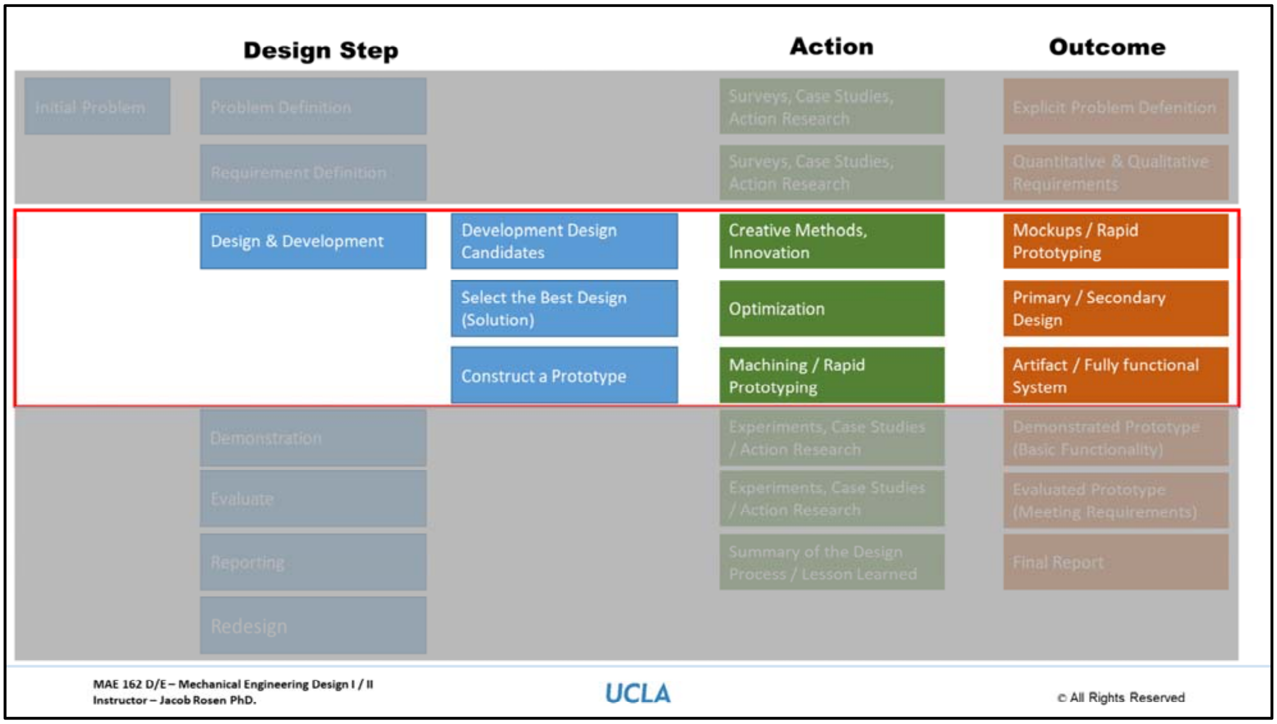
Design & Development

Developing Design Candidates
Select the Best Design (Solution)
Construct a Prototype

Design Process


Design Step
Action
Outcome
Initial Problem
Problem Definition
Surveys, Case Studies, Action Research
Explicit Problem Defenition
Requirement Definition
Surveys, Case Studies, Action Research
Quantitative & Qualitative Requirements
Design & Development
Development Design Candidates
Creative Methods, Innovation
Mockups / Rapid Prototyping
Select the Best Design (Solution)
Optimization
Primary / Secondary Design
Construct a Prototype
Machining / Rapid Prototyping
Artifact / Fully functional System
Demonstration
Experiments, Case Studies / Action Research
Demonstrated Prototype (Basic Functionality)
Evaluate
Experiments, Case Studies / Action Research
Evaluated Prototype (Meeting Requirements)
Reporting
Summary of the Design Process / Lesson Learned
Final Report
Redesign
MAE 162 D/E – Mechanical Engineering Design I / II
Instructor – Jacob Rosen PhD.
UCLA
© All Rights Reserved

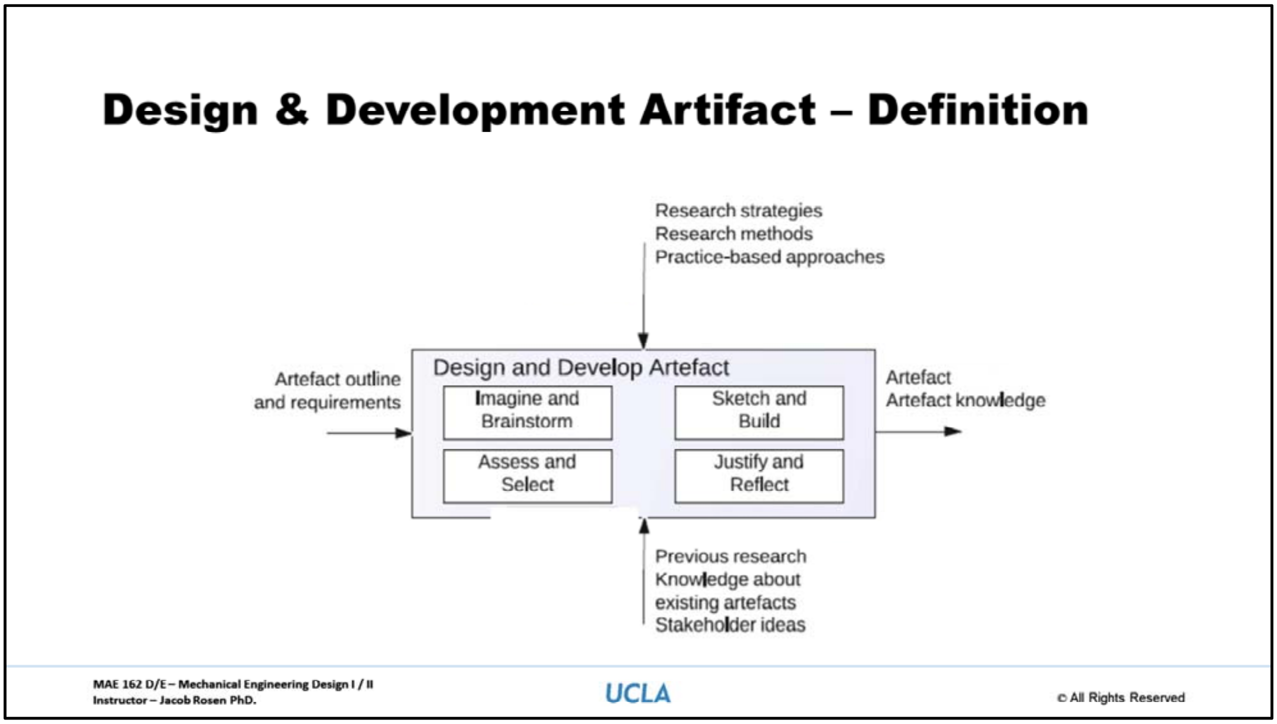
Design & Development Artifact - Definition

Create an artifact that addresses the explicated problem and fulfill the defined requirements.

MAE 162 D/E – Mechanical Engineering Design I / II
Instructor – Jacob Rosen PhD.

UCLA

The third activity of the method framework is Design and Develop Artefact, which creates an artefact fulfilling the requirements from the previous activity. This includes designing both the functionality and structure of the artefact. In other words, the activity can be expressed as follows:
Create an artefact that addresses the explicated problem and fulfils the defined requirements.
The primary result of this activity will be prescriptive knowledge, which can be embedded in the created artefact; see Sect. 2.2. Furthermore, the activity will produce descriptive knowledge about the design decisions taken and their rationale.

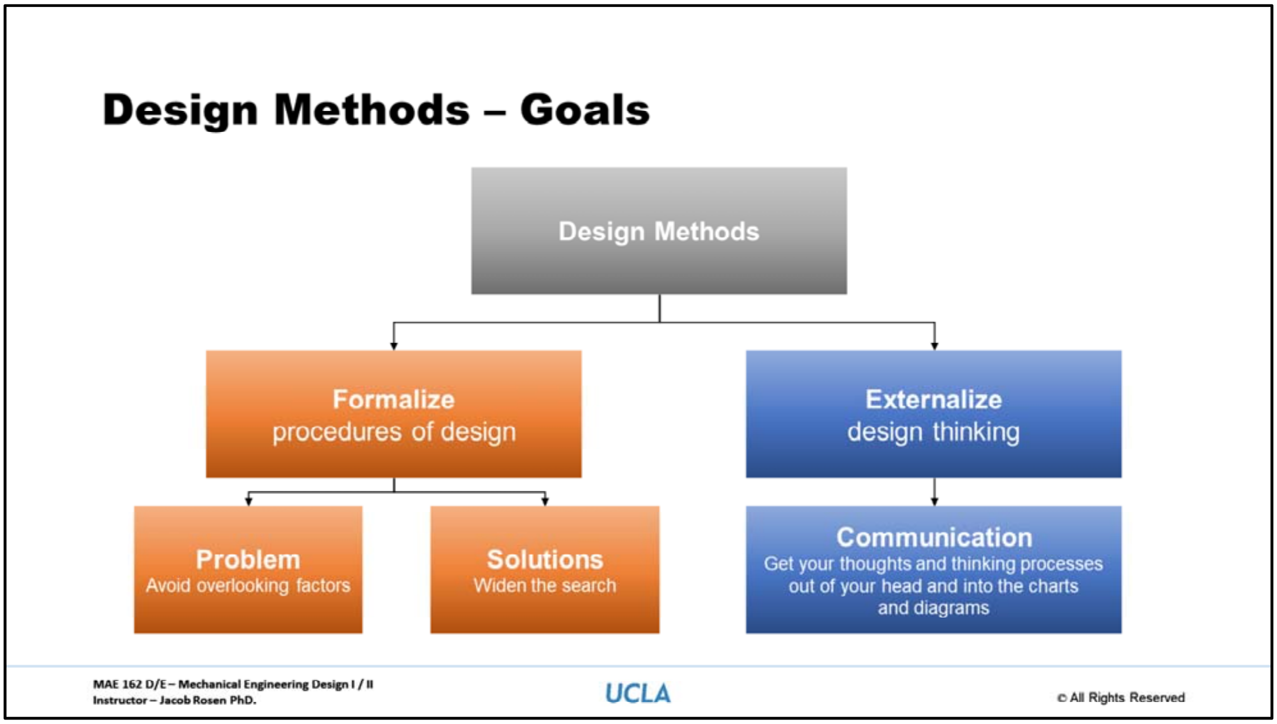


The activity Design and Develop Artefact can be structured and visualized as shown in Fig. 7.1. The input is an outline of the artefact and a set of requirements, which were provided by the previous activity. The output is an artefact that fulfils these requirements and the knowledge about it. The resources used by the activity consist of knowledge from the research literature and other written sources as well as knowledge embedded in artefacts and assertions from relevant stakeholders. The controls can include research strategies and methods and may also include any practice-based development approaches.

The activity Design and Develop Artefact can be structured and visualised as shown in Fig. 7.1. The input is an outline of the artefact and a set of requirements, which were provided by the previous activity. The output is an artefact that fulfils these requirements and the knowledge about it. The resources used by the activity consist of knowledge from the research literature and other written sources as well as knowledge embedded in artefacts and assertions from relevant stakeholders. The controls can include research strategies and methods and may also include any practice-based development approaches.

Reflect, the designers reflect about and argue for the design decisions that have been made. In practice, these sub-activities are carried out in parallel and iteratively.

The terms “design” and “development” have many different meanings in literature, and the relationships between them are often blurred. In this chapter, the sketch part of the sub-activity Sketch and Build can be seen as the design of an artefact, while the build part can be seen as the development of it. However, it could be argued that the two first sub-activities, Imagine and Brainstorm and Assess and Select, are also part of the design of the artefact. Moreover, many decisions made during development can be seen as design decisions.

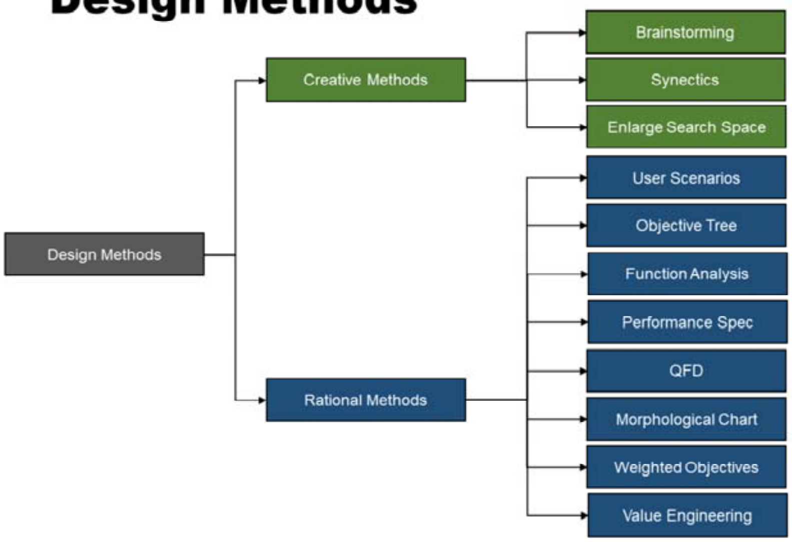


The new methods tend to have two principal features in common. One is that they *formalize* certain procedures of design, and the other is that they *externalize* design thinking. Formalization is a common feature of design methods because they attempt to avoid the occurrence of oversights, of overlooked factors in the design problem, of the kinds of errors that occur with informal methods. The process of formalizing a procedure also tends to widen the approach that is taken to a design problem and to widen the search for appropriate solutions; it encourages and enables you to think beyond the first solution that comes into your head.

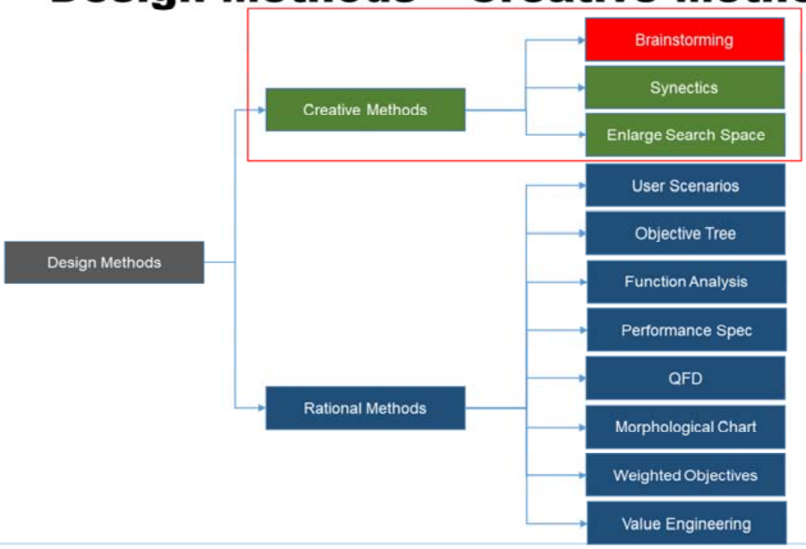
This is also related to the other general aspect of design methods, that they externalize design thinking, i.e. they try to get your thoughts and thinking processes out of your head and into the charts and diagrams that commonly feature in design methods. This externalizing is a significant aid when dealing with complex problems, but it is also a necessary part of team work, i.e. providing means by which all the members of the team can see what is going on and can contribute to the design process. Getting a lot of systematic work out of your head and onto paper also means that your mind can be more free to pursue the kind of thinking at which it is best:

intuitive and imaginative thinking.

Design Methods



Design Methods – Creative Methods



Brainstorming
Creative Methods - Design Methods

- **Aim**
  - Generating a large number of ideas,
  - Most of the ideas will subsequently be discarded,
  - Few novel ideas being identified as worth following up.
- **Protocol**
  - **Duration:** 20-30 min
  - **Group Leader Role**
    - Formulate the problem statement used as a starting point
    - Ensure that the format of the method is followed,
    - Ensure that it does not degenerate into a round-table discussion
  - **Step 1:**
    - Spend a few minutes, in silence, writing down the first ideas that come into your head
  - **Step 2**:
    - Each group member, in turn, read out one idea from his or her set.
    - The most important rule here is that no criticism is allowed from any other member of the group.
  - **Step 3**:
    - In response to every other person's idea is to try to build on it, to take it a stage further, to use it as a stimulus for other ideas, or to combine it with his or her own ideas.
    - Make a short pause after each idea is read out, to allow a moment for reflection and for writing down further new ideas.
  - **Step 4:**
    - Classify the ideas into related groups

MAE 162 D/E – Mechanical Engineering Design I / II
Instructor – Jacob Rosen PhD.

UCLA

The most widely known creative method is brainstorming. This is a method for generating a large number of ideas, most of which will subsequently be discarded, but with perhaps a few novel ideas being identified as worth following up. It is normally conducted as a small group session of about four to eight people.

The group of people selected for a brainstorming session should be diverse. It should not just be experts or those knowledgeable in the problem area, but should include a wide range of expertise and even laypeople if they have some familiarity with the problem area. The group must be nonhierarchical, although one person does need to take an organizational lead.

The role of thtJ ~Siilectdet' in a brainstorming session is to ensure that the format of the method is followed, and that it does not just degenerate into a round-table discussion. An important prior task for the leader is to formulate the problem statement used as a starting point. If the problem is stated too narrowly, then the range of ideas from the session may be rather limited. On the other hand, a very vague problem statement leads to equally vague ideas, which may be of no practical use. The problem can often be usefully formulated as a question, such as 'How can we improve on X?'

In response to the initial problem statement, the group members are asked to spend a few minutes, in silence, Writing down th~ fir~t i<l_eas that come into their heads. It is a good idea if each member has a pile of small record cards on which to write these and subsequent ideas. The ideas should be expressed succinctly, and written one per card.

The next, and major, part of the session is for each member of the group, in tum, to read out one idea from his or her set. The most important rule here is that *no criticism is allowed* from any oth~r member of the group. The usual responses to unconventional ideas, such as 'That's silly' or 'That will never work', kill off spontaneity and creativity. At this stage, the feasibility or otherwise of any idea is not important; evaluation and selection will come later.

