Introduction to

Analytic Methods for Design Practice

설계방법론

수업 개요 (1)

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교과서: 해석적 설계방법론, 동명사 (박경진, 강병수 저)

부교재: Analytic Methods for Design Practice, Springer (Gyung-Jin Park)

Introduction to Optimum Design, Elsevier (J.S. Arora)

평가: 중간-20, 출석-10, 과제-15, 수업참여-10, 프로젝트 1-15, 프로젝트 2-30

(수업참여, 과제에 대한 점수는 Quiz로 대치 될 수 있음)

****** 정직하지 못한 행위는 이유를 불문하고 F ******

수업 개요 (2)

수업 주: 강의 주와 실습 주로 나눈다.

강의 주: 교수가 강의 한다.

월요일: Y05-0206

수요일: Y05-0206

실습 주: 조교가 CAD실에서 실습한다.

화요일 반: 기계과 CAD실

수요일 반: 기계과 CAD실

휴대전화 울리면: -5

휴대전화 받으면: F

출석: 지정석에 앉는다. 매 시간 출결 확인한다.

매주 숙제 제출은 수요일에 한다.

1.1 What is Engineering Design?

- Decision making is typically carried out in the design process.
- Many engineers consider design as art.
- Researches are performed based on the scientific approaches.
- Are there any rigorous design methodologies with a definite form? Or are there any universal methods which can be used in any type of environment?
- Suppose we have a good design? How did we produce it?
- What is the best design? Does it exist?

❑ Characteristics of Design

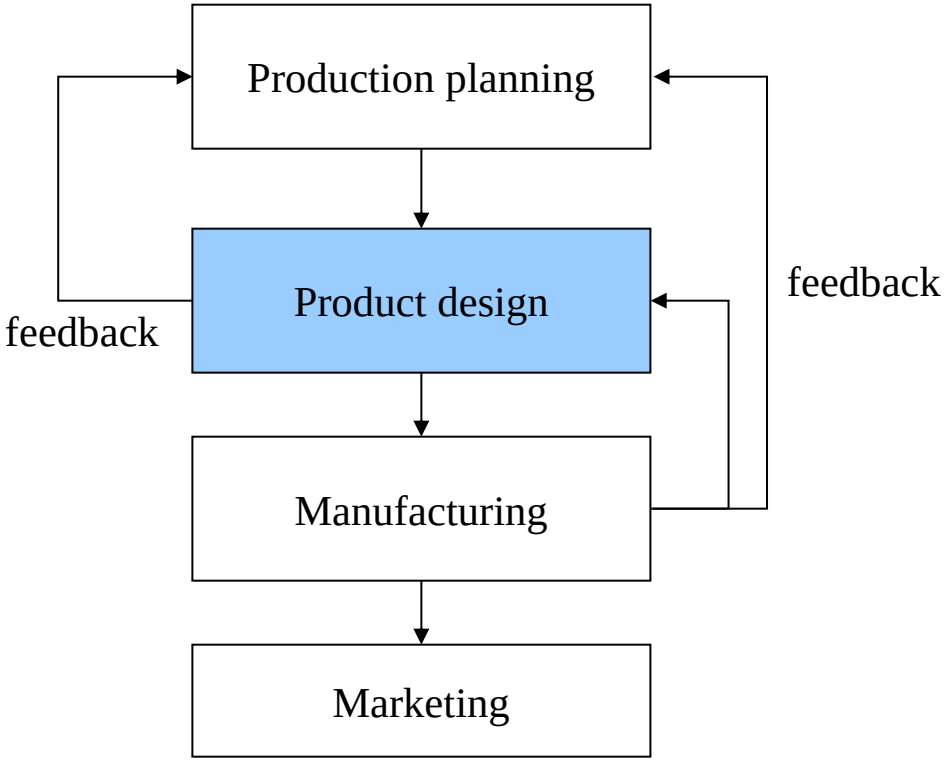
Open-ended:

There are multiple acceptable solutions and a solution can be improved upon.

