LECTURE #2
Introduction to Computer Aided Engineering

Introduction
- Catagorisation of CAE
- Elements of CAE
- Role of Computer-aided tools
- Computers in the design process
- CAD ?
- CAM ?
- CAD/CAM ?
- CIM ?
- Concurrent engineering
- Design for X
Computer aided engineering is the performance of engineering tasks and functions with the aid of a computer. These tasks are still administrated and controlled by the engineer. CAE is a well-established field but it has been poorly formalized and very fragmented.

**What is Computer Aided Engineering**

- **CAE** covers the whole field of CAD & CAM
- **CAD** involves computers in the design process
- **CAM** deals with numerically controlled machine tools, automatic testing equipment and production control techniques.
- **CIM** provides a link between design and manufacture
The computer & Engineer

- Reasoning
  - Logic
  - Intelligence
- Error handling
  - Tolerance
  - Detection
- Analysis
  - Numerical
  - Repetitive
- Information handling
  - Storage
  - Input
  - Output

Human capacities

Computer capacities

The need for CAE

Modern demands

- More sophisticated designs
- Greater productivity

The computer aided solution

CAE techniques provide the means to cope with the demand for increased productivity of more sophisticated and reliable product design and manufacture.
The Categorization of CAE

The mechanical / manufacturing engineers will use a variety of activities.

There is a computer assisted means for all of these:

- design
- analyse techniques
- manufacturing techniques
- numerical methods
- organization planning
- control
### Int to CAE

In CAE, the data can flow electronically between the departments and the whole operations can be monitored and controlled.

Computer extends the designers' capabilities:
- Organizing & handling time consuming operations
- Repetitive operations
- Analyse complex problems

### Impact of CAE on design

CAE is impacting engineering design.

The first CAE impact on detail design has occurred in draughting *(changing, redrawing, storing....)*.

In product line engineering decisions required. It requires standard engineering calculations, detail drawing, bill of materials *(BOM)*.
The elements of CAE

- Drafting & design
- Modeling & analysis
- Production planning & control
- Manufacturing

**CAE**

**CAD** computer aided design
**CADD** draughting & design
**DFA** design for assembly/automation
**CADCAM** link to CAM

**FEA** finite element analysis
**FDA** finite difference analysis
**continuous simulation**
**discrete event simulation**
**dynamic analysis**

**COMPUTER AIDED ENGINEERING**

- **Manufacture**
  - **CAM** computer aided manufacturing
  - **CNC** computer numerical control
  - **DNC** direct/distributed numerical control
  - **PLC** programmable logic control
  - **CMM** coordinate measuring machines
  - **FAS** flexible assembly system
  - **FMS** flexible manufacturing system

- **Production planning & control**
  - **CAPP** computer aided process planning
  - **MRP** material requirements planning
  - **BOM** bill of materials
  - **JIT** just-in-time
  - **Production planning & control**
  - **Scheduling**
  - **Quality control**
There is overlaps and can not be isolated. They depend on departments. The trend is to adapt concurrent engineering.

The link between the area draughting and design, modeling and analysis is very strong.

CAE in the product development process

- Specification
- Design
- Production planning
- Raw materials
- Design
- Manufacture components
- Inspection
- Final test and inspection
- Sub-and-final assembly
- Final test and inspection
- Delivery
- Custom use
- Customer appraisal
- Bought-in components
- Stores
- Raw materials
- CAM, CAD/CAM, CAPP, MRP, JIT
- CADD, MDA, FEA
- NC, CNC, DNC, FMS, PLC
- LAN
- CMM
- FAS, PLC
- Complaints & faults
- Repair
- Custom use
## Terms in CAE

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>CAD</td>
<td>computer-aided design</td>
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<tr>
<td>CADD</td>
<td>computer-aided design &amp; drafting</td>
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<tr>
<td>CAM</td>
<td>computer-aided manufacturing</td>
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<tr>
<td>CAPP</td>
<td>computer aided process planning</td>
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<tr>
<td>CIM</td>
<td>computer integrated manufacturing</td>
</tr>
<tr>
<td>CMM</td>
<td>coordinate measuring machine</td>
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<tr>
<td>DNC</td>
<td>direct numerical control</td>
</tr>
<tr>
<td>FAS</td>
<td>flexible assembly systems</td>
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<td>FMS</td>
<td>flexible manufacturing systems</td>
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<td>JIT</td>
<td>just-in-time</td>
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<td>LAN</td>
<td>local area network</td>
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<td>MDA</td>
<td>mechanism design analysis</td>
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<td>MRP</td>
<td>materials requirement planning</td>
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<tr>
<td>PLC</td>
<td>programmable logic controller</td>
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## Totally Automated Factory

If all the software and hardware tools are applied to every possible stage and are linked together with CIM (computer integrated manufacturing) environment.