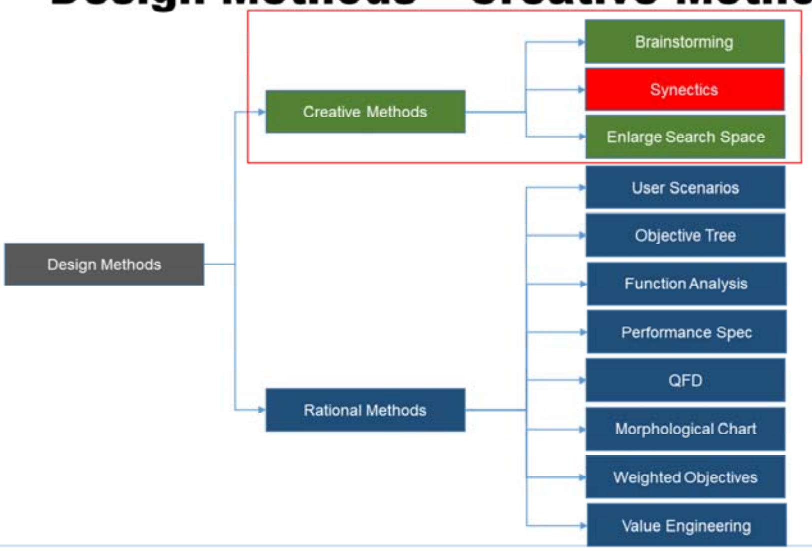
What each group member should do in response to every other person's idea is to try to build on it, to take it a stage further, to use it as a stimulus for other ideas, or to combine it with his or Her own ideas. For this reason, there should be a short pause after each idea is read out, to allow a moment for reflection and for writing down further new ideas. However, the session must not become too stilted; the atmosphere should be relaxed and free-wheeling. A brainstorming session should also be fun: humour is often an essential ingredient of creativity.

The group session should not last more than about21J-30 minutes, or should be wound up when no more new ideas are forthcoming. The group leader, or someone else, then collects all the cards and spends a separate period evaluating the ideas. useful aid to this evaluation is to sort or classify the ideas into related group~ this in itself often suggests further ideas, or indicates the major types of idea that there appear to be. If principal solution areas and one or two novel ideas result from a brainstorming session then it will have been worthwhile.

Participating in a brainstorming session is rather like playing a party game; and like a party game it only works well when everyone sticks to the rules. In fact, all design methods only work best when they are followed with some rigour, and not in a sloppy or half-hearted fashion. The essential rules of brainstorming are:

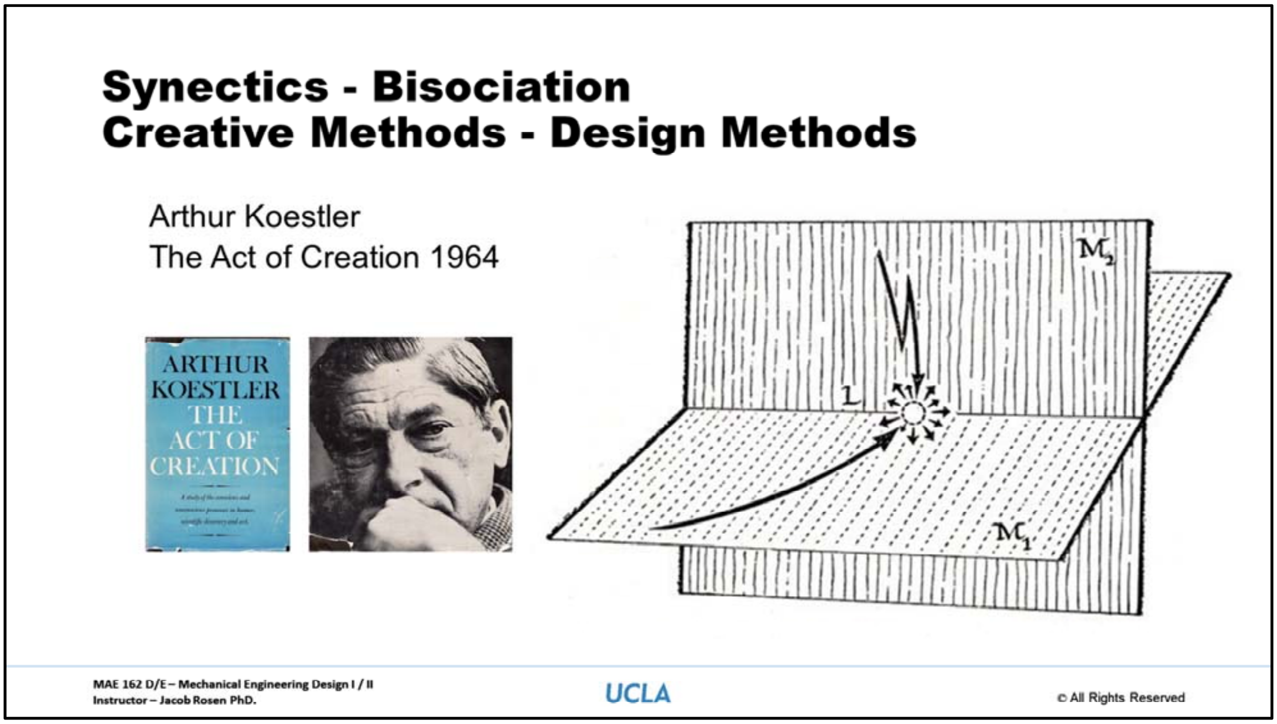
No criticism is allowed during the session.
• A large quantity of ideas is wanted.
• Seemingly crazy ideas are quite welcome.
• Keep all ideas short and snappy.
• Try to combine and improve on the ideas of others.

Design Methods – Creative Methods



Synectics
Creative Methods - Design Methods

- **Synectics -** Creative thinking often draws on analogical thinking, on the ability to see parallels or connections between apparently dissimilar topics.
- **Analogical Thinking (Definition) -** Analogical thinking is what we do when we use information from one domain (the source or analogy) to help solve a problem in another domain (the target).
- **Bisociation** - A blending of elements drawn from two previously unrelated patterns of thought into a new pattern.
- Blend of **bi- + association**; coined by Hungarian-British author Arthur Koestler in his 1964 book The Act of Creation.



The pattern underlying [the creative act] is *the perceiving of a situation or idea, L, in two self-consistent but habitually incompatible frames of reference, M1 and M2.* The event L, in which the two intersect, is made to vibrate simultaneously on two different wavelengths, as it were. While this unusual situation lasts, L is not merely linked to one associative context, but *bisociated* with two.
I have coined the term ‘bisociation’ in order to make a distinction between the routine skills of thinking on a single ‘plane,’ as it were, and the creative act, which … always operates on more than one plane. The former can be called single-minded, the latter double-minded, transitory state of unstable equilibrium where the balance of both emotion and thought is disturbed.

The procedure to be followed is this: first, determine the nature of M1 and M2 . . . by discovering the type of logic, the rules of the game, which govern each matrix. Often these rules are implied, as hidden axioms, and taken for granted — the code must be de-coded. The rest is easy: find the ‘link’ — the focal concept, word, or situation which is bisociated with both mental planes; lastly, define the character of the emotive charge and make a guess regarding the unconscious elements that it may contain.

Synectics - Creative Methods - Design Methods

- **Synectics versus Brainstorming**

Method	Brainstorming	Synectics
Number of Solutions	Large	Single
Length of the session	Short	Long

The use of analogical thinking has been formalized in a creative design method known as 'synectics'. Like brainstorming, synectics is a group activity in which criticism is ruled out, and the group members attempt to build, combine and develop ideas towards a creative solution to the set problem. Synectics is different from brainstorming in that the group tries to work collectively towards *i* particular solution, rather than generating a large number of ideas. A synectics session is much longer than brainstorming, and much more demanding.

Direct Analogy - Synectics – Types of Analogies
Creative Methods - Design Methods

- **Direct Analogy** – Seeking Biological solution to similar problem
  - Example – Velcro

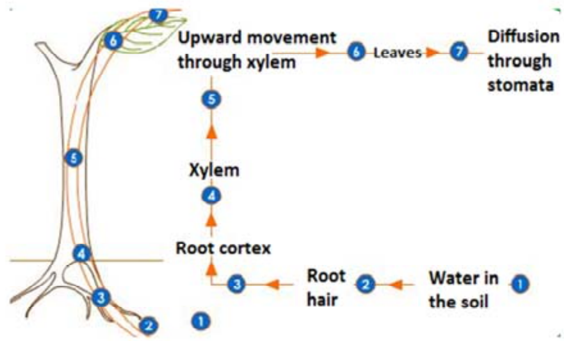
The inventor of velcro developed his idea from a direct analogy to plant burrs and dog's fur.

Personal Analogy - Synectics – Types of Analogies Creative Methods - Design Methods

- **Personal Analogy** – The team members imagine what it would be like to use oneself as the system or component that is being designed.

Symbolic Analogy - Synectics – Types of Analogies
Creative Methods - Design Methods

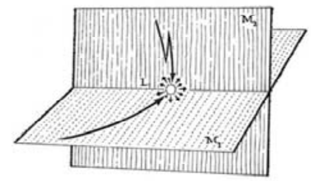
- **Symbolic Analogy** - Symbolic Analogy bases around examinations of objects' properties in an abstract fashion.



Fantasy Analogies - Synectics – Types of Analogies Creative Methods - Design Methods

- **Fantasy Analogies** - 'Impossible' wishes for things to be achieved in some 'magical' way.

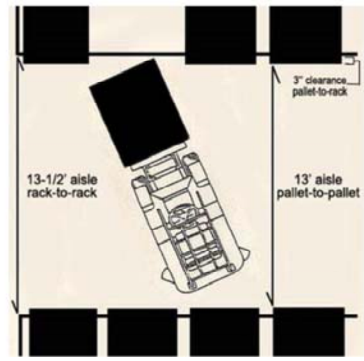
Session Protocol - Synectics
Creative Methods - Design Methods



- **Session Protocol**
  - **Starts with the 'problem as given'** - the problem statement as presented by the client or company management.
  - **Seek Analogies (Understand the Problem)** - help to 'make the strange familiar', i.e. expressing the problem in terms of some more familiar (but perhaps rather distant) analogy.
  - **Conceptualization of the 'problem as understood'** – Understand the key factor or elements of the problem that need to be resolved, or perhaps a complete reformulation of the problem.
  - **Seek Unusual & Creative Analogies (Create Solutions)** - May lead to novel solution concepts. The analogies are used to open up lines of development which are pursued as hard and as imaginatively as possible by the group.

A synectics session starts with the 'problem as given': the problem statement as presented by the client or company management. Analogies are then sought that help to 'make the strange familiar', i.e. expressing the problem in terms of some more familiar (but perhaps rather distant) analogy. This leads to a conceptualization of the 'problem as understood': the key factor or elements of the problem that need to be resolved, or perhaps a complete reformulation of the problem. The problem as understood is then used to guide the use of analogies again, but this time to 'make the familiar strange'. Unusual, creative analogies are sought, which may lead to novel solution concepts. The analogies are used to open up lines of development which are pursued as hard and as imaginatively as possible by the group.

Synectics – Analogies –
Example Fork Lift / Bendi Truck
Creative Methods - Design Methods



MAE 162 D/E – Mechanical Engineering Design I / II
Instructor – Jacob Rosen PhD.

UCLA

A design team looking for new versions of a company's forklift trucks focused on the problem area of using such trucks in warehouses for the stacking and removal of palletted goods. Conventional forklift trucks have to face head-on to the stacks in order to place and lift the pallets, and then be manoeuvred again within the aisle between the stacks in order to move to another location or to exit the warehouse. This means that the aisles have to be quite wide, using up warehouse space.

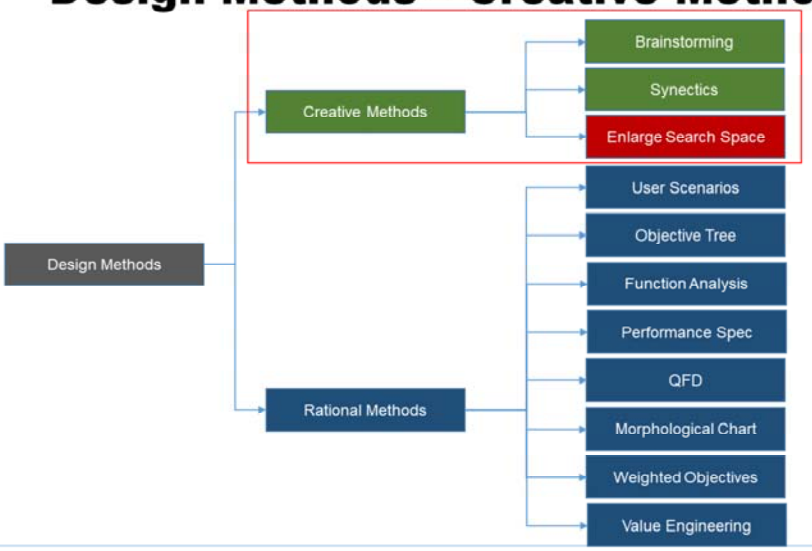
This example shows how synectics thinking can be used in the approach to such a problem. Direct analogies could be used to 'make the strange familiar', i.e. to familiarize the team with the new problem. For instance, analogies of the movement of snakes might be explored, leading to 'the problem as understood' being the need for a truck to twist sinuously in its maneuvering. To 'make the familiar strange', the team might use personal and fantasy analogies of the kind: 'If I was holding the pallet in my outstretched arms, going along the aisle, I would like to be able to twist my upper body through ninety degrees (without moving my feet) to place the pallet in the rack.' Symbolic analogies of rotating turrets and articulated skeletons could lead eventually to a new design concept of an articulated truck with forks mounted on a front section that could swivel through ninety degrees. The Translift 'Benditruck' was designed on these principles.

Synectics – Analogies –
Example Fork Lift / Bendi Truck
Creative Methods - Design Methods

Synectics – Analogies –
Example ForkLift / Benditruck
Creative Methods - Design Methods

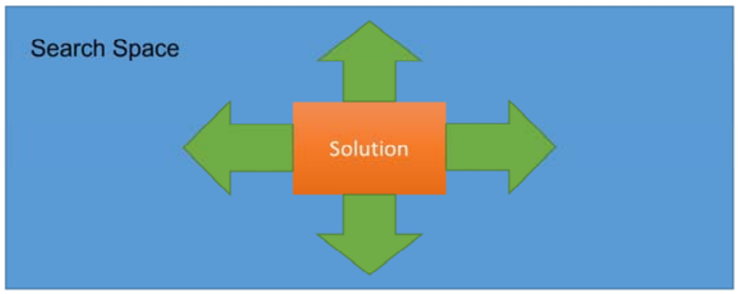
Synectics – Analogies –
Example Fork Lift / Bendi Truck
Creative Methods - Design Methods

Design Methods – Creative Methods



Enlarge the Search Space
Creative Methods - Design Methods

- **Aim**: A common form of mental block to creative thinking is to assume rather narrow boundaries within which a solution is sought. Many creativity techniques are aids to enlarging the 'search space'.

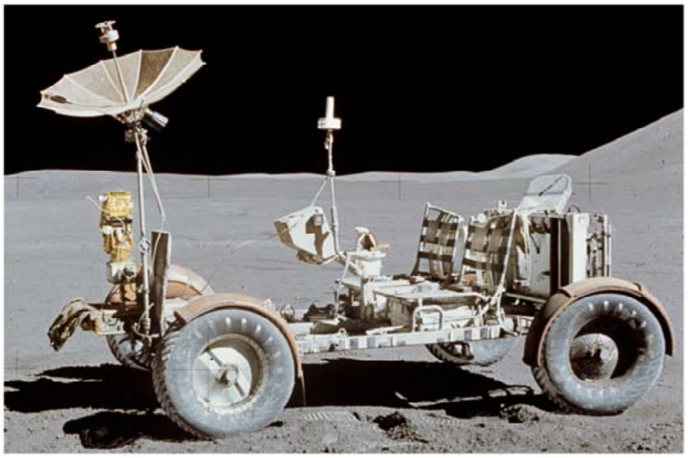


Transformation - Enlarge the Search Space
Creative Methods - Design Methods

- **Transformation** - 'transform' the search for a solution from one area to another. This often involves applying verbs that will transform the problem in some way, such as

magnify, minify, modify, unify, subdue, subtract, add, divide, multiply, repeat, replace, relax, dissolve, thicken, soften, harden, roughen, flatten, rotate, rearrange, reverse, combine, separate, substitute, eliminate.

Transformation – Example
Enlarge the Search Space
Creative Methods - Design Methods



MAE 162 D/E – Mechanical Engineering Design I / II
Instructor – Jacob Rosen PhD.

UCLA

The wheels were designed and manufactured by General Motors Defense Research Laboratories in Santa Barbara, California.[21] Ferenc Pavlics was given special recognition by NASA for developing the "resilient wheel".[22] They consisted of a spun aluminum hub and a 32-inch (81 cm) diameter, 9-inch (23 cm) wide tire made of zinc-coated woven 0.033-inch (0.84 mm) diameter steel strands attached to the rim and discs of formed aluminum. Titanium chevrons covered 50% of the contact area to provide traction. Inside the tire was a 25.5-inch (65 cm) diameter bump stop frame to protect the hub. Dust guards were mounted above the wheels.

https://youtu.be/dlxJ65WRy0E

From the Moon to Mars

YouTube https://youtu.be/4LOOTyuLjLU

NASA Reinvented The Wheel - Shape Memory Alloy Tires

YouTube https://youtu.be/pvKIzldni68

Field Trials Utah: Robot team simulates Mars mission in Utah

Random Input - Enlarge the Search Space Creative Methods - Design Methods

- **Random Input** - Creativity can be triggered by random inputs from whatever source.
  - Opening a dictionary or other book and choosing a word at random and using that to stimulate thought on the problem in hand.
  - Switch on a television set and use the first visual image as the random input stimulus.

Creativity can be triggered by random inputs from whatever source. This can be applied as a deliberate technique, e.g. opening a dictionary or other book and choosing a word at random and using that to stimulate thought on the problem in hand. Or switch on a television set and use the first visual image as the random input stimulus.

Why? Why? Why? - Enlarge the Search Space
Creative Methods - Design Methods

- **Why? Why? Why?** - .
  - Ask a string of questions ':why?' about the problem:
    - 'Why is this device necessary?' ‘
    - Why can't it be eliminated?'
  - Each answer is followed up, with another 'Why?' until a dead end is reached or an unexpected answer prompts an idea for a solution.
  - There may be several answers to any particular 'Why?', and these can be charted as a network of question-and-answer chains.

.Another way of extending the search space is to ask a string of questions ':why?' about the problem: such as 'Why is this device necessary?' 'Why can't it be eliminated?', etc. Each answer is followed up, like a persistent child, with another 'Why?' until a dead end is reached or an unexpected answer prompts an idea for a solution. There may be several answers to any particular 'Why?', and these can be charted as a network of question-and-answer chains.