Ill-structured:

In science and analysis, we generally use mathematical formulae in a structured way and obtain a solution. There are no such formulae in design.

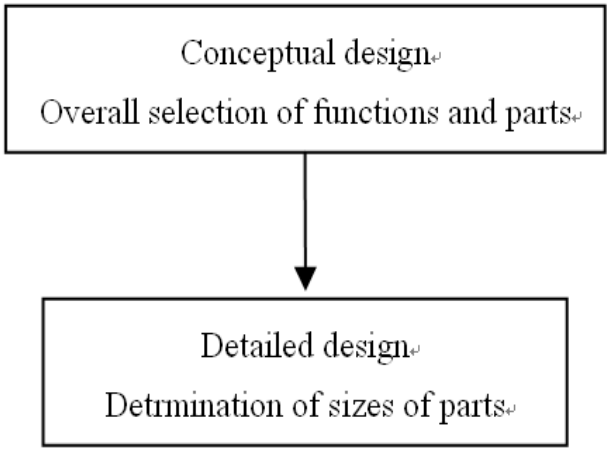
❑ Flow of Product Design and Manufacturing



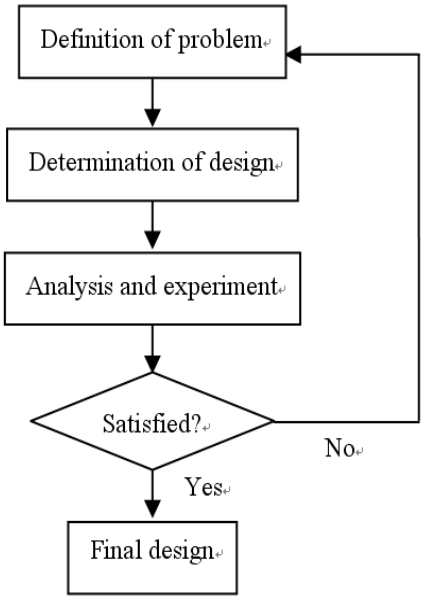
(1) Conceptual design

(2) Detailed design

Which one gives more impact? Where do we have to spend more resources?



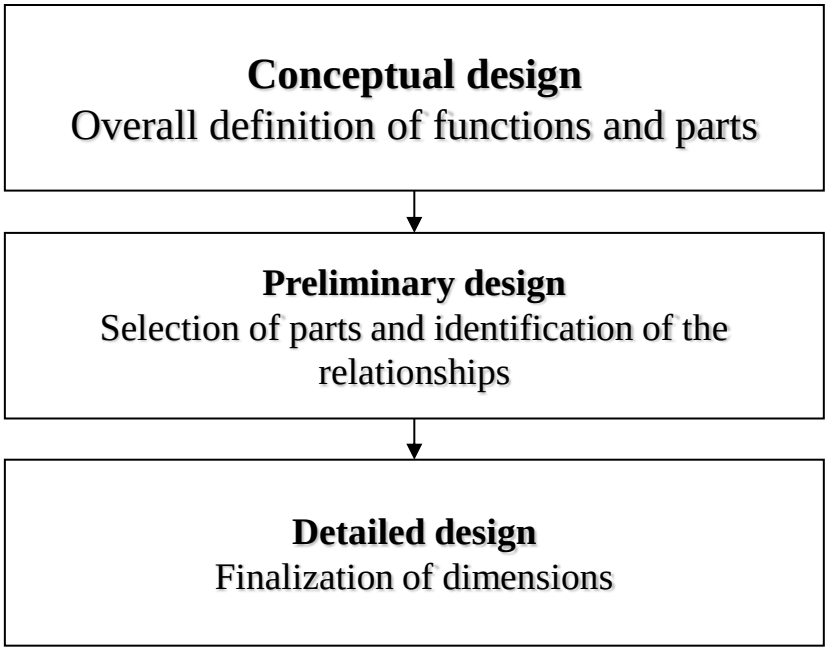
Sequence of design



Detailed design process

❑ A Flow with Preliminary Design

Classification of design based on the sequence:



Sequence of design

❑ Other Classification

(1) System design vs. Element design

(2) Creative design; Imitative design; Design improvement

1.3 Analytic Design Methodology

- Analytic design is a design activity using scientific principles or a process with rigorous methods to achieve a good design. The utilized principle is a design methodology.
- Is design methodology a technique or a philosophy?
- Where did we apply analytic design methods?
- Answer: system design, detailed design, improving design
- What did we find? Was it correct?

❑ The Aspects Pursued in Design

- Beauty: aesthetic design, industrial design
- Rationality: science based design, recent engineering design

❑ Analysis vs. Synthesis

- Analysis pursues a unique solution of a problem in an analytical way.
- In synthesis, various aspects of sciences, intuition and artistic talents are synthesized.

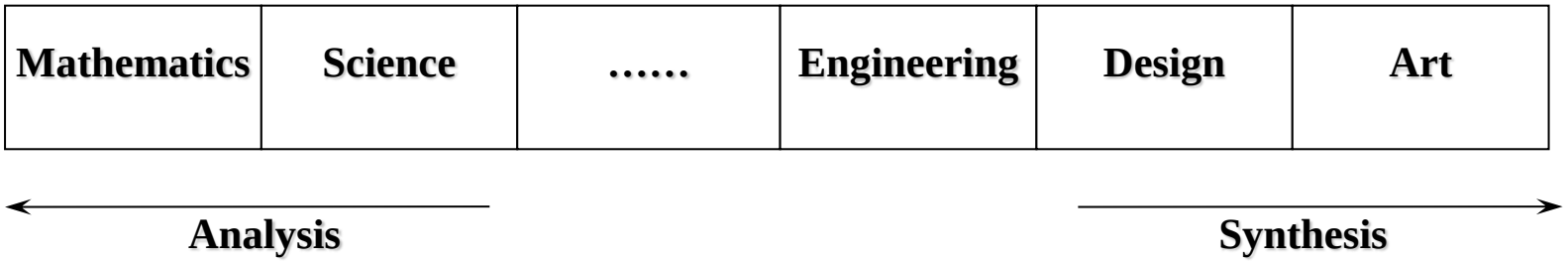


Figure 1.2. Analysis vs. Synthesis

❑ Analysis vs. Synthesis (2)

In analysis:

- The problem is often well defined.
- Various mathematical as well as scientific principles are utilized.
- Objective approach

In synthesis:

- Intuitions, experiences and artistic sense are used.
- Creativity is important.
- Subjective approach

Science based design method

- The objective approach is used in synthesis.
- Axiomatic design: A representative science based method

❑ Design Process

Engineering design:

The systematic, intelligent generation and evaluation of specifications for artifacts whose form and function achieve stated objectives and satisfy specified constraints.

Specification: A condition that a resultant design should satisfy

Artifact: A piece or product that is artificially manufactured

Objective: A target that a design pursues

Constraint: A limit or restriction in design, similar to a specification

OPTIMIZATION

- A design is found to minimize or maximize a performance index (objective function) while the constraints are satisfied.
- Finding an optimum means determination of the values of design variables.
- The objective function and constraints should be expressed by functional forms and functions of the design variables.
- Formulation of the problem is the initial and the most important step.
- Sometimes, it is very difficult or almost impossible to formulate an optimization problem in practical engineering.