It is rare! Needs more human intervention.
Specification stage (Conceptual design)

Computer application is limited with word processing or desktop publishing. Spreadsheet program are useful because of their ability to quickly make multiple calculations without requiring the user to reenter all of the data.

Limited computer applications

Design stage

- Manufacture needs to be planned
- The methods and processes used for manufacturing
- The scheduling of production
- The acquisition of raw materials & bought-in components.
- The control of quality
Computers in manufacturing

The ability to construct accurate, easily modified models is helping make manufacturers more competitive.

Implementation of a typical CAD and CAM process on a CAD/CAM system

Definition of geometric model
Definition translator
Geometric model
Interface algorithms
Design and analysis algorithms
Drafting & detailing
Documentation
To CAM process

Geometric model
Interface algorithms
Process planning
NC programs
Inspection
Assembly
Packaging
To shipping and marketing
CAD
Geometric Modeling
Engineering Analysis
Design Review and Evaluation
Automated drafting

Computers in CAD

Some of the tools provided in a CAD environment are,
• Innovative and conceptual design
• Qualitative design analysis
• Structuring of part (eg. assemblies)
• Knowledge based/intelligent design tools
• Engineering design information (standards lookup, or electronic catalogues)
• Optimization
• Design interfaces, and tools

Some applications are well suited to 2D CAD systems,
• PCBs (Printed Circuit Board Design)
• ICs (Integrated Circuit Design)
• Mapping (road maps, topographical maps)
Advantages of CAD systems

- Visualization
- Minimizes design errors
- Graphical display of hard to visualize information
- Standardized drawings, and documents
- Faster lead time
- Customer perception is improved
- Productivity improvement over time
- Developing alternate concepts
- Evaluation of alternate concepts
- Analytical investigation of parts
- Experimental investigation
- Detailed drawings and specifications
- Preliminary 'construction' of design prototype
- Easy bridge to prototype construction
- Easy to change designs
- Optimization

CAD tools to support the design process

<table>
<thead>
<tr>
<th>Design Phase</th>
<th>Required CAD tools</th>
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<tbody>
<tr>
<td>Design conceptualization</td>
<td>Geometric modeling techniques; graphics aids, manipulations, and visualization</td>
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<tr>
<td>Design modeling and simulation</td>
<td>Same as above; animation; assemblies; special modeling packages</td>
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<tr>
<td>Design analysis</td>
<td>Analysis packages; customized programs and packages</td>
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<td>Design optimization</td>
<td>Customized applications; structural optimization</td>
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<td>Design evaluation</td>
<td>Dimensioning; tolerances; bill of materials; NC</td>
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<td>Design communication and</td>
<td>Drafting and detailing; shaded images</td>
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<td>documentation</td>
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</table>
Definition of CAD tools based on their constituents

- Computer graphics concepts
- Design tools (analysis, codes, heuristics, etc.)
- Geometric modeling

CAD tools + computers

Hardware (central unit, display terminals, input/output devices)
Software (graphics, modeling, applications, programs)

Definition of CAD tools based on their implementation in a design environment

CAM
Classification

**Planning**
- Cost Estimating
- CAPP
- NC Part Programming
- Machinability Data Systems
- Computerized Work Standards
- Materials Requirement Planning
- Capacity Planning
- Production & Inventory Planning

**Control**
- Process Monitoring
- Process Control
- Shop Floor Control
- Cost Control
- Computer Aided Quality Control

CAM tools required to support the manufacturing process

<table>
<thead>
<tr>
<th>Manufacturing Phase</th>
<th>Required CAM tools</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process planning</td>
<td>CAPP techniques; cost analysis, material and tooling specification</td>
</tr>
<tr>
<td>Part programming</td>
<td>NC programming</td>
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<tr>
<td>Inspection</td>
<td>Inspection software</td>
</tr>
<tr>
<td>Assembly</td>
<td>Robotics simulation and programming</td>
</tr>
</tbody>
</table>
Definition of CAM tools based on their constituents

CAM tools

- Manufacturing tools (processes, heuristics, etc.)
- CAD (Computer Aided Design)
- Networking concepts

Hardware (central unit, display terminals, input/output devices)
Software (CAD databases, NC, CAAP, MRP, etc.)
Networking (of robots, manufacturing cells, material handling systems, etc.)

Definition of CAM tools based on their implementation in a design environment

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What is CAD/CAM? . . .

Using computers for design and manufacturing.