Counter Planning - Enlarge the Search Space
Creative Methods - Design Methods

- **Counter Planning**
  - **Thesis – Antithesis – Synthesis -** The concept of the dialectic, i.e. pitting an idea (**the thesis**) against its opposite (**the antithesis**) in order to generate a new idea (**the synthesis**).
  - **Conventional - Opposite - Compromise** - Challenge a conventional solution to a problem by proposing its deliberate opposite, and seeking a compromise.
  - **Synthesis** - Two completely different solutions can be deliberately generated, with the intention of combining the best features of each into a new synthesis.

This method is based on the concept of the dialectic, i.e. pitting An idea (the thesis) against its opposite (the antithesis) in order to generate a new idea (the synthesis). It can be used to challenge a conventional solution to a problem by proposing its deliberate opposite, and seeking a compromise. Alternatively, two completely different solutions can be deliberately generated, with the intention of combining the best features of each into a new synthesis.

Generalized Creative Methods
Creative Methods - Design Methods

- **'Ah-ha!' moment - Generalized Creative Methods**
- This general pattern is the following sequence
  - ***Recognition*** is the first realization or acknowledgement that 'a problem' exists.
  - ***Preparation*** is the application of deliberate effort to understand the problem.
  - ***Incubation*** is a period of leaving it to 'mull over' in the mind, allowing one's subconscious to go to work.
  - ***Illumination*** is the (often quite sudden) perception or formulation of the key idea.
  - ***Verification*** is the hard work of developing and testing the idea.

The methods above are some techniques which have been found useful when it is necessary for a designer or design team to 'turn on' their creative thinking. But creative, original ideas can also seem to occur quite spontaneously, without the use of any such aids to creative thinking. Is there, therefore, a more general process of creative thinking which can be developed?

Psychologists have studied accounts of creative thinking from a wide range of scientists, artists and designers. In fact, as most people have also experienced, these highly creative individuals generally report that they experience a very sudden creative insight that suggests a solution to the problem they have been working on. There is a sudden 'illumination', just like the light-bulb flashing on that cartoonists use to suggest someone having a bright idea.

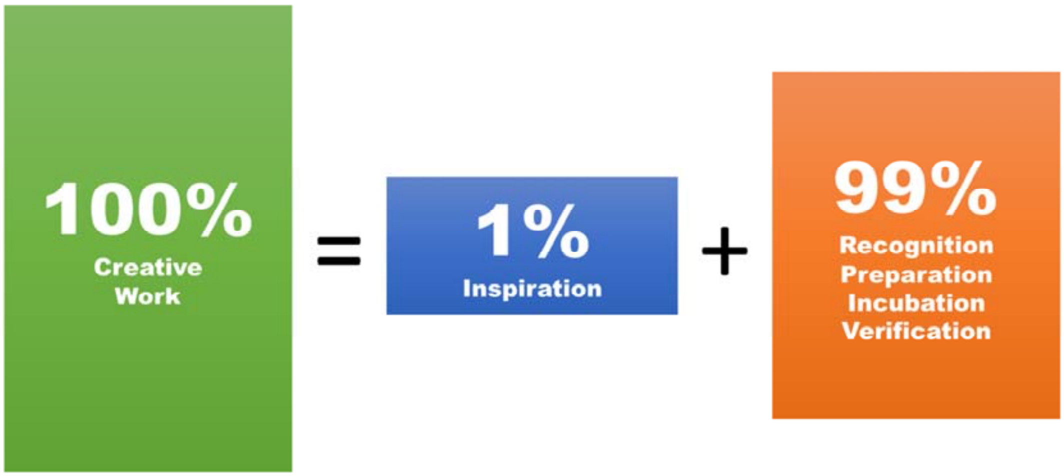
This creative' Ah-ha!' experience often occurs when the individual is not expecting it, and after a period when they have been thinking about something else. This is rather like the common phenomenon of suddenly remembering a name or word that could not be recalled when it was wanted.

However, the sudden illumination of a bright idea does not usually occur without considerable background work on a problem.

The illumination or key insight is also usually just the germ of an idea that needs a lot of further work to develop it into a proper, complete solution to the problem.
Similar kinds of thought sequence occur often enough in creative thinking for ;psychologists to suggest that there is a general pattern to it. This general pattern is the following sequence: recognition Preparation – incubation - illumination- verification.
• Recognition is the first realization or acknowledgement that 'a problem' exists.
• Preparation is the application of deliberate effort to understand the problem.
• Incubation is a period of leaving it to 'mull over' in the mind, allowing one's subconscious to go to work.
• *Illumination* is the (often quite sudden) perception or formulation of the key idea.
Verification is the hard work of developing and testing the idea.

The process is essentially work – relaxation – work, with the creative insight occurring in a period. The hard work of preparation and verification is essential. Like most other kinds of creative activity, creative work is 1% inspiration and 99*%:* perspiration
The sudden illumination is often referred to as a 'creative leap', but it is perhaps not helpful to think of creative design as relying on a flying leap from the problem space into the solution space. The creative event in design is not so much a 'leap' from problem to solution as the building of a 'bridge' between the problem space and the solution space by the identification of a key solution concept. This concept is recognized by the designer as embodying a satisfactory match of relationships between problem and solution.
• *Verifieation* is the hard work of developing and testing the idea

Generalized Creative Methods
Creative Methods - Design Methods



YouTube https://youtu.be/QEoqBjRZr1g

Albert Einstein: How did he come up with ideas? | Understanding Einstein's Mind

YouTube https://youtu.be/ijj58xD5fD
Version 1: How taking a bath led to Archimedes' principle - Mark Salata

YouTube https://youtu.be/0v86Yk14rf8

Version 2: The real story behind Archimedes' Eureka! - Armand D'Angour

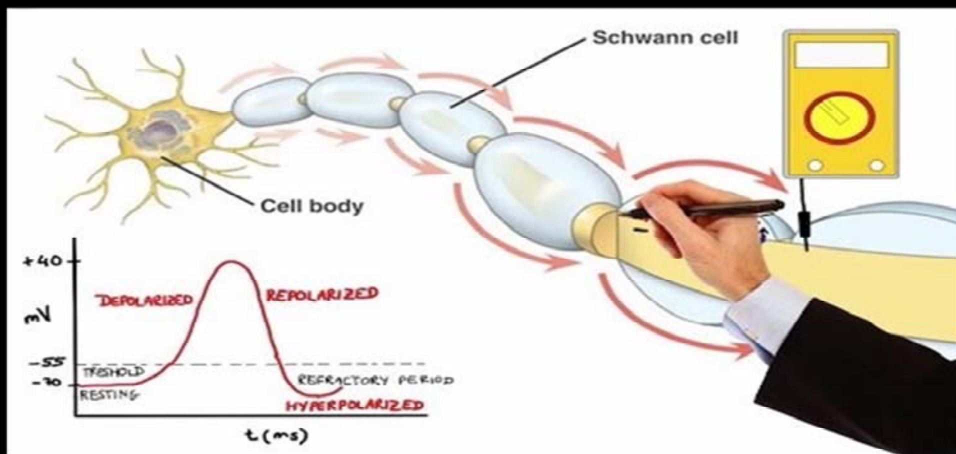
YouTube https://youtu.be/91XI7M9I3no

Einstein's miracle year –TED Ed - Larry Lagerstrom

Generalized Creative Methods
Creative Methods - Design Methods

- **Work – Relaxation – Work** - The process is essentially work – relaxation – work, with the creative insight occurring in a period.

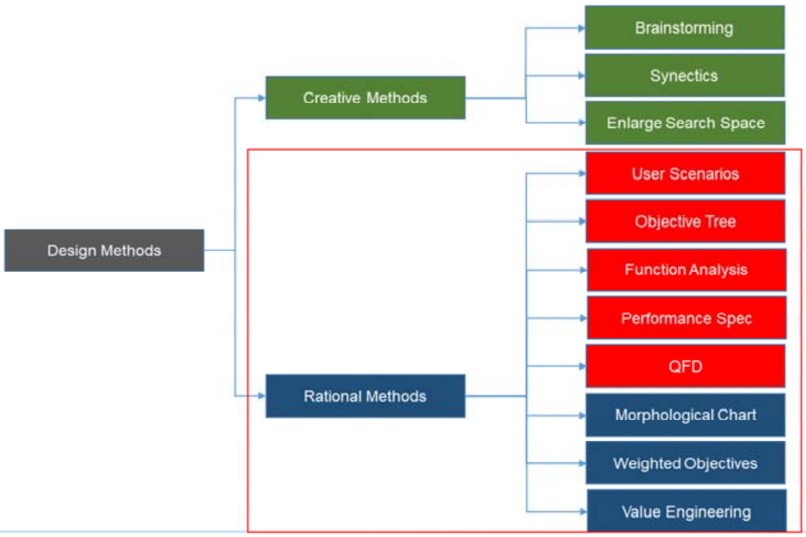
UCLA



YouTube https://youtu.be/XnksofQN8_s

NEURON ACTION POTENTIAL

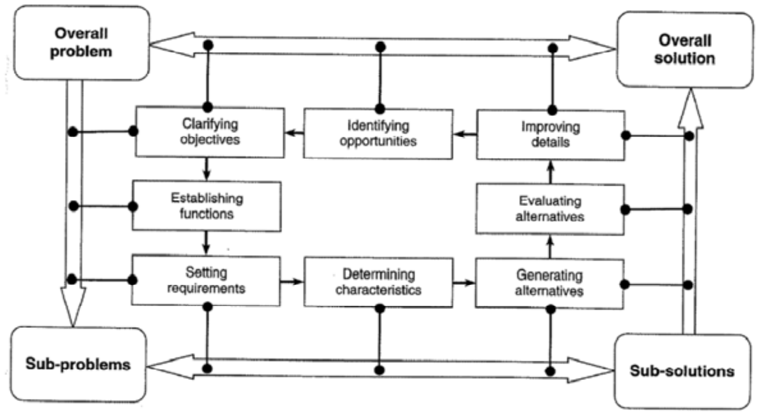
Design Methods – Rational Methods



Rational Methods - Design Methods

General Aim	Method	Specific Aim
Identify Opportunities	User Scenarios	Identify and define an opportunity for a new or improved product.
Clarify Objectives	Objective Tree	Clarify design objectives and sub objectives, and the relationships between them.
Establishing Function	Function Analysis	Establish the functions required, and the system boundary, of a new design.
Setting Requirements	Performance Specification	Make an accurate specification of the performance required of a design solution.
Determining Characteristics	Quality Function Deployments (QFD)	Set targets to be achieved for the engineering characteristics of a product, such that they satisfy customer requirements.
Generating Alternatives	Morphological Chart	Generate the complete range of alternative design solutions for a product.
Evaluating Alternatives	Weighted Objectives	Compare the utility values of alternative design proposals, on the basis of performance against differentially weighted objectives.
Improving Details	Value Engineering	Increase or maintain the value of a product to its purchaser whilst reducing its cost to its producer.

Rational Methods - Design Methods



Generating Alternatives

Morphological Chart Method

Generating Alternatives – Introduction
Rational Methods - Design Methods

- **Solution Generation** - The generation of solutions is, of course, the essential, central aspect of designing
- **Variation / Modification to an Existing Artifact** - most designing is actually a variation from or modification to an already existing product or machine. Clients and customers usually want improvements rather than novelties.

The generation of solutions is, of course, the essential, central aspect of d esigning. Whether one sees it as a mysterious act of creativity or as a logical process of problem solving, the whole purpose of design is to make a proposal for something new- something which does not yet exist.
The focus of much writing and teaching in design is therefore on novel products or machines, which often appear to have arisen spontaneously from the designer's mind. However, this overlooks the fact that most designing is actually a variation from or modification to an already existing product or machine. Clients and customers usually want improvements rather than novelties.
Making variations on established themes is therefore an important feature of design activity. It is also the way in which much creative thinking actually develops. In particular, creativity can often be seen as the reordering or recombination of existing elements.

Variation

- *In a display there are 3 students and 3 chairs standing in a row.*
- *In how many different orders can the students sit on these chairs?*

UCLA

Variation

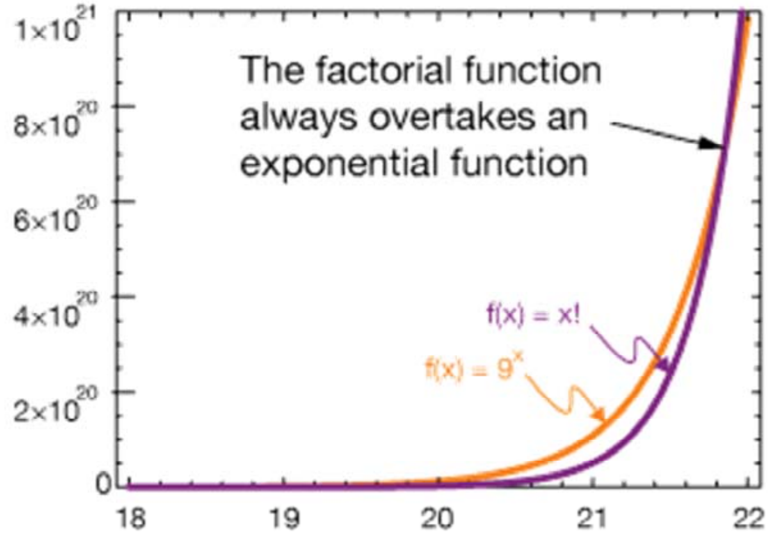
- *3!=1x2x3=6*

MAE 162 D/E – Mechanical Engineering Design I / II
Instructor – Jacob Rosen PhD.

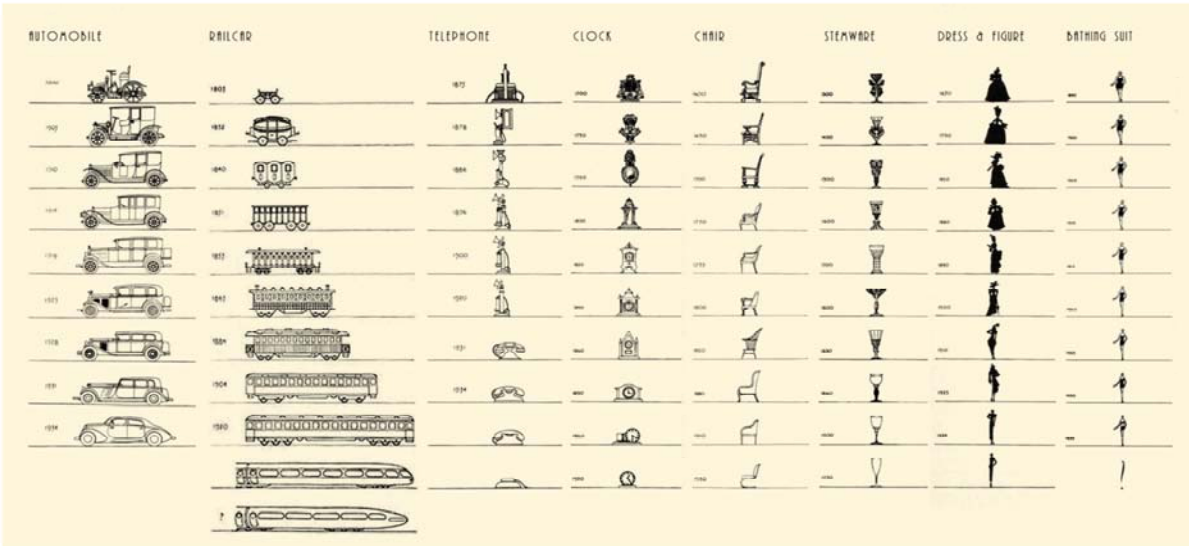
UCLA

Variations (Factorial)

Number of Objects	Factorial	Number of orders
1	1!	1
2	2!	2
3	3!	6
4	4!	24
5	5!	120
6	6!	720
7	7!	5040
8	8!	40,320
9	9!	362,880
10	10!	3,628,800
20	20!	2,432,902,000,000,000,000e=2.4e+18
26	26!	403,291,460,000,000,000,000,000,000=4.0329146e+26

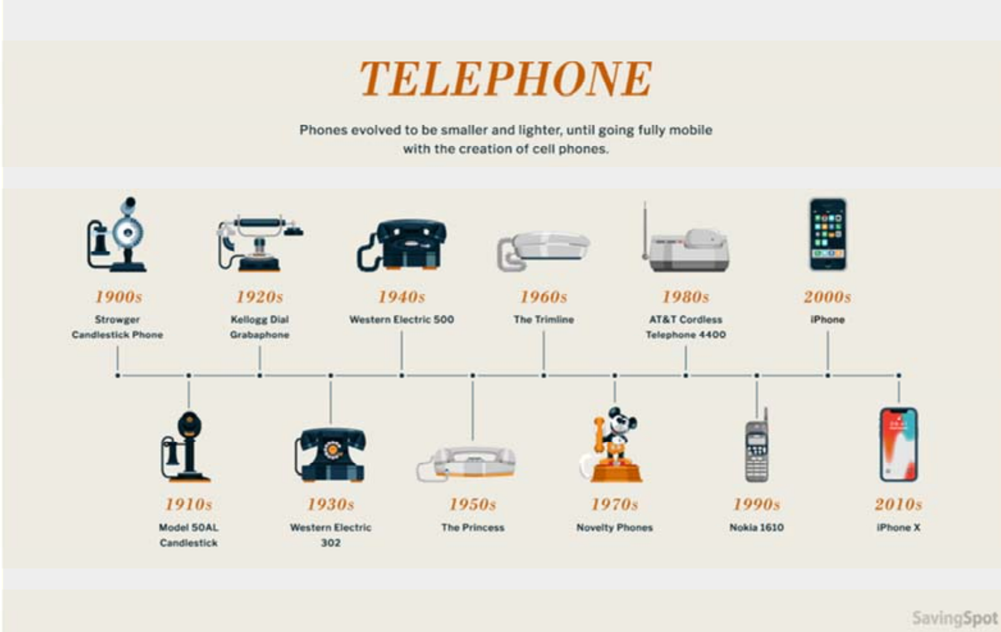

The factorial function
always overtakes an
exponential function
f(x) = x!
f(x) = 9^x
1×10^21
8×10^20
6×10^20
4×10^20
2×10^20
0
18
19
20
21
22

UCLA



Raymond Loewy, this chart from 1934

[The Evolution of 8 Objects Americans Use Every Day]



MAE 162 D/E – Mechanical Engineering Design I / II
Instructor – Jacob Rosen PhD.