❑ Design Optimization: Definition

Optimization problem: Formulation (definition)

Find	$\mathbf{b}$	
to minimize	$f(\mathbf{b})$	
subject to	$h_i(\mathbf{b}, \mathbf{z}) = 0$	$i = 1, \ldots, l$
	$g_j(\mathbf{b}, \mathbf{z}) < 0$	$j = 1, \ldots, m$
	$\mathbf{b}_L < \mathbf{b} < \mathbf{b}_U$	

- Optimization is a process to obtain a solution of the above problem.
- The solution is a Karush-Kuhn-Tucker (KKT) solution in mathematics.
- It may be impossible to get a KKT solution directly.
- Numerical algorithms are employed.

1.5 Structural Optimization

- Optimization is employed in the design of structures.
- Analytic governing equation is utilized for analysis of structures.
- Generally, the finite element method is used for the governing equation.
- Classification of structural optimization according to the characteristics of the design variables
  - Size optimization: Section Properties, Thickness
  - Shape optimization: Coordinates of FEM, Analysis domain is changed.
  - Configuration optimization: Transformation Matrix in FEM, It may be treated as a subset of shape optimization.
  - Topology optimization: Existence of elements in FEM
- Analysis methods
  - Linear static analysis
  - Nonlinear static analysis: Not very popular yet
  - Other methods are not frequently used.

❑ Structural Optimization

- Structural optimization

  : An area where optimization is applied most actively due to the development of FEM

  - Objective function: weight, displacement, stress, natural frequency
  - Constraints: weight, displacement, stress, natural frequency
  - Design variables: section properties, thickness (Size optimization)

    : shape domain (Shape optimization)

$$\mathbf{Kz} = \mathbf{f}$$

: Equilibrium (governing) Eq.

: used in the optimization process as equality constraints

❑ Structural Optimization: FEM Equations as Equability Constraints

Formulation of structural optimization

Find	$\mathbf{b}$	
to minimize	$f(\mathbf{b})$	
subject to	$h_i(\mathbf{b},\mathbf{z}) = 0$	$i = 1,\ldots,l$
	$g_j(\mathbf{b},\mathbf{z}) < 0$	$j = 1,\ldots,m$
	$\mathbf{b}_L < \mathbf{b} < \mathbf{b}_U$	

Interpretation of constraints

$h_i(\mathbf{b},\mathbf{z}) = \mathbf{K}(\mathbf{b})\mathbf{z} - \mathbf{f} = 0$: Linear FEM Eq.

or $= \mathbf{K}\mathbf{y} - \xi\mathbf{M}\mathbf{y} = 0$

$g_j(\mathbf{b},\mathbf{z})$: $\sigma \le \sigma_a$: Stress

$\delta \le \delta_a$: Displacement

$\xi_0 \le \xi$: Frequency

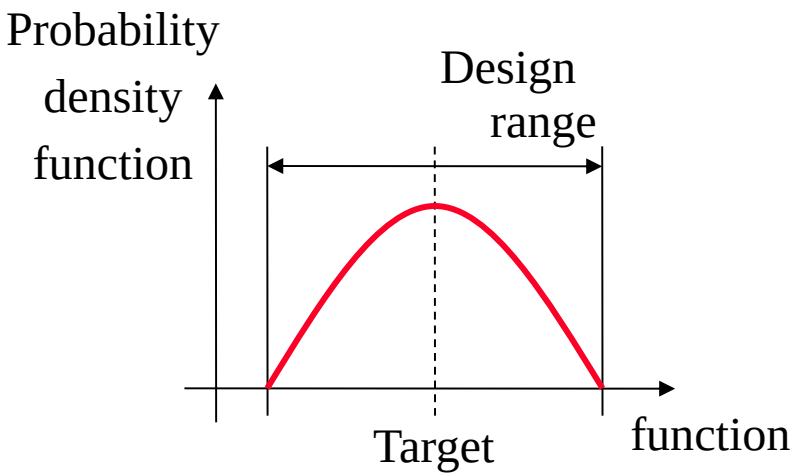
1.6 Robust Design

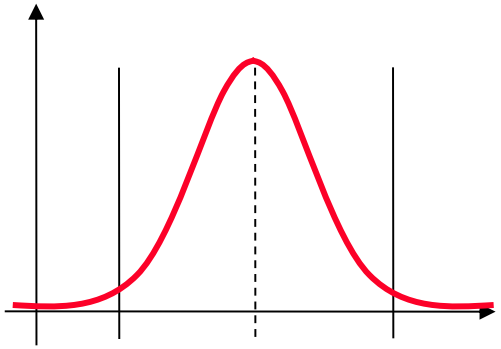
- Nominal design vs. robust design
- Tolerances of the nominal design is considered in the robust design.
- Insensitive design is pursued.