Computerize the easier tasks, which are tedious and mistake prone when done manually.

In CAD, design product geometries, do analysis, and produce final documentation.

In CAM, parts are planned for manufacturing (e.g. generating NC code), and then manufactured with the aid of computers.
What is CAD/CAM? . . .

**CAD/CAM** tends to provide solutions to existing problems.

For example, analysis of a part under stress is much easier to do with FEM, than by equations, or by building prototypes.

**CAD/CAM** systems are easy to mix with humans. This technology is proven, and has been a success for many companies.

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What is CAD/CAM? . . .

There is no ‘ONE WAY’ of describing CAD/CAM.

It is a collection of technologies which can be run independently, or connected.

If connected they are commonly referred to as CIM.
What is the difference between CAD, CAM & CIM . . .

CAD/CAM involves the use of computers to make Design and Manufacturing more profitable.

Parts of CIM use CAD/CAM techniques and products to try and make the factory fully connected using computers.

• The essential difference is CAD/CAM provides the tools, CIM is the philosophy which is used when organizing the computers, programs, etc. and all the information that flows between them.
• Another way to think of CIM is that it allows the structure of an organization to be entered into the computers.
• CIM focuses on connecting the various CAD/CAM modules.
Definition of CAD/CAM tools based on their constituents

- Design tools (analysis, codes, heuristics, etc.)
- Geometric modeling
- CAD/CAM tools
- Networking, integration & automation concepts
- Manufacturing tools (processes, heuristics, etc.)

Computer Integrated Manufacturing (CIM)

- CIM is a concept for integrating all components involved in the production of an item.
- The engineering functions including NC, CNC, DNC, CAD/CAM, GT, CAPP, MRP, AGVs are integrated with business activities.
- Integration media is through communication networks using LAN/WAN/INTERNET technology.
Computer Integrated Manufacturing (CIM)

The product cycle includes
• idea generation
• product design
• procurement
• process planning
• product manufacture
• quality control
• packaging/shipping
• after sales service

Scope of CAD/CAM & CIM
Integrated Manufacturing Database

**Production planning & control**
- Master production planning
- Capacity planning & adjustment
- Stock inventory
- Bill-of-materials etc.
- Quality statistics

**Design**
- Component models
- Assembly models
- Analysis data
- Materials data

**Marketing/Sales**
- Order control
- Cost estimating
- Market surveys
- Product performance

**Manufacturing**
- Process planning
- CNC planning
- Robot control programs

**Integrated Manufacturing database**

CONCURRENT ENGINEERING
Concurrent Engineering

It is greatly facilitated by the use of CAE.

Alternative to over the wall engineering. (Sequential engineering)

Parallel engineering.

Concurrent Engineering

For maximum productivity a concurrent, parallel or simultaneous engineering approach should be adopted. This approach requires that the design process, and hence the design team.

- designer
- process engineer
- marketing person
- manufacturing engineer
Concurrent Engineering

- ... 21st Century’s response to competitive conditions of the world market.

- CE refers to the process of considering simultaneously the requirements of assembly and manufacturing with design requirements in order to reduce unit cost of production, improve quality and reduce total lead time.

- CE is managing mutual dependences of designing, manufacturing, distribution, support and service.

- CE’s aim is to minimize life-cycle cost, maximize customer satisfaction, maximize flexibility, minimize lead time from conception to delivery to the customer.

Geographically Distributed Teams

Company A

Enterprise data & information

Company B

Transparent global network
Sequential design

Each department has its own responsibility. When the task designated to that department is complete, the results are thrown over the wall to the next department.
Breaking Down Barriers
Sequential design: Walls between functional areas

This over the wall approach to engineering has been common practice until quite recently;
The trend, is to adopt a concurrent engineering strategy to design and development where product idea are realized by a team made up of members of many departments.
Concurrent Engineering

• Simultaneous decision making by design teams
• Integrates product design & process planning
• Details of design more decentralized
• Needs careful scheduling - tasks done in parallel
Concurrent Engineering

being used to transmit
- 3-D solid models to tool designers,
- part vendors
- numerical control programmers for manufacturing development via internet.

Concurrent Product Development
Sequential vs. Concurrent Product Development

Sequential

- Activity A
- Activity B
- Activity C

Time to market

Concurrent

Competitive Advantage!

Sequential vs. Concurrent Product Development

Serial process

- Marketing
- Design
- Engineering

Concurrent engineering

- Marketing
- Design
- Engineering

Manufacturing
### Conventional Collaboration

- **Communication**
  - face-to-face discussion,
  - memos, telephone, whiteboard,
  - bulletin board, wall charts, etc.