UCLA

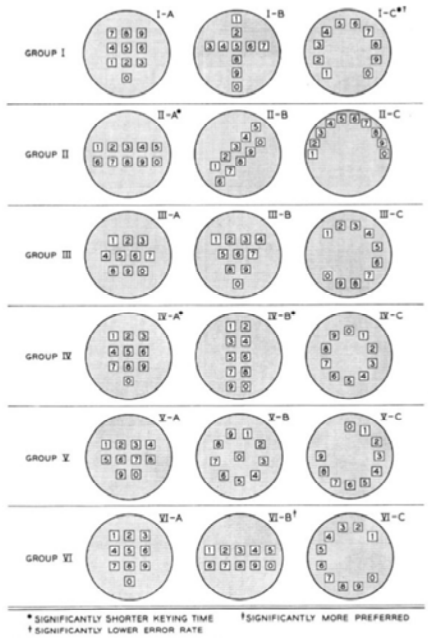
There aren't many sticky-outy bits on the average smartphone these days, but can you imagine what it would look like with a rotary dial on the front? That was the norm for landline telephones until 1963, when industrial psychologist John E Karlin brought the idea for a **telephone keypad** to his bosses at Bell Laboratories.

A simple idea, maybe. But remarkably, the order of the numbers on the keypad was trialed in 16 different combinations before Karlin decided he'd found the one that would win over loyal rotary-diallers.


JKL
5
GHI
4
DEF
3
ABC
2
1
MNO
6
PRS
7
TUV
8
WXY
9
0
Speaker

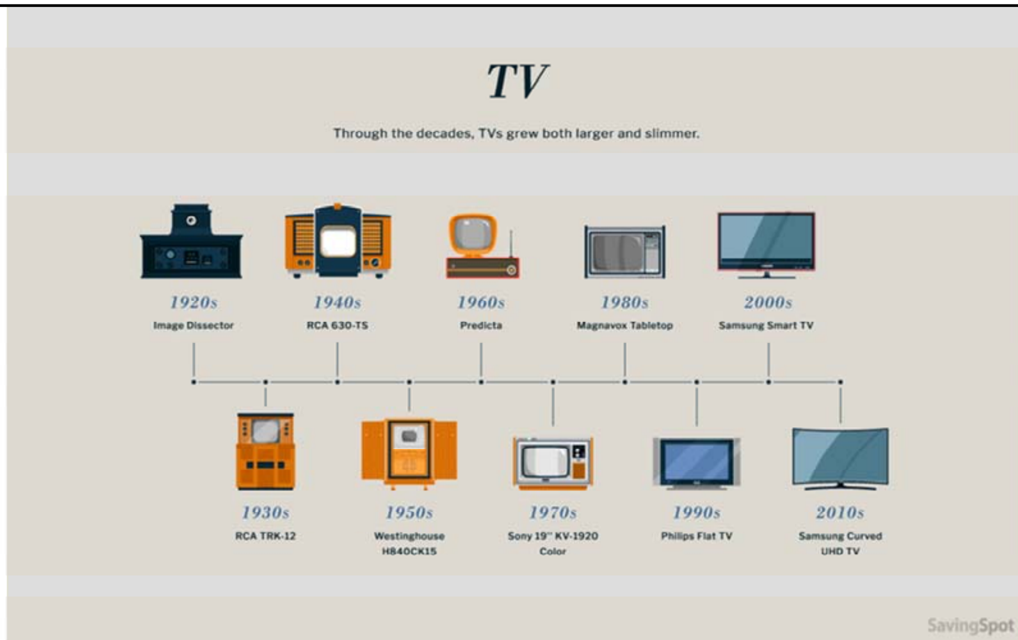
https://youtu.be/1OADXNGnJok

Dial a rotary phone


GROUP I
GROUP II
GROUP III
GROUP IV
GROUP V
GROUP VI
* SIGNIFICANTLY SHORTER KEYING TIME
† SIGNIFICANTLY MORE PREFERRED
† SIGNIFICANTLY LOWER ERROR RATE

YouTube https://youtu.be/kCSzjExvbTQ

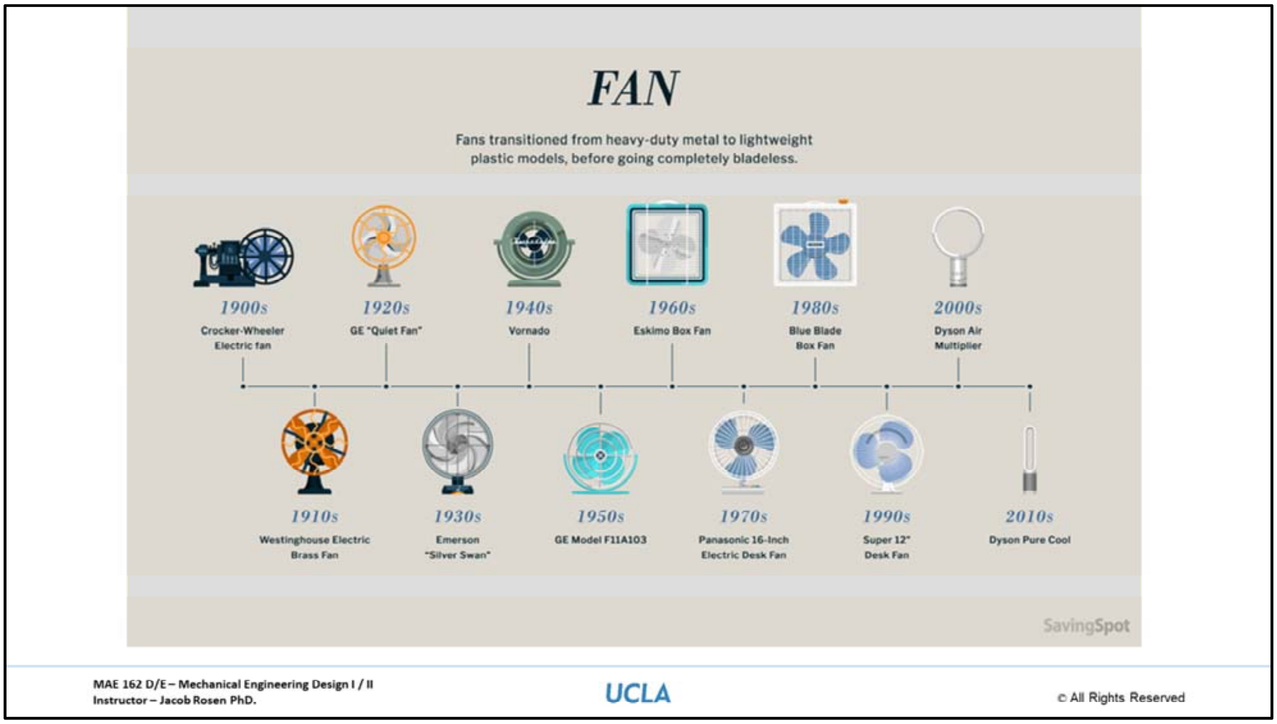
Phone Buttons - Numberphile



MAE 162 D/E – Mechanical Engineering Design I / II
Instructor – Jacob Rosen PhD.

UCLA

From the 1920s on, Americans began to experience the world through their television set. Mass communication like this began to change the world. Meanwhile, the remarkable evolution of the actual television set went relatively unnoticed.
The first TV sets were designed as furniture, reflecting both their size and the part they would come to play in everyday American life. Smaller, portable sets and consoles made TVs more convenient in the 70s and 80s. But in recent decades, TV designers have scaled things up again: plasma, LCD and OLED technology has enabled them to create bigger, lightweight sets for a more cinematic experience.



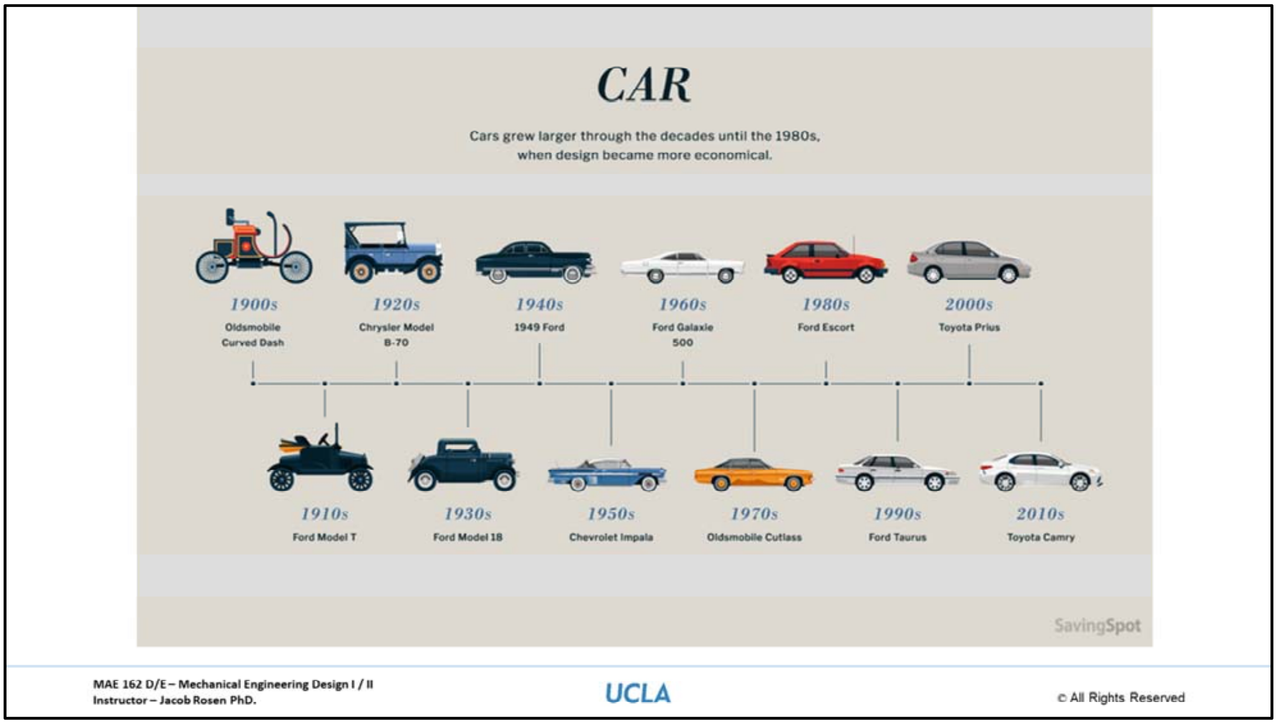
The first mechanical fan was invented nearly two millennia ago, during the Han dynasty in China. It took just one man to cool an entire hall by operating a rotary system composed of seven 10-foot wheels. But it was not until boy genius **Schuyler Skaats Wheeler** motorized two rotating blades in 1882 that we would have the first self-propelling fan. What a cool guy!

But in the 2000's it was Dyson who again entered the fold to revolutionize the domestic fan, with a bladeless – bladeless! – design. The Dyson Multiplier sucked air through the bottom and blew out it cooler, while the Pure Cool now filters that air using low-force velocity to trap unwanted particles. Are the rotary blade's days numbered?

Can you imagine a world before the **first motorized vacuum cleaner**, in 1901? Ives McGaffey did. In 1869, he created the very modern sounding Whirlwind, which was operated with a hand-pump! Imagine what he would make of the mighty Roomba robot today.

But there is one name that can't be ignored in the world of the vacuum: James Dyson. He built over 5,000 prototypes in the fifteen years leading up to his unveiling of the bagless Dual Cyclone Machine.

There wasn't much call for Bluetooth earbuds in the early 1900s. Recorded music was still a long way off from being portable. But you could access an early form of podcast over your telephone – and you would listen through a stethoscope-style headset. This was the Electrophone system.
It was only in the 50s and 60s that headphones started to be truly desirable items. The Koss SP3 was the first stereo headphone in 1958, giving those space-age bachelors and bachelorettes the feeling that they were right there where the music was recorded.

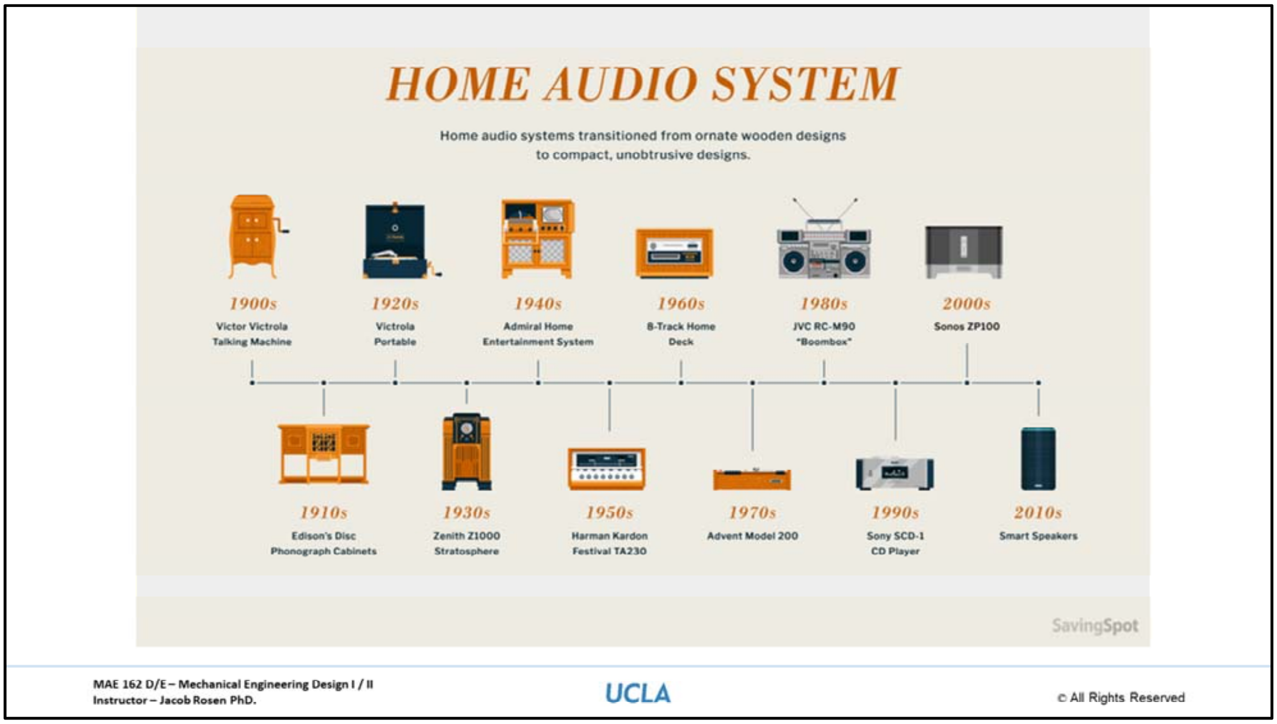


You might not expect Henry Ford's first car designs to include electric windows, but no windows or doors at all? Ford had just the horse and cart for inspiration, and it wouldn't be until the 1920s that 'closed' cars came into fashion.
The 1950s was a boom time for the American automobile. While Europeans scaled down, stateside cars grew to reflect the burgeoning wealth of the American middle-classes. Just check that racy Chevy Impala! This sort of car didn't stay on the road long, but it sure made an impact.

Sneakers actually originated in the 19th century, with the invention of plimsolls so quiet you could 'sneak around' in them. It wasn't until the 1940s that they started to become a fashion thing, and sneakers for women didn't arrive until the jogging craze of the mid-1970s!

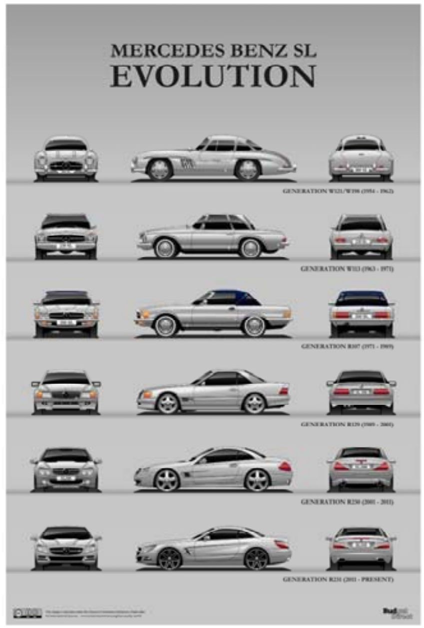
But as every Generation X kid knows, sneakers really came of age in the 1990s as designers capitalized on the increasing mainstream appeal of hip-hop and street fashion. 1990 saw the first Nikes to boast an exposed air cushion.

This was the Eiffel Tower, the Anglepoise lamp, the Brompton bicycle moment for sneakers: the moment when form and function convened in a revolutionary design that would change the way we look at objects.



Just a decade ago the very idea of a home audio system felt dated: you carried your tunes in your pocket, and docked your device wherever you found a speaker. Today, it is the speakers themselves that are the device. Networked throughout your home, Alexa will play whatever song you can think to ask 'her.'

It's a far cry from the Victor Victrola Talking Machine of the 1900s, when 'His Masters Voice' referred to the novelty of hearing recorded voices on a disc made of shellac.


MERCEDES BENZ SL
EVOLUTION

Generating Alternatives – Morphological Chart Rational Methods - Design Methods

Aim - Generate the complete range of alternative design solutions - The aim of the morphological chart method is to generate the complete range of alternative design solutions for a product, and hence to widen the search for potential new solutions.

1. **List the features / functions / design blocks** - List the features or functions that are essential to the product. Whilst not being too long, the list must comprehensively cover the functions, at an appropriate level of generalization.

2. **List the means by which features/functions might be achieved -** For each feature or function list the means by which it might be achieved. These lists might include new ideas as well as known existing components or sub solutions (3-8).

3. **Draw up a chart containing all the possible sub solutions (Morph Chart)**. This morphological chart represents the total solution space for the product, made up of the combinations of sub solutions.

4. **Construction a Solution - Identify feasible combinations of sub solutions -** The total number of possible combinations may be very large, and so search strategies may have to be guided by constraints or criteria.
   - **Method 1** – choose only a restricted set of sub solutions from each row - say, those that are known to be efficient or practical, or look promising
   - **Method 2 -** identify the infeasible sub solutions, or incompatible pairs of sub solutions, and so rule out those combinations that would include them

Generating Alternatives – Morphological Chart Rational Methods - Design Methods

- **When to stop generating solutions**
  - **Generate broad range of the design space**
    - **Representative**
    - **Diverse**
    - **Creative**
  - **20 solutions**
  - **Method 1** – choose only a restricted set of sub solutions from each row - say, those that are known to be efficient or practical, or look promising
  - **Method 2** - identify the infeasible sub solutions, or incompatible pairs of sub solutions, and so rule out those combinations that would include them

Example: Water Bottle Morphological Chart

Example: Water Bottle Morphological Chart – Step 1

- 1. **List the features / functions / design blocks** - List the features or functions that are essential to the product. Whilst not being too long, the list must comprehensively cover the functions, at an appropriate level of generalization.