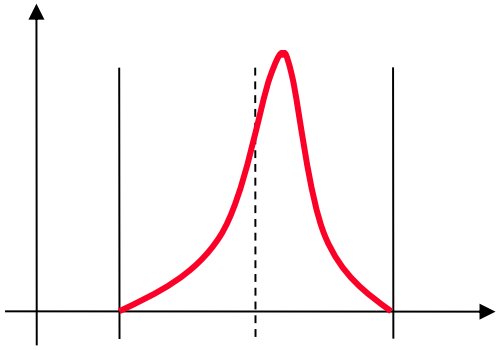
- Taguchi method
- Robust optimization
- Axiomatic design

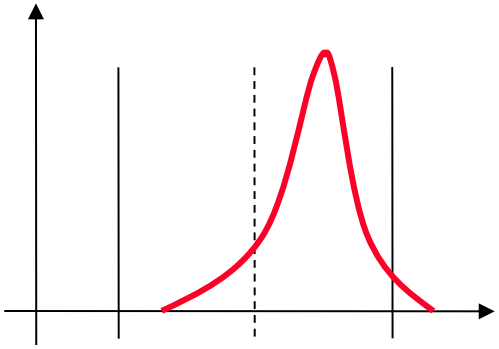
❑ Robust Design

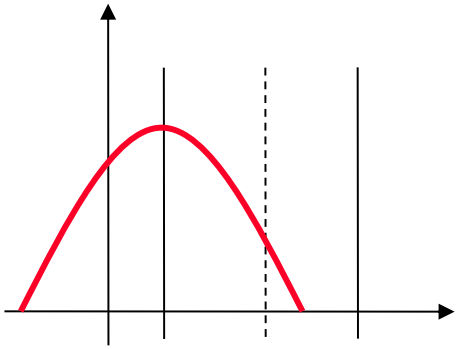
Which one is the best?