- **Collaboration**
  - meetings, co-located workgroup

- **Knowledge management**
  - notebooks, binders, printed reports, photocopies, drawings, forms, data files

### Virtual Collaboration

- **Communication**
  - fax, telephone, mail
  - email, discussion groups, shared whiteboard, videoconferencing

- **Collaboration**
  - application sharing, shared network workspace *(files in shared directories)*

- **Knowledge management**
  - Product data management system, document management system, distributed databases

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### Concurrent Engineering

It gives rise to new approaches to product development.

It enhances the effectiveness of existing productivity tools and these include

- design for the market,
- design for manufacture DFM
- design for assembly DFA.
A growing emphasis on Concurrent Engineering, as it involves cross-functional teams, parallel design and vendor partnering etc.

A successful design must satisfy requirements for functionality, appearance, and cost, durability and reliability.
Design for X

DFA  Design For Assembly
DFM  Design For Manufacturability
DFD  Design For Disassembly
DFI  Design For Install ability
DFM  Design For Maintainability
DFML Design For Material Logistics
DFP  Design For Portability (Software)
DFQ  Design For Quality
DFR  Design For Redesign
DFR  Design For Reliability
DFR  Design For Reuse
DFS  Design For Safety
DFS  Design For Simplicity
DFS  Design For Speed
DFT  Design For Test
DFE  Design For Environment
DFESD Design For Electrostatic Discharge
DFEMC Design For Electro-Magnetic Compatibility

Design for Market

responsible for the marketing of the product are involved very early on in the design process and continue to be involved throughout the evolution of the design and manufacture.

involves the customer in design decisions:

physical models or

impressions of the design proposals.
Design for Manufacturing

Involvement of the manufacturing and production planning & control departments provides a valuable contribution to the manufacturability of a design.

**DFM** is the application of certain rules to the design of components that ensure cost-effective manufacture.

Design for Manufacturing

The basic objectives of DFM are to assure that the product can be maintained throughout its useful life-cycle at reasonable expense without any difficulty.
Design for Manufacturing

main concepts

reliability of systems

defined as the probability of failure free
system or equipment operation during
a prescribed time period and under specified
conditions

maintainability

defined as the probability that a failed
system can be repaired in a specific interval
of downtime

Design For Assembly

Consider how components are fitted together
to form a subassembly or assembly.

Much of these considerations will affect
component design as well as that of the
overall product.
Design for Assembly

• systematic method
• analyzes product designs
  • to improve assembly easy
  • to reduce assembly time.
• a central element of DFM

Well established technique for cost reduction at the design-manufacture interface
defined as a process for improving product design for easy and low-cost assembly, focusing on functionality and on assemblability concurrently.
Design for Assembly

The aim
help the designer to produce an efficient and economic design, simplify the product

Design for Assembly

Implementation of DFA at the early conceptual stage of design has led to enormous benefits:

- simplification of products,
- lower assembly
- manufacturing costs,
- reduced overheads,
- improved quality
- reduced time to market.
Design for Assembly

broadened to include consideration of the difficulty of manufacture of the individual parts to be assembled.

providing the necessary basis for teamwork and simultaneous engineering.

Design for Assembly

The application of DFA guides the designer towards a product with an optimum number of parts

requires simple, cost-effective assembly operations and the most appropriate manufacturing processes and materials for its components.

include improved quality and reliability, and a reduction in production equipment and part inventory.
Quantitative evaluation methods

- Boothroyd-Dewhurst method,
- the Hitachi Assemblability evaluation method,
- the Lucas DFA method
- IPA Stuttgart method

Boothroyd-Dewhurst Method

- to determine the suitable assembly method,
- to reduce the number of each part be assembled,
- to get the handling and insertion processes easily

based on a system of penalties for the particular activity, including
  part’s handling,
  part’s insertion
using these penalties a quantitative judgement options
Boothroyd-Dewhurst Method

based on three principles:
(a) relying on an existing design which is iteratively evaluated and improved.
(b) the application of criteria to each part to determine if it should be separate from all other parts,
(c) estimation of the handling and assembly costs for each part using the appropriate assembly process

the process follows these steps:
- Select an assembly method for each part
- Analyze the parts for the given assembly methods
- Refine the design in response to shortcomings identified by the analysis
- Loop to step 2 until the analysis yields a sufficient design
FA facilitates part count reduction by evaluation of each component in order to determine. 
**FA is essential for the performance of the product.**
Individual components are assessed in terms of:
- their relative motion,
- material type
- the need for removal for replacement / repair

Manufacturing Analysis determines the relative cost of producing each component based on the manufacturing processes used.
determined using a basic processing cost per annum ($Pc$) for an ideal design a design-dependent relative cost ($Rc$) the cost of the material used ($Mc$).