Design Block				
Mouth Piece				
Container				
Handle				
Geometry D:H Ratio				
Shape				

Example: Water Bottle Morphological Chart – Step 2 & 3

2. List the means by which features/functions might be achieved - For each feature or function list the means by which it might be achieved. These lists might include new ideas as well as known existing components or sub solutions.

3. **Draw up a chart containing all the possible sub solutions (Morph Chart)**. This morphological chart represents the total solution space for the product, made up of the combinations of sub solutions.

Design Block	Option 1	Option 2	Option 3	Option 4
Mouth Piece	Twist Top	Faucet	Rubber Nipple	Pull Top
Container	Plastic	Disposal	Metal	Glass
Handle	Top	Body	Attached (pouch)	
Geometry D:H Ratio	<1:2	1:2 – 1:3	> 1:3	
Shape	Ergonomic	Pouch	Straight	Ribbed

Number of solutions
4x4x3x3x4=576

Example: Water Bottle Morphological Chart – Step 4

4. **Identify feasible combinations of sub solutions** - The total number of possible combinations may be very large, and so search strategies may have to be guided by constraints or criteria.

Design Block	Option 1	Option 2	Option 3	Option 4
Mouth Piece	Twist Top	Faucet	Rubber Nipple	Pull Top
Container	Plastic	Disposal	Metal	Glass
Handle	Top	Body	Attached (pouch)	
Geometry D:H Ratio	<1:2	1:2 – 1:3	> 1:3	
Shape	Ergonomic	Pouch	Constant Diameter	Ribbed

Metal Water Bottle

Note: Skip a line (design block)

Example: Water Bottle Morphological Chart – Step 4

4. **Identify feasible combinations of sub solutions** - The total number of possible combinations may be very large, and so search strategies may have to be guided by constraints or criteria.

Design Block	Option 1	Option 2	Option 3	Option 4
Mouth Piece	Twist Top	Faucet / Spigot	Rubber Nipple	Pull Top
Container	Plastic	Disposal	Metal	Glass
Handle	Top	Body	Attached (pouch)	
Geometry D:H Ratio	<1:2	1:2 – 1:3	> 1:3	
Shape	Ergonomic	Pouch	Constant Diameter	Ribbed

Water Pouch Backpack

Note: Skip a line (design block)

Example: Water Bottle Morphological Chart – Step 4

4. **Identify feasible combinations of sub solutions** - The total number of possible combinations may be very large, and so search strategies may have to be guided by constraints or criteria.

Water bottle Disposable

Design Block	Option 1	Option 2	Option 3	Option 4
Mouth Piece	Twist Top	Faucet / Spigot	Rubber Nipple	Pull Top
Container	Plastic	Disposal	Metal	Glass
Handle	Top	Body	Attached (pouch)	
Geometry D:H Ratio	<1:2	1:2 – 1:3	> 1:3	
Shape	Ergonomic	Pouch	Constant Diameter	Ribbed

Note: Multiple options of the same design block

Example: Water Bottle Morphological Chart – Step 4

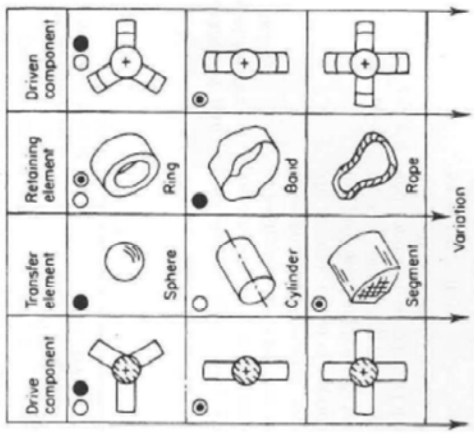
4. **Identify feasible combinations of sub solutions** - The total number of possible combinations may be very large, and so search strategies may have to be guided by constraints or criteria.

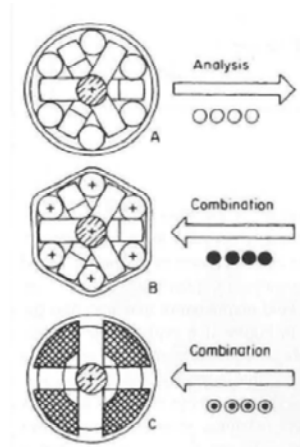
Design Block	Option 1	Option 2	Option 3	Option 4
Mouth Piece	Twist Top	Faucet / Spigot	Rubber Nipple	Pull Top
Container	Plastic	Disposal	**Metal**	Glass
Handle	Top	Body	Attached (pouch)	
Geometry D:H Ratio	<1:2	1:2 – 1:3	> 1:3	
Shape	Ergonomic	**Pouch**	Constant Diameter	Ribbed

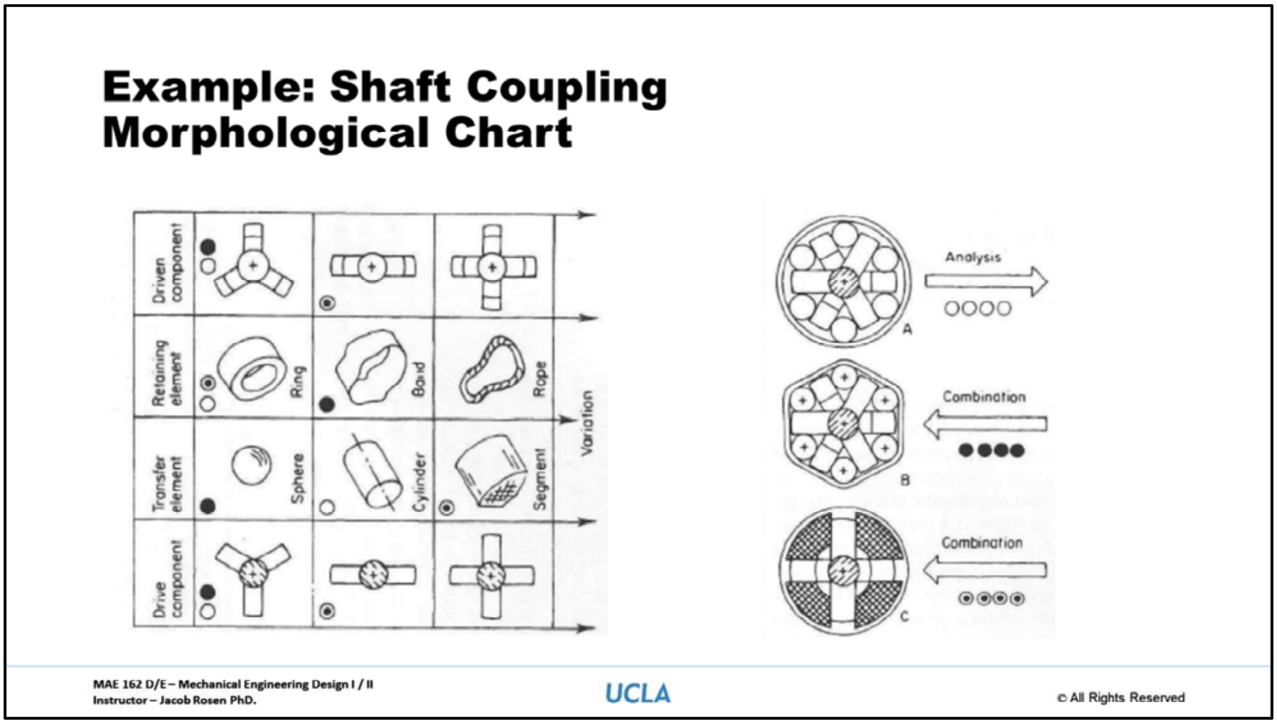
Note: Non Reasonable solutions

Example: Shaft Coupling Morphological Chart

Example: Shaft Coupling Morphological Chart

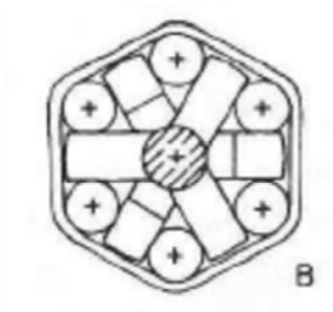


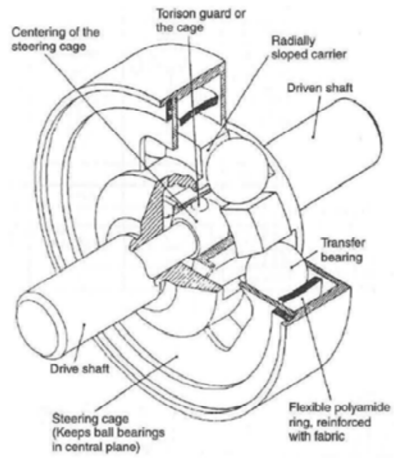




The example is that of a shaft
coupling similar to the conventional 'Oldham' coupling, which transmits torque even in the case of radial and axial offsets of the shafts. Figure 10.4 shows a part of the morphological chart that was drawn up. One solution type (A) was analysed into its components and elements (presented here in columns, rather than rows) and the various subsolutions listed in pictures and words. Two new alternative combinations (B and C) are shown by the different sets of dots in the squares of the chart. One of these (B) was developed and patented as a novel design,

Example: Shaft Coupling Morphological Chart





MAE 162 D/E – Mechanical Engineering Design I / II
Instructor – Jacob Rosen PhD.

UCLA

The example is that of a shaft coupling similar to the conventional 'Oldham' coupling, which transmits torque even in the case of radial and axial offsets of the shafts. Figure 10.4 shows a part of the morphological chart that was drawn up. One solution type (A) was analysed into its components and elements (presented here in columns, rather than rows) and the various subsolutions listed in pictures and words. Two new alternative combinations (B and C) are shown by the different sets of dots in the squares of the chart. One of these (B) was developed and patented as a novel design,

Example: Fork Lift Truck Morphological Chart

MAE 162 D/E – Mechanical Engineering Design I / II
Instructor – Jacob Rosen PhD.

UCLA

This example is concerned with finding alternative versions of the conventional forklift truck used for lifting and carrying loads in factories, warehouses, etc. If we investigate a few of these machines we might identify the essential generic features as follows:

- Means of support which allows movement.
- Means of moving the vehicle.
- Means of steering the vehicle.
- Means of stopping the vehicle.
- Means of lifting loads.
- Location for operator.

These features seem to be common to all forklift trucks, although different versions have different means of achieving the functions. For example, most such trucks run on wheels (means of support) that allow the vehicle to go anywhere on a flat surface, but some 1 are constrained to run on rails.

When we look at the means of moving the vehicle, we might conclude that this is too general a feature and we decide that it should be broken down into separate features for (a) the means of propulsion (normally driven wheels), (b) the power source (such as electric motor, petrol engine or diesel engine) and (c)

There are a staggering 90 000 possible forklift truck designs in the chart. Of course, some of these are not practicable solutions, or imply incompatible options - for example, an air cushion vehicle could not have steering by wheels. A typical, conventional forklift truck would comprise the following set of options from the chart:

Support	Wheels
Propulsion	Driven wheels
Power	Diesel engine
Transmission	Gears and shafts
Steering	Turning wheels
Stopping	Brakes
Lifting	Rack and pinion
Operator	Seated at rear.

Example: Fork Lift Truck Morphological Chart

Feature	Means				
Support	Wheels	Track	Air cushion	Slides	Pedipulators
Propulsion	Driven wheels	Air thrust	Moving cable	Linear induction	
Power	Electric	Petrol	Diesel	Bottled gas	Steam
Transmission	Gears and shafts	Belts	Chains	Hydraulic	Flexible cable
Steering	Turning wheels	Air thrust	Rails		
Stopping	Brakes	Reverse thrust	Ratchet		
Lifting	Hydraulic ram	Rack and pinion	Screw	Chain or rope hoist	
Operator	Seated at front	Seated at rear	Standing	Walking	Remote control

This example is concerned with finding alternative versions of the conventional forklift truck used for lifting and carrying loads in factories, warehouses, etc. If we investigate a few of these machines we might identify the essential generic features as follows:

- Means of support which allows movement.
- Means of moving the vehicle.
- Means of steering the vehicle.
- Means of stopping the vehicle.
- Means of lifting loads.
- Location for operator.

These features seem to be common to all forklift trucks, although different versions have different means of achieving the functions. For example, most such trucks run on wheels (means of support) that allow the vehicle to go anywhere on a flat surface, but some 1 are constrained to run on rails.

When we look at the means of moving the vehicle, we might conclude that this is too general a feature and we decide that it should be broken down into separate features for (a) the means of propulsion (normally driven wheels), (b) the power source (such as electric motor, petrol engine or diesel engine) and (c)

transmission type (gears and shafts, belt, hydraulic, etc.). Adding some new and perhaps rather fanciful alternatives to the conventional alternatives would enable a list like the following to be generated:

Feature

1. Support
2. Propulsion
3. Power
4. Transmission
5. Steering
6. Stopping
7. Lifting
8. Operator

Means

1. Wheels, track, air cushion, slides, pedipulators.
2. Driven wheels, air thrust, moving cable, linear induction.
3. Electric, petrol, diesel, bottled gas, steam.
4. Gears and shafts, belts, chains, hydraulic, flexible cable.
5. Turning wheels, air thrust, rails.
6. Brakes, reverse thrust, ratchet.
7. Hydraulic ram, rack and pinion, screw, chain or rope hoist.
8. Seated at front, seated at rear, standing, walking, remote control.

A morphological chart incorporating these lists is shown in Figure 10.8. You might like to calculate how many possible different solution combinations there are in this chart.

Example: Fork Lift Truck Morphological Chart

Feature	Means				
Support	Wheels	Track	Air cushion	Slides	Pedipulators
Propulsion	Driven wheels	Air thrust	Moving cable	Linear induction	
Power	Electric	Petrol	Diesel	Bottled gas	Steam
Transmission	Gears and shafts	Belts	Chains	Hydraulic	Flexible cable
Steering	Turning wheels	Air thrust	Rails		
Stopping	Brakes	Reverse thrust	Ratchet		
Lifting	Hydraulic ram	Rack and pinion	Screw	Chain or rope hoist	
Operator	Seated at front	Seated at rear	Standing	Walking	Remote control

The inclusion of a few unconventional options in the chart suggests some possibilities for radical new designs. For instance, the idea of 'pedipulators' (i.e. walking mechanisms similar to legs and feet) might lead to designs suitable for use on rough ground such as building sites - or even capable of ascending flights of steps.

The chart can also be used to help generate somewhat less fanciful but nonetheless novel design ideas. For example, the idea of using rails for steering might well be appropriate in some large warehouses, where the rails could be laid in the aisles between storage racks. The vehicle would have wheels for support and for providing propulsion. It would be electrically powered since it would be used indoors. One of the problems of electric vehicles is the limited battery power, so we might propose that our new design would pick up power from a live electric rail - like electric trains. This might be feasible in a fully automated warehouse which would not have the safety problems associated with people having t~ cross the rails. The 'operator' feature would therefore be remote control. A compatible set of subsolutions for this new design therefore becomes:

Support	Wheels
Propulsion	Driven wheels
Power	Electric motor
Transmission	Belt
Steering	Rails
Stopping	Brakes
Lifting	Screw
Operator	Remote control.

Example: Fork Lift Truck Morphological Chart

MAE 162 D/E – Mechanical Engineering Design I / II
Instructor – Jacob Rosen PhD.

UCLA

This example is concerned with finding alternative versions of the conventional forklift truck used for lifting and carrying loads in factories, warehouses, etc. If we investigate a few of these machines we might identify the essential generic features as follows:

- Means of support which allows movement.
- Means of moving the vehicle.
- Means of steering the vehicle.
- Means of stopping the vehicle.
- Means of lifting loads.
- Location for operator.

These features seem to be common to all forklift trucks, although different versions have different means of achieving the functions. For example, most such trucks run on wheels (means of support) that allow the vehicle to go anywhere on a flat surface, but some 1 are constrained to run on rails.

When we look at the means of moving the vehicle, we might conclude that this is too general a feature and we decide that it should be broken down into separate features for (a) the means of propulsion (normally driven wheels), (b) the power source (such as electric motor, petrol engine or diesel engine) and (c)

There are a staggering 90 000 possible forklift truck designs in the chart. Of course, some of these are not practicable solutions, or imply incompatible options - for example, an air cushion vehicle could not have steering by wheels. A typical, conventional forklift truck would comprise the following set of options from the chart:

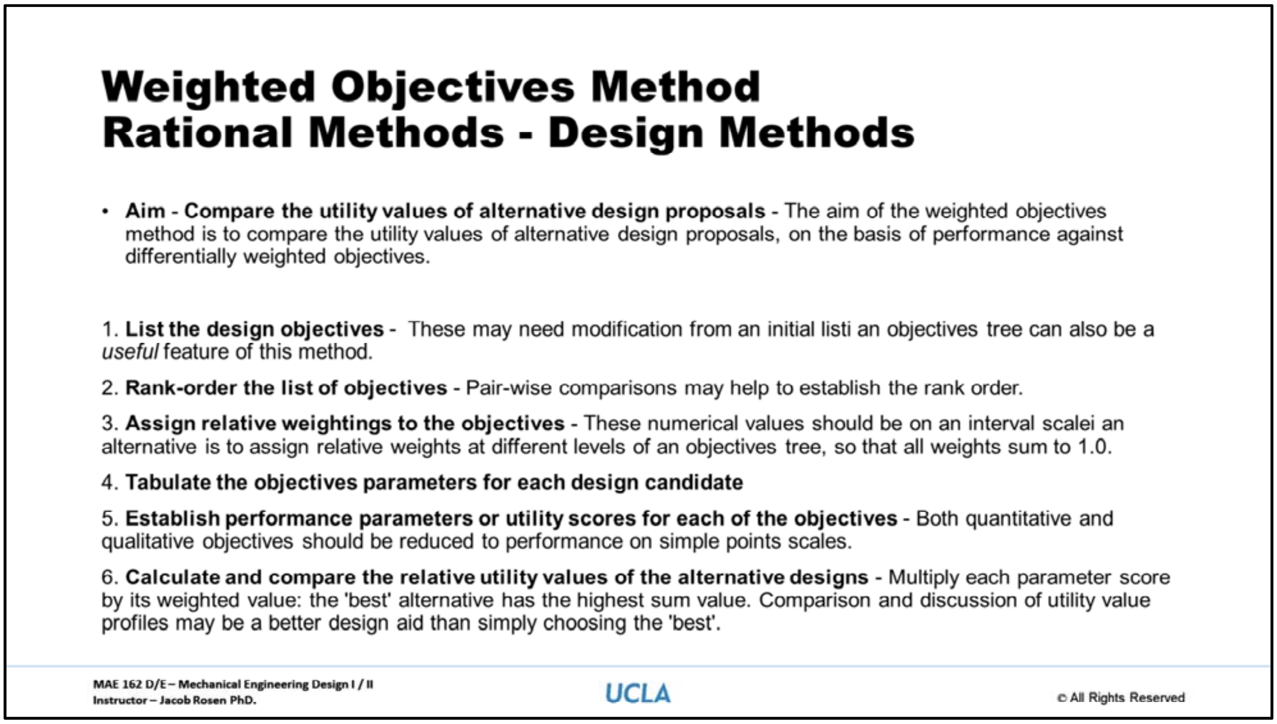
Support	Wheels
Propulsion	Driven wheels
Power	Diesel engine
Transmission	Gears and shafts
Steering	Turning wheels
Stopping	Brakes
Lifting	Rack and pinion
Operator	Seated at rear.

YouTube https://youtu.be/FSrcMaid0mg

Aliens - Power Loader

Evaluating Alternatives

Weighted Objectives Method



When a range of alternative designs has been created, the designer is then faced with the problem of selecting the best one. At various points in the design process there may also be d ecisions of choice to be made between alternative subsolutions or alternative features that might be incorporated into a final design. Choosing between alternatives is therefore a common feature of design activity. Choices can be made by guesswork, by 'intuition', by experience or by arbitrary decision. However, it is better if a choice can be made by some more rational, or at least open, procedure. Not only will the designer feel more secure in making the choice, but others involved in decision-making, such as clients, managers and colleagues in the design team, will be able to participate in, or assess the validity of, the choice.

If some of the previous design methods have already been used in the design process, then there should be some information available which should guide a choice between alternatives. For example, design proposals can be checked against criteria established by the performance specification method; and if design objectives have been established by the objectives tree method then these can be used in the evaluation of alternative designs.

In fact, the evaluation of alternatives can only be done by considering the objectives that the design is supposed to achieve. An evaluation assesses the overall 'value' or 'utility' of a particular design proposal with respect to the design objectives. However, different objectives may be regarded as having different 'values' in comparison with each other - i.e. may be regarded as being
When a range of alternative designs has been created, the designer is then faced with the problem of selecting the best one. At various points in the design process there may also be d ecisions of choice to be made between alternative subsolutions or alternative features that might be incorporated into a final design. Choosing between alternatives is therefore a common feature of design activity.
Choices can be made by guesswork, by 'intuition', by experience or by arbitrary decision. However, it is better if a choice can be made by some more rational, or at least open, procedure. Not only will the designer feel more secure in making the choice, but others involved in decision-making, such as clients, managers and colleagues in the design team, will be able to participate in, or assess the validity of, the choice.
If some of the previous design methods have already been used in the design process, then there should be some information available which should guide a choice between alternatives. For example, design proposals can be checked against criteria established by the performance specification method; and if design objectives have been established by the objectives tree method then these can be used in the evaluation of alternative designs.
In fact, the evaluation of alternatives can only be done by considering the objectives that the design is supposed to achieve. An evaluation assesses the overall 'value' or 'utility' of a particular design proposal with respect to the design objectives. However, different objectives may be regarded as having different 'values' in comparison with each other - i.e. may be regarded as being

Example: Shaft Hub – Dynamics Test Rig

MAE 162 D/E – Mechanical Engineering Design I / II
Instructor – Jacob Rosen PhD.

UCLA

In order to make any kind of evaluation it is necessary to have a set of criteria, and these must be based on the design objectives - i.e. what it is that the design is meant to achieve. These objectives should have been established at an early point in the d esign process. However, at the later stages of the process- when evaluation becomes especially important- the early set of objectives may well have become modified, or may not be entirely appropriate to the designs that have actually been developed. Some clarification of the set of objectives may therefore be necessary as a preliminary stage in the evaluation procedure.

The objectives will include technical and economic factors, user requirements, safety requirements, and so on. A comprehensive list should be drawn up. Wherever possible, an objective should be stated in such a way that a quantitative assessment can be made of the performance achieved by a design on that objective. Some objectives will inevitably relate to qualitative aspects of the design; these may later be allocated 'scores', but the earlier warning about limitations on the use of arithmetic must be remembered.

Example: Test Rig
Weighted Objectives Method – Step 1

List the design objectives - These may need modification from an initial list of an objectives tree can also be a *useful* feature of this method.

- **Quantitative assessment - performance** - An objective should be stated in such a way that a quantitative assessment can be made of the performance achieved by a design on that objective.

Example: Test Rig

Objectives

- (A) Reliable Operation
- (B) High Safety
- (C) Simple Production
- (D) Good Operational Characteristics

MAE 162 D/E – Mechanical Engineering Design I / II
Instructor – Jacob Rosen PhD.

UCLA

In order to make any kind of evaluation it is necessary to have a set of criteria, and these must be based on the design objectives - i.e. what it is that the design is meant to achieve. These objectives should have been established at an early point in the d esign process. However, at the later stages of the process- when evaluation becomes especially important- the early set of objectives may well have become modified, or may not be entirely appropriate to the designs that have actually been developed. Some clarification of the set of objectives may therefore be necessary as a preliminary stage in the evaluation procedure.

The objectives will include technical and economic factors, user requirements, safety requirements, and so on. A comprehensive list should be drawn up. Wherever possible, an objective should be stated in such a way that a quantitative assessment can be made of the performance achieved by a design on that objective. Some objectives will inevitably relate to qualitative aspects of the design; these may later be allocated 'scores', but the earlier warning about limitations on the use of arithmetic must be remembered.

Example: Test Rig
Weighted Objectives Method – Step 2

Rank-order the list of objectives - Pair-wise comparisons help to establish the rank order.

Step 2.1 - Each objective is considered in turn against each of the others. A figure 1 or 0 is entered into the relevant matrix cell in the chart, depending on whether the first objective is considered more or less important than the second, and so on.

For example, start with objective A and work along the chart row, asking 'Is A more important than B?' ... 'than C?' . . . 'than D?', etc. If it is considered more important, a 1 is entered in the matrix cell; if it is considered less important, a 0 is entered.

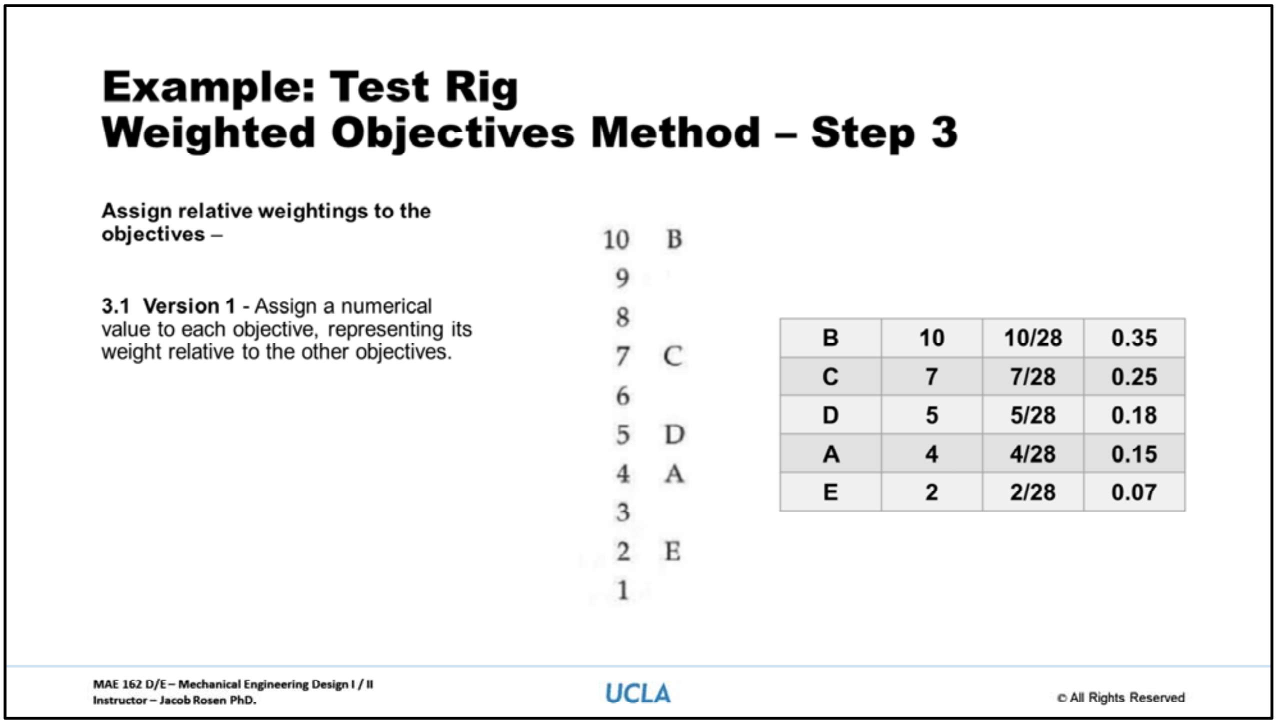
Verification Note: The upper right triangle matrix is inverted to the bottom lower triangle matric (inverse symmetry along the diagonal)

Step 2.2 – Sum up the rows and order the objective according to their ranks

Objectives	A	B	C	D	E	Row totals
A	—	0	0	0	1	1
B	1	—	1	1	1	4
C	1	0	—	1	1	3
D	1	0	0	—	1	2
E	0	0	0	0	—	0

Ranked Order of Objectives

B
C
D
A
E

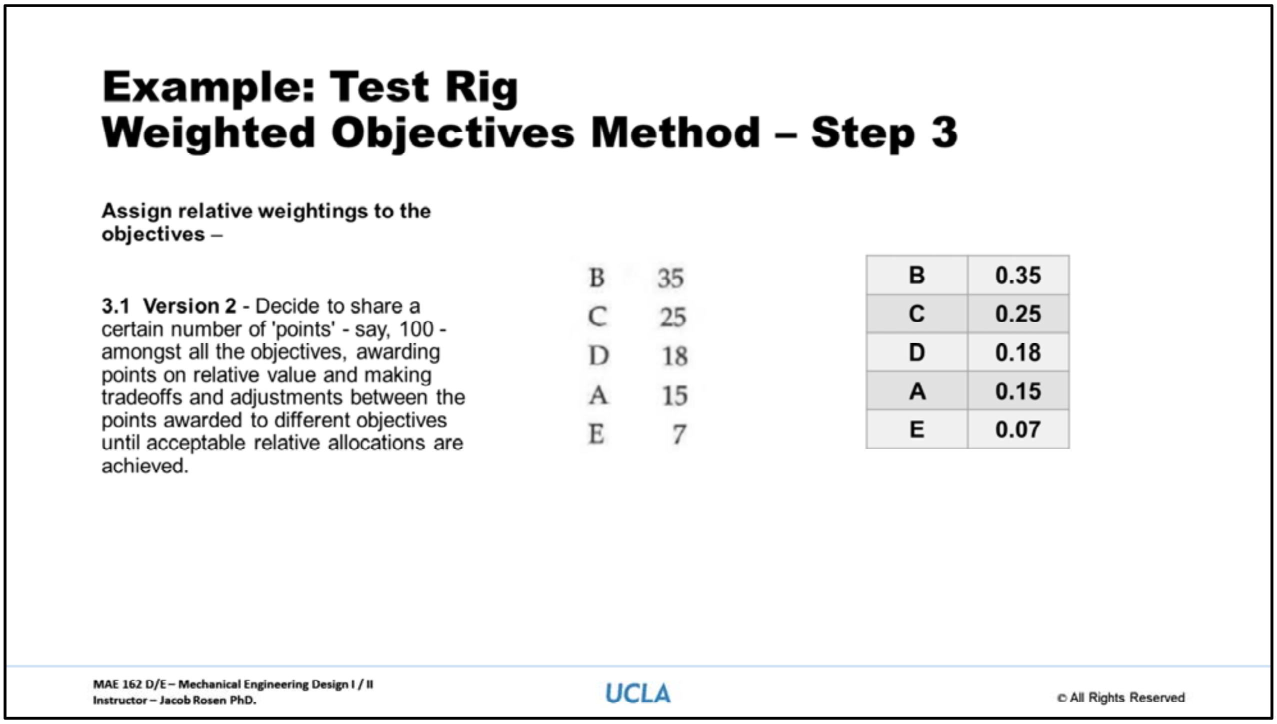


The next step is to assign a numerical value to each objective, representing its weight relative to the other objectives. A simple way of doing this is to consider the rank-ordered list as though the objectives are placed in positions of relative importance, or value, on a scale of, say, 1 to 10 or 1 to 100. In the example above, the rankordered objectives might be placed in relative positions on a scale of 1 to 10 like this:

10 B
9
8
7 c
6
5 D
4 A
3
2 E
1

The most important objective, B, has been given the value 10, and the others then given values relative to this. Thus, objective C is valued as about 70% of the value of objective B; objective A is valued twice as highly as objective E, etc. The corresponding scale values are the relative weights of the objectives. (Note that the highest and lowest ranked objectives are not necessarily placed at the absolute top and bottom positions of the scale.)

If you can achieve such relative weightings, and feel confident about the relative positions of the objectives on the scale, then you have converted the ordinal rank-order scale into an *interval* value scale, which can be used for arithmetic operations.



An alternative procedure is to decide to share a certain number of 'points' - say, 100 - amongst all the objectives, awarding points on relative value and making tradeoffs and adjustments between the points awarded to different objectives until acceptable relative allocations are achieved. This can be done on a team basis, with members of the team each asked to allocate, or 'spend', a fixed number of total points between the objectives according to how highly they value them. If 100 points were allocated amongst objectives A to E in the earlier example, the results might be:

B 35
c 25
D 18
A 15
E 7

Example: Test Rig
Weighted Objectives Method – Step 3

3.2 Repeat the weight assignment to each level of the objective tree (Bottom left corner of each triangle)

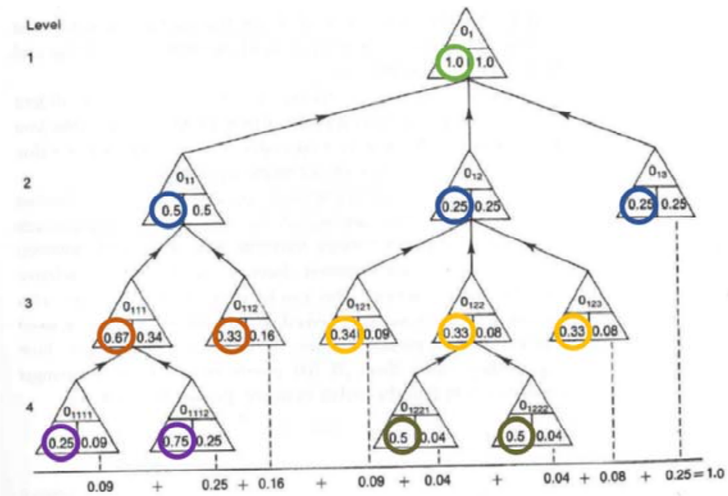
Note: the sum of all the branches are equal to 1

Level 1: 1

Level 2: 0.5+0.25+0.25=1

Level 3: 0.67+0.34=1 ; 0.34+0.33+0.33=1

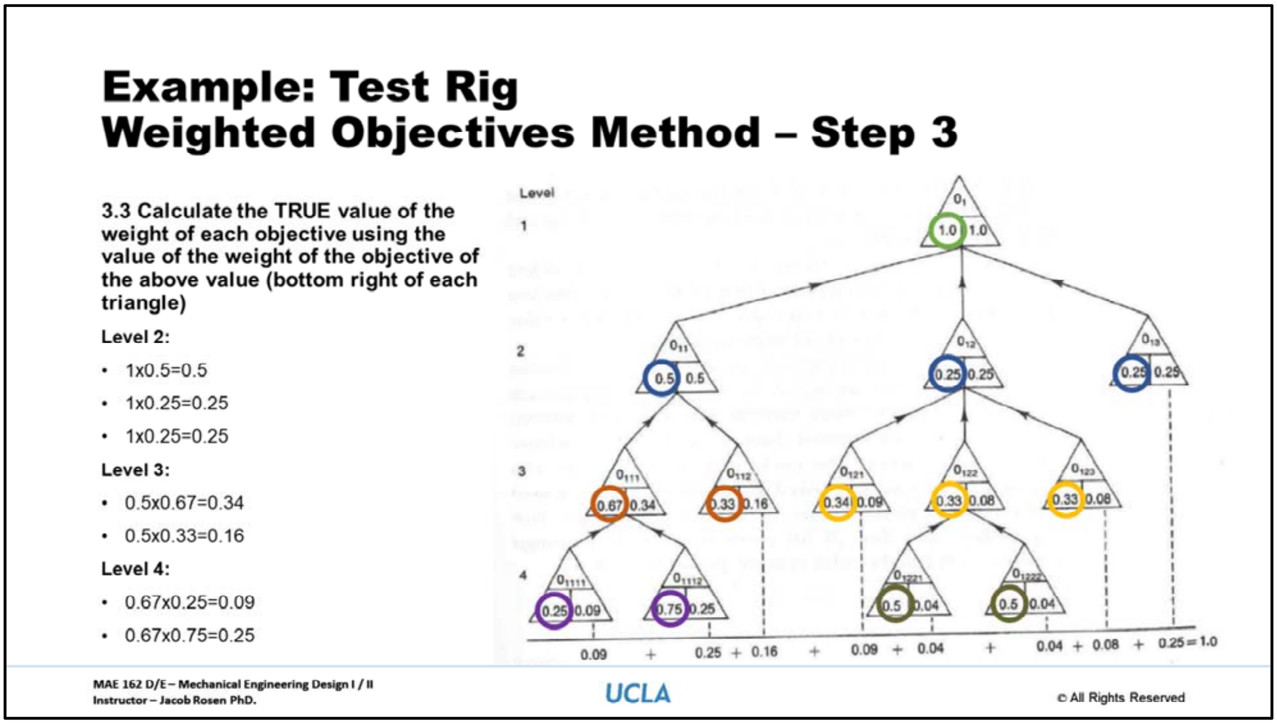
Level 4: 0.25+0.75=1 ; 0.5+0.5=1



UCLA

An objectives tree can be used to provide what is probably a more reliable method of assigning weights. The highest-level, overall objective is given the value 1.0; at each lower level, the subobjectives are then given weights relative to each other but which also total 1.0. However, their 'true' weights are calculated as a fraction of the 'true' weight of the objective above them.

This is clarified in Figure 11.1. Each box in the tree is labelled with the objective's number (O0, O1, O111 etc.), and given two values: its value relative to its neighbors at the same level, and its 'true' value or value relative to the overall objective. Thus, in this example, objectives O111 and O112 are given values relative to each other of 0.67: 0.33; but their ' true' values can only total 0.5 (the 'true' value of objective O11) and are therefore calculated as 0.67 x 0.5 = 0.34 and 0.33 x 0.5 = 0.16.