The Handling Analysis evaluates the suitability of a component for manual handling and automated feeding to the point of assembly.
The evaluation:
- component shape
- characteristics,
- size,
- weight,
- orientation,
- mechanical properties.

Careful selection
- leads to improvements in safety
- reduces the likelihood of component damage / incorrect insertions.
- reduces capital spend on equipment
- improves assembly times.
Assembly Analysis is used:
- to highlight problems & inefficient operations associated with the build sequence & component interfaces,
- to identify the tooling requirements of the design.

Assembly Analysis scores the difficulty associated with gripping each component inserting it into the assembly for both manual & automated operations.
Suitability for part function

Quite often a particular component is manufactured in a certain way because a particular process is there rather than it being the most appropriate. A component may be more cheaply produced:

- forming
- impact extrusion
- machining

Suitability for manufacturing process

The process planning of the component affects the design rather than the design influencing the process used for its manufacture.

Therefore a component’s geometry and appearance and the way it is to be manufactured are arrived at more or less simultaneously.
Variety control

Minimize the range of parts for a company’s product range as well as reducing the number of different parts within any one product.

standardizing on one type of component

Standardization

This is an aspect of variety control which is also discussed below as being a crucial factor for a design for assembly strategy. No company is so diverse in its product range that it can not carry out some degree of standardization of component parts.
Processes or procedures for integration of design and manufacture, with the goals of reducing manufacturing costs and improving product quality are termed as DFM. Associated with this for assembly is DFA.

### DFM Guidelines
- Minimizing total number of parts
- Standardize components
- Use common parts across product lines
- Design parts to be multifunctional
- Design parts for ease of fabrication
- Avoid too tight tolerances
- Avoid secondary operations
- Utilize the special characteristics of processes

### Assembly process consist of two parts
- Handling
- Manual
- Automated
- Robotic
- Insertion

### DFA Guidelines
- Minimizing total number of parts
- Minimizing assembly surfaces
- Avoid separate fasteners
- Minimize assembly direction
- Maximize compliance in assembly
- Minimize handling in assembly

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### Integrated structure of DFA and DFM

- **Design Concept**
- **Design For Assembly**
- **Selection of materials and process**
- **Best design concept**
- **Design For Manufacture**
- **Prototype**
- **Production**

- **Suggestions for simplification of product structure**
- **Suggestions for more economic materials & processes**

- **Detail design for minimum manufacturing costs**
Design for Automated Assembly

Many of the principles which can be applied to an assembly and which make it easier to put together by automated process.

Here are some of the important issues:
- Insertion direction and geometry
- Layered or sandwich construction
- Tangle free components
- Easy fastening

Insertion direction and geometry

Insertion of components from the side requires more complex programming and specialized equipment.

Most standard pick and place devices (SCARA or Cartesian robots) can only effect vertical insertion.
Layered or sandwich construction

Orientating a partly build product at various stages throughout its assembly can be an unnecessary and costly task.

Adopting a layered or sandwich type construction of a product it can remain in one orientation.

Tangle free components

Springs and other components prone to tangling can be modified to partially or even totally eliminates the problem.

ease the orientation and presentation of such components to the assembly process and in a manual situation the operator is not spending a large proportion of time untangling small items
Easy fastening

As evaluation of the fastening together of components may also yield benefits. Some fastenings are difficult to undo for maintenance and quite often result in the case being rendered useless.

A CASE STUDY: PACKAGING
DESIGN FOR ASSEMBLY & MAINTAINABILITY IN COMPUTER AIDED ENGINEERING
Case Study : Packaging

Fruit juice packages are filled with pasteurized product and packaged under sterilized and closed conditions using roll shaped packaging board which is got by board suppliers.

Flowchart of filling & packaging system
Current design

pushed to exit of machine with help of expeller subassembly group after finishing filling and formation processes.

This group follows a certain route with a guide chain

 Current design

⑦ the main support of subassembly and the holes which stay up to this part is for chain connection links. ⑧ fixed onto ⑦ with screw by guidance of welded pin.

As time passed, the length of chain gets longer and loses its tightness.
### DFA evaluation

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DFA Index = \( \frac{4 \times 3}{93.09} = \% \ 12.9 \)

### New design

The welded pin divided from the main support

Multi pieces bushings’ design changed

unnecessary fastening parts (nut, washer) eliminated
### DFA evaluation

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**DFA Index = 4 x 3 / 50.13 = % 23.9**

### Comparison

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<th>Material &amp; Manufacturing Cost (YTL)</th>
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