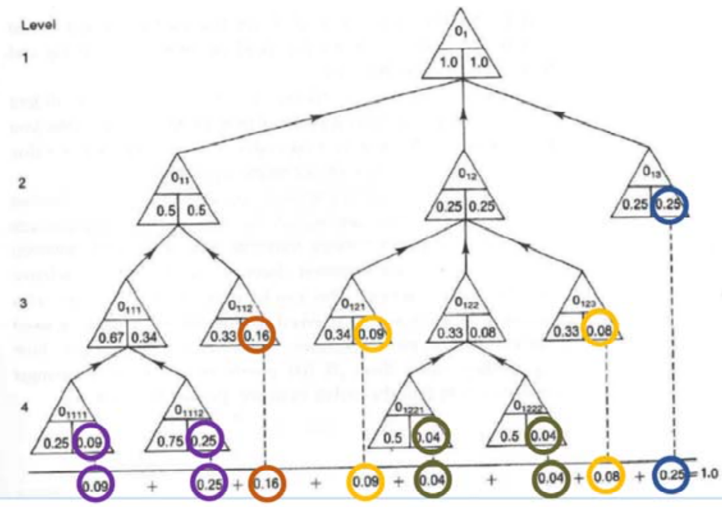
An objectives tree can be used to provide what is probably a more reliable method of assigning weights. The highest-level, overall objective is given the value 1.0; at each lower level, the subobjectives are then given weights relative to each other but which also total 1.0. However, their 'true' weights are calculated as a fraction of the 'true' weight of the objective above them.

This is clarified in Figure 11.1. Each box in the tree is labelled with the objective's number (O0, O1, O111 etc.), and given two values: its value relative to its neighbors at the same level, and its 'true' value or value relative to the overall objective. Thus, in this example, objectives O111 and O112 are given values relative to each other of 0.67: 0.33; but their ' true' values can only total 0.5 (the 'true' value of objective O11) and are therefore calculated as 0.67 x 0.5 = 0.34 and 0.33 x 0.5 = 0.16.

Example: Test Rig
Weighted Objectives Method – Step 3

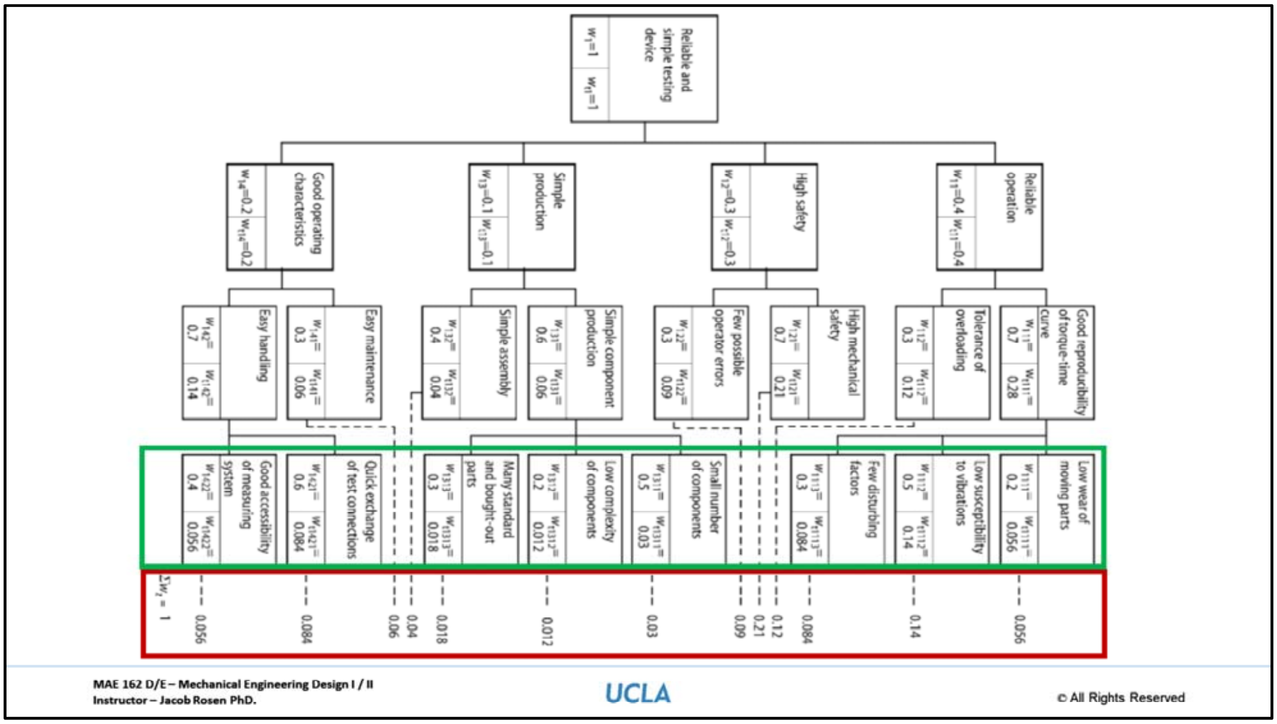
3.4 Drop down all the TRUE weights of all the objectives

Note: The sum of all the weights mare equal to zero



UCLA

Using this procedure it is easier to assign weights with some consistency because it is relatively easy to compare subobjectives in small groups of two or three and with respect to a single higherlevel objective. All the 'true' weights add up to 1.0, and this also ensures the arithmetical validity of the weights.


Reliable and simple testing device
Reliable operation
High safety
Simple production
Good operating characteristics
Good reproducibility of torque-time curve
Tolerance of overloading
High mechanical safety
Few possible operator errors
Simple component production
Simple assembly
Easy maintenance
Easy handling
Low wear of moving parts
Low susceptibility to vibrations
Few disturbing factors
Small number of components
Low complexity of components
Many standard and bought-out parts
Quick exchange of test connections
Good accessibility of measuring system
0.056
0.14
0.084
0.12
0.21
0.09
0.03
0.012
0.018
0.04
0.06
0.084
0.056
MAE 162 D/E – Mechanical Engineering Design I / II
Instructor – Jacob Rosen PhD.
UCLA
© All Rights Reserved

No	Evaluation criteria	Wt.	Parameters	Unit	Variant V_1 Magn. m_{i1}	Value v_{i1}	Weighted value wv_{i1}	Variant V_2 Magn. m_{i2}	Value v_{i2}	Weighted value wv_{i2}	Variant V_3 Magn. m_{i3}	Value v_{i3}	Weighted value wv_{i3}	Variant V_4 Magn. m_{i4}	Value v_{i4}	Weighted value wv_{i4}
1	Low wear of moving parts	0.056	Amount of wear	-	high	3	0.168	low	6	0.336	average	4	0.224	low	6	0.336
2	Low susceptibility to vibrations	0.14	Natural frequency	s^{-1}	410	3	0.420	2370	7	0.980	2370	7	0.980	<410	2	0.280
3	Few disturbing factors	0.084	Disturbing factors	-	high	2	0.168	low	7	0.588	low	6	0.504	(average)	4	0.336
4	Tolerance of overloading	0.12	Overload reserve	%	5	5	0.600	10	7	0.840	10	7	0.840	20	8	0.960
5	High mechanical safety	0.21	Expected mechan. safety	-	average	4	0.840	high	7	1.470	high	7	1.470	very high	8	1.680
6	Few possible operator errors	0.09	Possibilities of operator errors	-	high	3	0.270	low	7	0.630	low	6	0.540	average	4	0.360
7	Small number of components	0.03	No. of components	-	average	5	0.150	average	4	0.120	average	4	0.120	low	6	0.180
8	Low complexity of components	0.012	Complexity of components	-	low	6	0.072	low	7	0.084	average	5	0.060	high	3	0.036
9	Many standard and bought-out parts	0.018	Proportion of standard and bought-out components	-	low	2	0.036	average	6	0.108	average	6	0.108	high	8	0.144
10	Simple assembly	0.04	Simplicity of assembly	-	low	3	0.120	average	5	0.200	average	5	0.200	high	7	0.280
11	Easy maintenance	0.06	Time and cost or maintenance	-	average	4	0.240	low	8	0.480	low	7	0.420	high	3	0.180
12	Quick exchange of test connections	0.084	Estimated time needed to exchange test connections	min	180	4	0.336	120	7	0.588	120	7	0.588	180	4	0.336
13	Good accessibility of measuring systems	0.056	Accessibility of measuring systems	-	good	7	0.392	good	7	0.392	good	7	0.392	average	5	0.280
		$\Sigma w_i =$ 1.0				$OV_1 = 51$ $R_1 = 0.39$	$OWV_1 =$ 3.812 $WR_1 = 0.38$		$OV_2 = 85$ $R_2 = 0.65$	$OWV_2 =$ 6.816 $WR_2 = 0.68$		$OV_3 = 78$ $R_3 = 0.60$	$OWV_3 =$ 6.446 $WR_3 = 0.64$		$OV_4 = 68$ $R_4 = 0.52$	$OWV_4 =$ 5.388 $WR_4 = 0.54$

Example: Test Rig
Weighted Objectives Method – Step 4

Tabulate the objectives parameters for each design candidate

Using this procedure it is easier to assign weights with some consistency because it is relatively easy to compare subobjectives in small groups of two or three and with respect to a single higherlevel objective. All the 'true' weights add up to 1.0, and this also ensures the arithmetical validity of the weights.

No.	Evaluation criteria	Wt.	Objective Parameters	Unit	Variant V_1 (e.g. Eng.$_1$) Magn. m_{i1}	Value v_{i1}	Weighted value WV_{i1}	Variant V_2 (e.g. Eng.$_2$) Magn. m_{i2}	Value v_{i2}	Weighted value WV_{i2}	…	Variant V_j Magn. m_{ij}	Value v_{ij}	Weighted value WV_{ij}	…	Variant V_m Magn. m_{im}	Value v_{im}	Weighted value WV_{im}
1	Low fuel consumption	0.3	Fuel consumption	$\frac{g}{kWh}$	240			300			…	m_{1j}			…	m_{1m}		
2	Light weight construction	0.15	Mass per unit power	$\frac{kg}{kW}$	1.7			2.7			…	m_{2j}			…	m_{2m}		
3	Simple production	0.1	Simplicity of components	–	low			average			…	m_{3j}			…	m_{3m}		
4	Long service life	0.2	Service life	km	80000			150000			…	m_{4j}			…	m_{4m}		
⋮	⋮	⋮	⋮	⋮	⋮			⋮				⋮				⋮		
i		W_i			m_{i1}			m_{i2}			…	m_{ij}			…	m_{im}		
⋮	⋮	⋮	⋮	⋮	⋮			⋮				⋮				⋮		
n		W_n			m_{n1}			m_{n2}			…	m_{nj}			…	m_{nm}		
		$\sum_{i=1}^{n} W_i = 1$																

No	Evaluation criteria	Wt.	Parameters	Unit	Variant V_1			Variant V_2			Variant V_3			Variant V_4		
					Magn. m_{i1}	Value V_{i1}	Weighted value WV_{i1}	Magn. m_{i2}	Value V_{i2}	Weighted value WV_{i2}	Magn. m_{i3}	Value V_{i3}	Weighted value WV_{i3}	Magn. m_{i4}	Value V_{i4}	Weighted value WV_{i4}
1	Low wear of moving parts	0.056	Amount of wear	-	high	3	0.168	low	6	0.336	average	4	0.224	low	6	0.336
2	Low susceptibility to vibrations	0.14	Natural frequency	s^{-1}	410	3	0.420	2370	7	0.980	2370	7	0.980	<410	2	0.280
3	Few disturbing factors	0.084	Disturbing factors	-	high	2	0.168	low	7	0.588	low	6	0.504	(average)	4	0.336
4	Tolerance of overloading	0.12	Overload reserve	%	5	5	0.600	10	7	0.840	10	7	0.840	20	8	0.960
5	High mechanical safety	0.21	Expected mechan. safety	-	average	4	0.840	high	7	1.470	high	7	1.470	very high	8	1.680
6	Few possible operator errors	0.09	Possibilities of operator errors	-	high	3	0.270	low	7	0.630	low	6	0.540	average	4	0.360
7	Small number of components	0.03	No. of components	-	average	5	0.150	average	4	0.120	average	4	0.120	low	6	0.180
8	Low complexity of components	0.012	Complexity of components	-	low	6	0.072	low	7	0.084	average	5	0.060	high	3	0.036
9	Many standard and bought-out parts	0.018	Proportion of standard and bought-out components	-	low	2	0.036	average	6	0.108	average	6	0.108	high	8	0.144
10	Simple assembly	0.04	Simplicity of assembly	-	low	3	0.120	average	5	0.200	average	5	0.200	high	7	0.280
11	Easy maintenance	0.06	Time and cost or maintenance	-	average	4	0.240	low	8	0.480	low	7	0.420	high	3	0.180
12	Quick exchange of test connections	0.084	Estimated time needed to exchange test connections	min	180	4	0.336	120	7	0.588	120	7	0.588	180	4	0.336
13	Good accessibility of measuring systems	0.056	Accessibility of measuring systems	-	good	7	0.392	good	7	0.392	good	7	0.392	average	5	0.280
		$\Sigma w_i = 1.0$				$OV_1 = 51$ $R_1 = 0.39$	$OWV_1 = 3.812$ $WR_1 = 0.38$		$OV_2 = 85$ $R_2 = 0.65$	$OWV_2 = 6.816$ $WR_2 = 0.68$		$OV_3 = 78$ $R_3 = 0.60$	$OWV_3 = 6.446$ $WR_3 = 0.64$		$OV_4 = 68$ $R_4 = 0.52$	$OWV_4 = 5.388$ $WR_4 = 0.54$

Example: Test Rig
Weighted Objectives Method – Step 5

5. **Establish performance parameters or utility scores for each of the objectives** - Both quantitative and qualitative objectives should be reduced to performance on simple points scales.

11-point scale	Meaning	5-point scale	Meaning
0	Totally useless solution	0	Inadequate
1	Inadequate solution		
2	Very poor solution	1	Weak
3	Poor solution		
4	Tolerable solution		
5	Adequate solution	2	Satisfactory
6	Satisfactory solution		
7	Good solution	3	Good
8	Very good solution		
9	Excellent solution	4	Excellent
10	Perfect or ideal solution		

Value scale			
Use-value analysis		Guideline VDI 2225	
Pts.	Meaning	Pts.	Meaning
0	absolutely useless solution	0	unsatisfactory
1	very inadequate solution		
2	weak solution	1	just tolerable
3	tolerable solution		
4	adequate solution	2	adequate
5	satisfactory solution		
6	good solution with few drawbacks	3	good
7	good solution		
8	very good solution	4	very good (ideal)
9	solution exceeding the requirement		
10	ideal solution		

11-point scale	Meaning	5-point scale	Meaning
0	Totally useless solution	0	Inadequate
1	Inadequate solution		
2	Very poor solution	1	Weak
3	Poor solution		
4	Tolerable solution		
5	Adequate solution	2	Satisfactory
6	Satisfactory solution		
7	Good solution	3	Good
8	Very good solution		
9	Excellent solution	4	Excellent
10	Perfect or ideal solution		

Value Scale		Parameter magnitudes			
Use-value analysis Pts	VDI 2225 Pts	Fuel consumption g/kWh	Mass per unit power kg/kW	Simplicity of components	Service life
0	0	400	3.5	extremely complicated	$20 \cdot 10^3$
1		380	3.3		30
2	1	360	3.1	complicated	40
3		340	2.9		60
4	2	320	2.7	average	80
5		300	2.5		100
6	3	280	2.3	simple	120
7		260	2.1		140
8	4	240	1.9	extremely simple	200
9		220	1.7		300
10		200	1.5		$500 \cdot 10^3$

No	Evaluation criteria	Wt.	Parameters	Unit	Variant V_1			Variant V_2			Variant V_3			Variant V_4		
					Magn. m_{i1}	Value V_{i1}	Weighted value WV_{i1}	Magn. m_{i2}	Value V_{i2}	Weighted value WV_{i2}	Magn. m_{i3}	Value V_{i3}	Weighted value WV_{i3}	Magn. m_{i4}	Value V_{i4}	Weighted value WV_{i4}
1	Low wear of moving parts	0.056	Amount of wear	-	high	3	0.168	low	6	0.336	average	4	0.224	low	6	0.336
2	Low susceptibility to vibrations	0.14	Natural frequency	s^{-1}	410	3	0.420	2370	7	0.980	2370	7	0.980	<410	2	0.280
3	Few disturbing factors	0.084	Disturbing factors	-	high	2	0.168	low	7	0.588	low	6	0.504	(average)	4	0.336
4	Tolerance of overloading	0.12	Overload reserve	%	5	5	0.600	10	7	0.840	10	7	0.840	20	8	0.960
5	High mechanical safety	0.21	Expected mechan. safety	-	average	4	0.840	high	7	1.470	high	7	1.470	very high	8	1.680
6	Few possible operator errors	0.09	Possibilities of operator errors	-	high	3	0.270	low	7	0.630	low	6	0.540	average	4	0.360
7	Small number of components	0.03	No. of components	-	average	5	0.150	average	4	0.120	average	4	0.120	low	6	0.180
8	Low complexity of components	0.012	Complexity of components	-	low	6	0.072	low	7	0.084	average	5	0.060	high	3	0.036
9	Many standard and bought-out parts	0.018	Proportion of standard and bought-out components	-	low	2	0.036	average	6	0.108	average	6	0.108	high	8	0.144
10	Simple assembly	0.04	Simplicity of assembly	-	low	3	0.120	average	5	0.200	average	5	0.200	high	7	0.280
11	Easy maintenance	0.06	Time and cost or maintenance	-	average	4	0.240	low	8	0.480	low	7	0.420	high	3	0.180
12	Quick exchange of test connections	0.084	Estimated time needed to exchange test connections	min	180	4	0.336	120	7	0.588	120	7	0.588	180	4	0.336
13	Good accessibility of measuring systems	0.056	Accessibility of measuring systems	-	good	7	0.392	good	7	0.392	good	7	0.392	average	5	0.280
		$\Sigma w_i = 1.0$				$OV_1 = 51$ $R_1 = 0.39$	$OWV_1 = 3.812$ $WR_1 = 0.38$		$OV_2 = 85$ $R_2 = 0.65$	$OWV_2 = 6.816$ $WR_2 = 0.68$		$OV_3 = 78$ $R_3 = 0.60$	$OWV_3 = 6.446$ $WR_3 = 0.64$		$OV_4 = 68$ $R_4 = 0.52$	$OWV_4 = 5.388$ $WR_4 = 0.54$

No.	Evaluation criteria	Wt.	Parameters	Unit	Variant V_1 (e.g. $Eng._1$)			Variant V_2 (e.g. $Eng._2$)			…	Variant V_j			…	Variant V_m		
					Magn. m_{i1}	Value v_{i1}	Weighted value WV_{i1}	Magn. m_{i2}	Value v_{ij}	Weighted value WV_{ij}		Magn. m_{ij}	Value v_{ij}	Weighted value WV_{ij}		Magn. m_{im}	Value V_{im}	Weighted value WV_{im}
1	Low fuel consumption	0.3	Fuel consumption	$\frac{g}{kWh}$	240	8	2.4	300	5	1,5	…	m_{1j}	V_{1j}	WV_{1j}	…	m_{1m}	V_{1m}	WV_{1m}
2	Lightweight construction	0.15	Mass per unit power	$\frac{kg}{kW}$	1,7	9	1.35	2.7	4	0,6	…	m_{2j}	V_{2j}	WV_{2j}	…	m_{2m}	V_{2m}	WV_{2m}
3	Simple production	0.1	Simplicity of components	-	complicated	2	0.2	average	5	0,5	…	m_{3j}	V_{3j}	WV_{3j}	…	m_{3m}	V_{3m}	WV_{3m}
4	Long service life	0.2	Service life	km	80 000	4	0.8	150 000	7	1,4	…	m_{4j}	V_{4j}	WV_{4j}	…	$m^4{}_m$	V_{4m}	WV_{4m}
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮		⋮	⋮	⋮		⋮	⋮	⋮
i		W_i			m_{i1}	V_{i1}	WV_{i1}	m_{i2}	V_{i2}	WV_{i2}	…	m_{ij}	V_{ij}	WV_{ij}	…	m_{im}	V_{im}	WV_{im}
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮		⋮	⋮	⋮		⋮	⋮	⋮
n		W_n			m_{n1}	V_{n1}	WV_{n1}	m_{n2}	V_{n2}	WV_{n2}	…	m_{nj}	V_{nj}	WV_{nj}	…	m_{nm}	V_{nm}	WV_{nm}
		$\sum_{i=1}^{n} W_i =$				OV_1 R_1	OWV_1 WR_1		OV_2 R_2	OWV_2 WR_2			OV_j R_j	OWV_j WR_j			OV_m R_m	OWV_m WR_m

Example: Test Rig
Weighted Objectives Method – Step 5

5. **Calculate and compare the relative utility values of the alternative designs** - Multiply each parameter score by its weighted value: the 'best' alternative has the highest sum value. Comparison and discussion of utility value profiles may be a better design aid than simply choosing the 'best'.

$$\text{Unweighted: } OV_j = \sum_{i=1}^{n} v_{ij}$$

$$\text{Weighted: } OWV_j = \sum_{i=1}^{n} w_i \cdot v_{ij} = \sum_{i=1}^{n} wv_{ij}$$

$$\text{Unweighted: } R_j = \frac{OV_j}{v_{\max} \cdot n} = \frac{\sum_{i=1}^{n} v_{ij}}{v_{\max} \cdot n}$$

$$\text{Weighted: } WR_j = \frac{OWV_j}{v_{\max} \cdot \sum_{i=1}^{n} w_i} = \frac{\sum_{i=1}^{n} w_i \cdot v_{ij}}{v_{\max} \cdot \sum_{i=1}^{n} w_i}$$

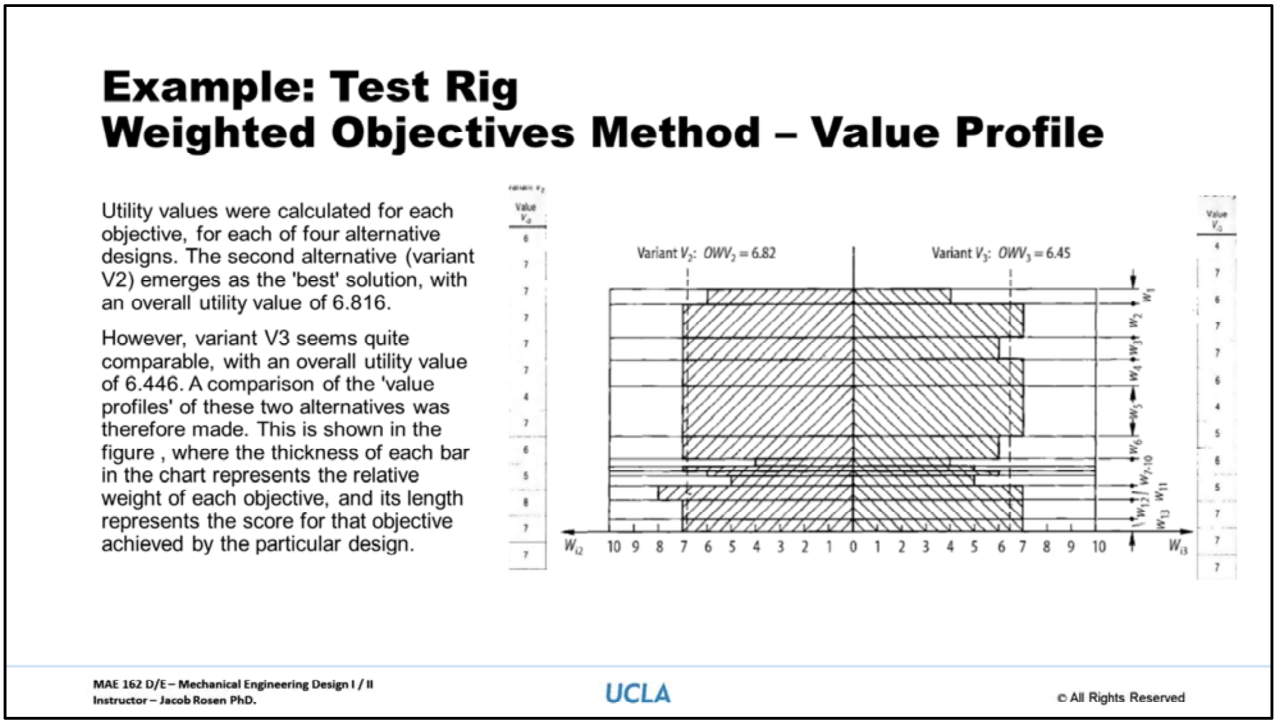
Evaluation criteria			Parameters		Variant V_1 (e.g. $Eng._1$)			Variant V_2 (e.g. $Eng._2$)			…	Variant V_j			…	Variant V_m		
No.		Wt.		Unit	Magn. m_{i1}	Value v_{i1}	Weighted value wv_{i1}	Magn. m_{i2}	Value v_{ij}	Weighted value wv_{ij}		Magn. m_{ij}	Value v_{ij}	Weighted value wv_{ij}		Magn. m_{im}	Value v_{im}	Weighted value wv_{im}
1	Low fuel consumption	0.3	Fuel consumption	$\frac{g}{kWh}$	240	8	2.4	300	5	1,5	…	m_{1j}	v_{1j}	wv_{1j}	…	m_{1m}	v_{1m}	wv_{1m}
2	Lightweight construction	0.15	Mass per unit power	$\frac{kg}{kW}$	1,7	9	1.35	2.7	4	0,6	…	m_{2j}	v_{2j}	wv_{2j}	…	m_{2m}	v_{2m}	wv_{2m}
3	Simple production	0.1	Simplicity of components	-	compli-cated	2	0.2	average	5	0,5	…	m_{3j}	v_{3j}	wv_{3j}	…	m_{3m}	v_{3m}	wv_{3m}
4	Long service life	0.2	Service life	km	80 000	4	0.8	150 000	7	1,4	…	m_{4j}	v_{4j}	wv_{4j}	…	$m4_m$	v_{4m}	wv_{4m}
⋮	⋮	⋮						⋮	⋮	⋮		⋮	⋮	⋮		⋮	⋮	⋮
i		w_i						m_{i2}	v_{i2}	wv_{i2}	…	m_{ij}	v_{ij}	wv_{ij}	…	m_{im}	v_{im}	wv_{im}
⋮	⋮	⋮						⋮	⋮	⋮		⋮	⋮	⋮		⋮	⋮	⋮
n		w_n						m_{n2}	v_{n2}	wv_{n2}	…	m_{nj}	v_{nj}	wv_{nj}	…	m_{nm}	v_{nm}	wv_{nm}
		$\sum_{i=1}^{n} w_i = 1$							OV_2 R_2	OWV_2 WR_2			OV_j R_j	OWV_j WR_j			OV_m R_m	OWV_m WR_m

Unweighted $R_j = \frac{OV_j}{v_{max} \cdot n}$

Weighted: $WR_j = \frac{OWV_j}{v_{max} \cdot \sum_{i=1}^{n} w_i}$

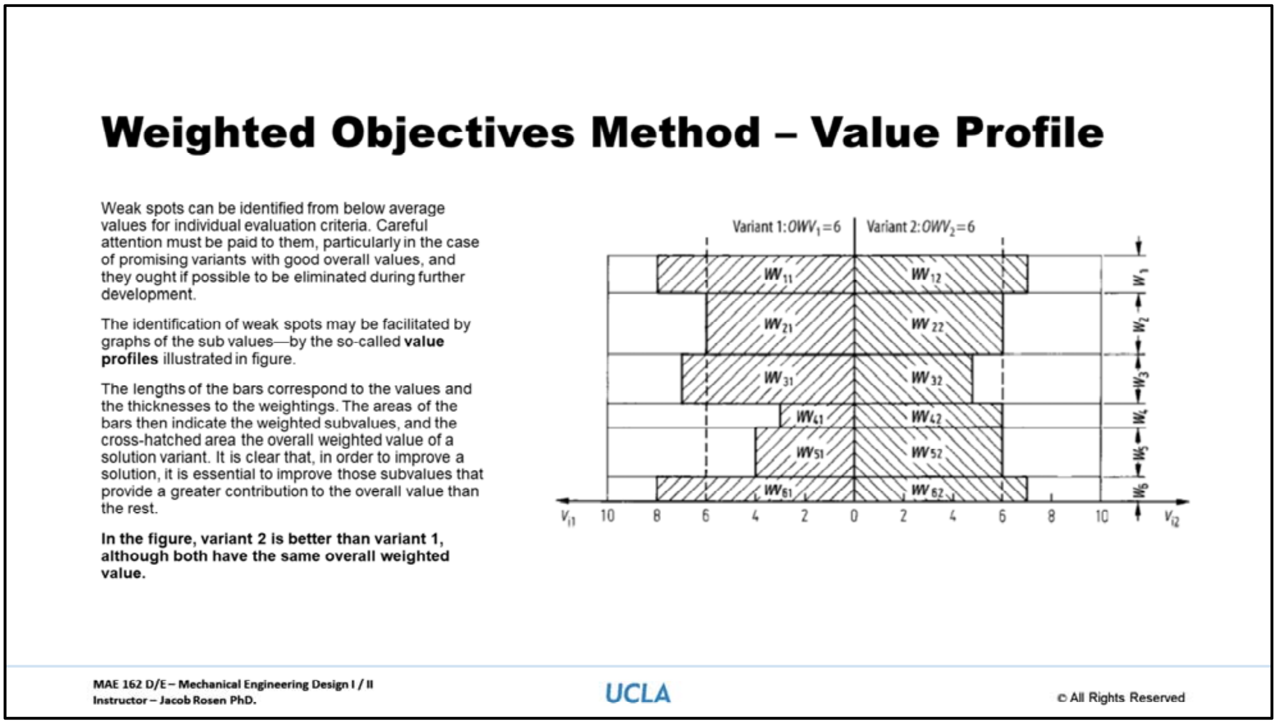
Unweighted: $OV_j = \sum_{i=1}^{n} v_{ij}$ Weighted: $OWV_j = \sum_{i=1}^{n} w_i v_{ij}$

No.	Evaluation criteria	Wt.	Parameters	Unit	Variant V_1 Magn. m_{i1}	Value V_{i1}	Weighted value WV_{i1}	Variant V_2 Magn. m_{i2}	Value V_{i2}	Weighted value WV_{i2}	Variant V_3 Magn. m_{i3}	Value V_{i3}	Weighted value WV_{i3}	Variant V_4 Magn. m_{i4}	Value V_{i4}	Weighted value WV_{i4}
1	Low wear of moving parts	0.056	Amount of wear	-	high	3	0.168	low	6	0.336	average	4	0.224	low	6	0.336
2	Low susceptibility to vibrations	0.14	Natural frequency	s^{-1}	410	3	0.420	2370	7	0.980	2370	7	0.980	<410	2	0.280
3	Few disturbing factors	0.084	Disturbing factors	-	high	2	0.168	low	7	0.588	low	6	0.504	(average)	4	0.336
4	Tolerance of overloading	0.12	Overload reserve	%	5	5	0.600	10	7	0.840	10	7	0.840	20	8	0.960
5	High mechanical safety	0.21	Expected mechan. safety	-	average	4	0.840	high	7	1.470	high	7	1.470	very high	8	1.680
6	Few possible operator errors	0.09	Possibilities of operator errors	-	high	3	0.270	low	7	0.630	low	6	0.540	average	4	0.360
7	Small number of components	0.03	No. of components	-	average	5	0.150	average	4	0.120	average	4	0.120	low	6	0.180
8	Low complexity of components	0.012	Complexity of components	-	low	6	0.072	low	7	0.084	average	5	0.060	high	3	0.036
9	Many standard and bought-out parts	0.018	Proportion of standard and bought-out components	-	low	2	0.036	average	6	0.108	average	6	0.108	high	8	0.144
10	Simple assembly	0.04	Simplicity of assembly	-	low	3	0.120	average	5	0.200	average	5	0.200	high	7	0.280
11	Easy maintenance	0.06	Time and cost or maintenance	-	average	4	0.240	low	8	0.480	low	7	0.420	high	3	0.180
12	Quick exchange of test connections	0.084	Estimated time needed to exchange test connections	min	180	4	0.336	120	7	0.588	120	7	0.588	180	4	0.336
13	Good accessibility of measuring systems	0.056	Accessibility of measuring systems	-	good	7	0.392	good	7	0.392	good	7	0.392	average	5	0.280
		$\Sigma w_i = 1.0$				$OV_1 = 51$ $R_1 = 0.39$	$OWV_1 = 3.812$ $WR_1 = 0.38$		$OV_2 = 85$ $R_2 = 0.65$	$OWV_2 = 6.816$ $WR_2 = 0.68$		$OV_3 = 78$ $R_3 = 0.60$	$OWV_3 = 6.446$ $WR_3 = 0.64$		$OV_4 = 68$ $R_4 = 0.52$	$OWV_4 = 5.388$ $WR_4 = 0.54$



Utility values were calculated for each objective, for each of four alternative designs. The second alternative (variant V2) emerges as the 'best' solution, with an overall utility value of 6.816. However, variant V3 seems quite comparable, with an overall utility value of 6.446. A comparison of the 'value profiles' of these two alternatives was therefore made. This is shown in Figure 11.5, where the thickness of each bar in the chart represents the relative weight of each objective, and its length represents the score for that objective achieved by the particular design.
The chart shows that V2 has a more consist~nt profile than V3, with fewer relatively weak spots in its profile. V2 therefore seems to be a good 'all-round' design, and the comparison confirms it as being the best of the alternatives. However, improvement of V3 in perhaps just one or two of its lower-scoring parameters might easily push it into the lead.

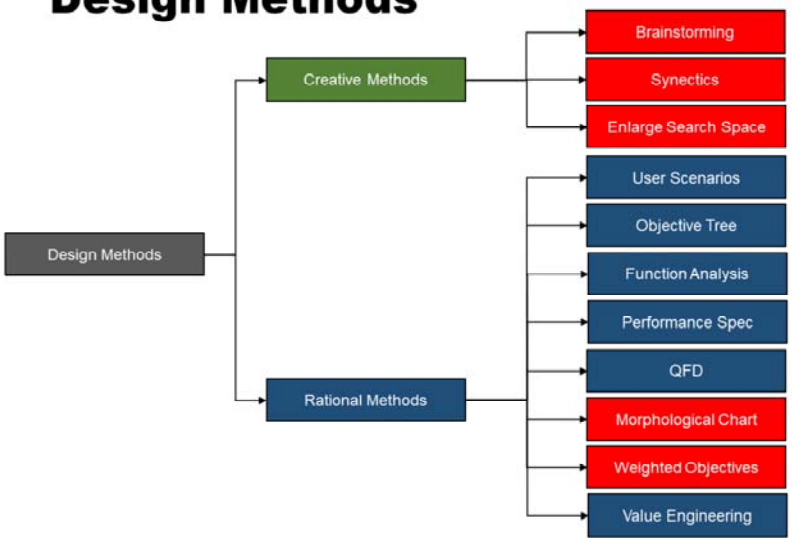
It appears that variant*V*2 has the highest overall value and the best overall rating. However, variant *V*3 follows close behind. For the detection of weak spots, a value profile was drawn (see Figure 6.56). The profile shows that variant *V*2 is well balanced with respect to all of the important evaluation criteria. With a weighted rating of 68%, variant *V*2 thus represents a good principle solution (concept) with which to start the embodiment design phase, during which the identified weak spots have to be addressed



Weak spots can be identified from below average values for individual evaluation criteria. Careful attention must be paid to them, particularly in the case of promising variants with good overall values, and they ought if possible to be eliminated during further development. The identification of weak spots may be facilitated by graphs of the subvalues—for instance, by the so-called value profiles illustrated in Figure 3.38. In it, the lengths of the bars correspond to the values and the thicknesses to the weightings. The areas of the bars then indicate the weighted subvalues, and the cross-hatched area the overall weighted value of a solution variant. It is clear that, in order to improve a solution, it is essential to improve those subvalues that provide a greater contribution to the overall value than the rest. This is the case with the evaluation criteria that have an above average bar thickness (great importance) but a below average bar length. Apart from a high overall value, it is important to obtain a balanced value profile, with no serious weak spots. Thus, in Figure 3.38, variant 2 is better than variant 1, although both have the same overall weighted value.

There are also cases in which a minimum permissible value is stipulated for all sub-values; that is, any variant that does not fulfil this condition has to be rejected, and all variants that do fulfil it are developed further. In the literature this procedure is described as the “determination of satisfactory solutions”

Design Methods



References

- Books
  - Chapter 7 – Design and Development Artifact, An Introduction to Design Science , Johannesson, Paul, Perjons, Erik
  - Chapters 4,10,11,12, Engineering Design Methods, Nigel Cross, Wiley
  - The Act of Creation, Arthur Koestler

- Websites
  - NASA - Reinventing the Wheel
  - The Evolution of 8 Objects Americans Use Every Day
  - Squaring the Circle: 15 Telephone Keypad Layouts that Could Have Been

- Videos