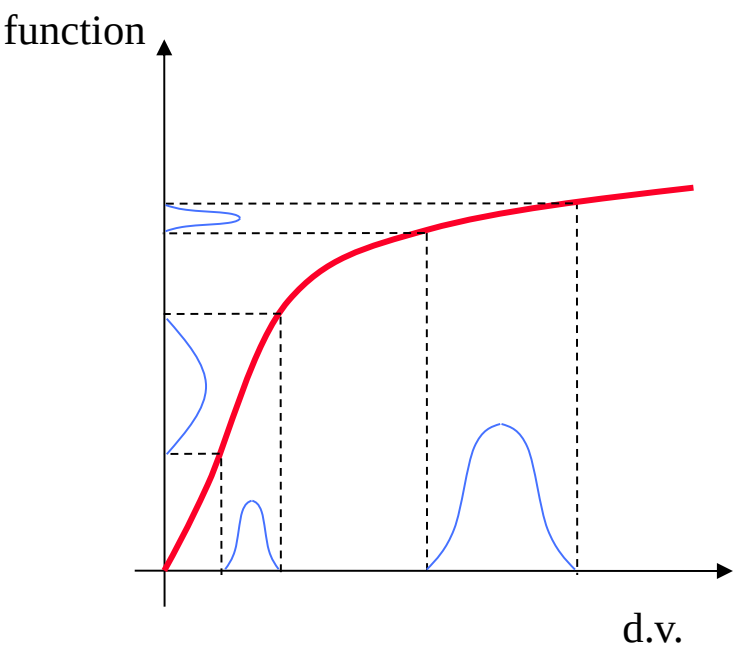


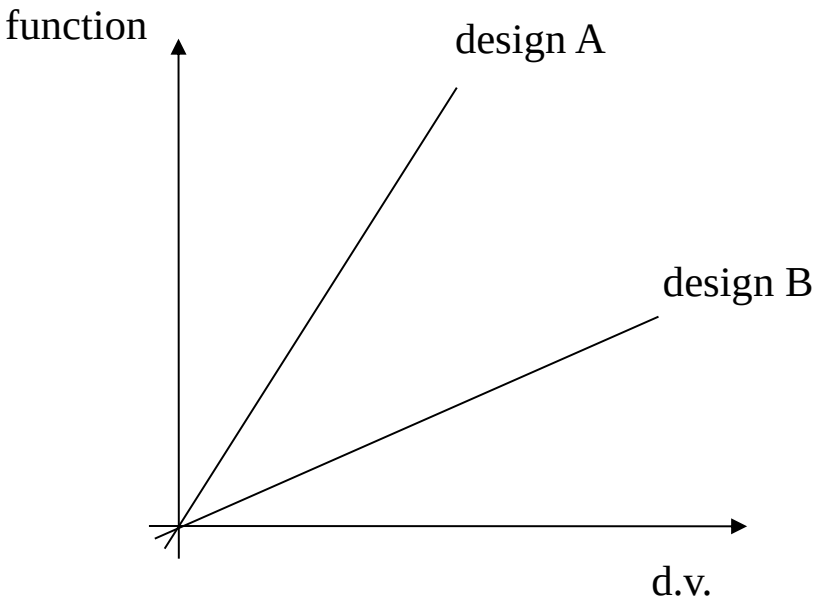






How can we determine design variables?



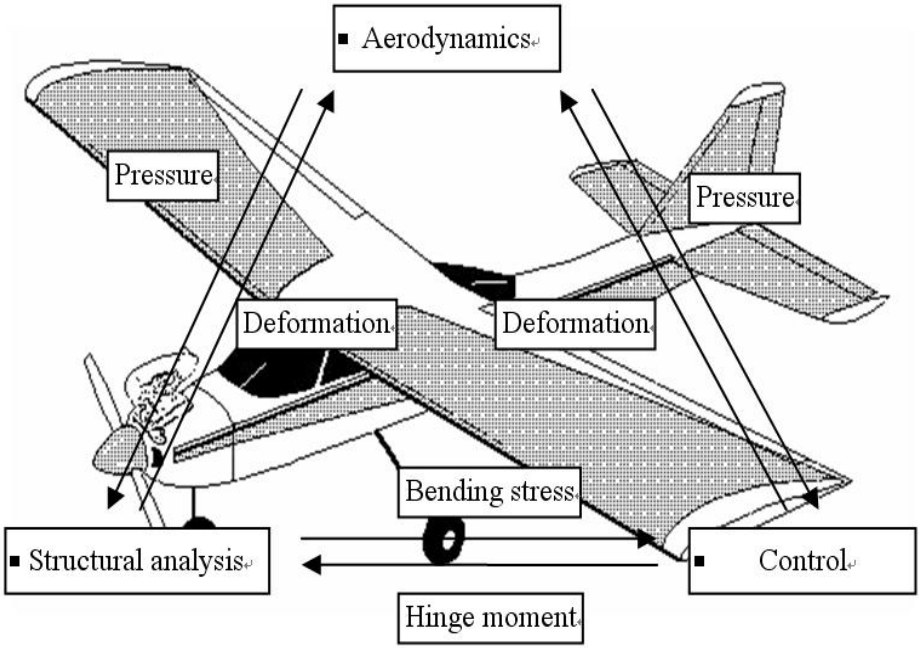


Sensitive design

Insensitive design

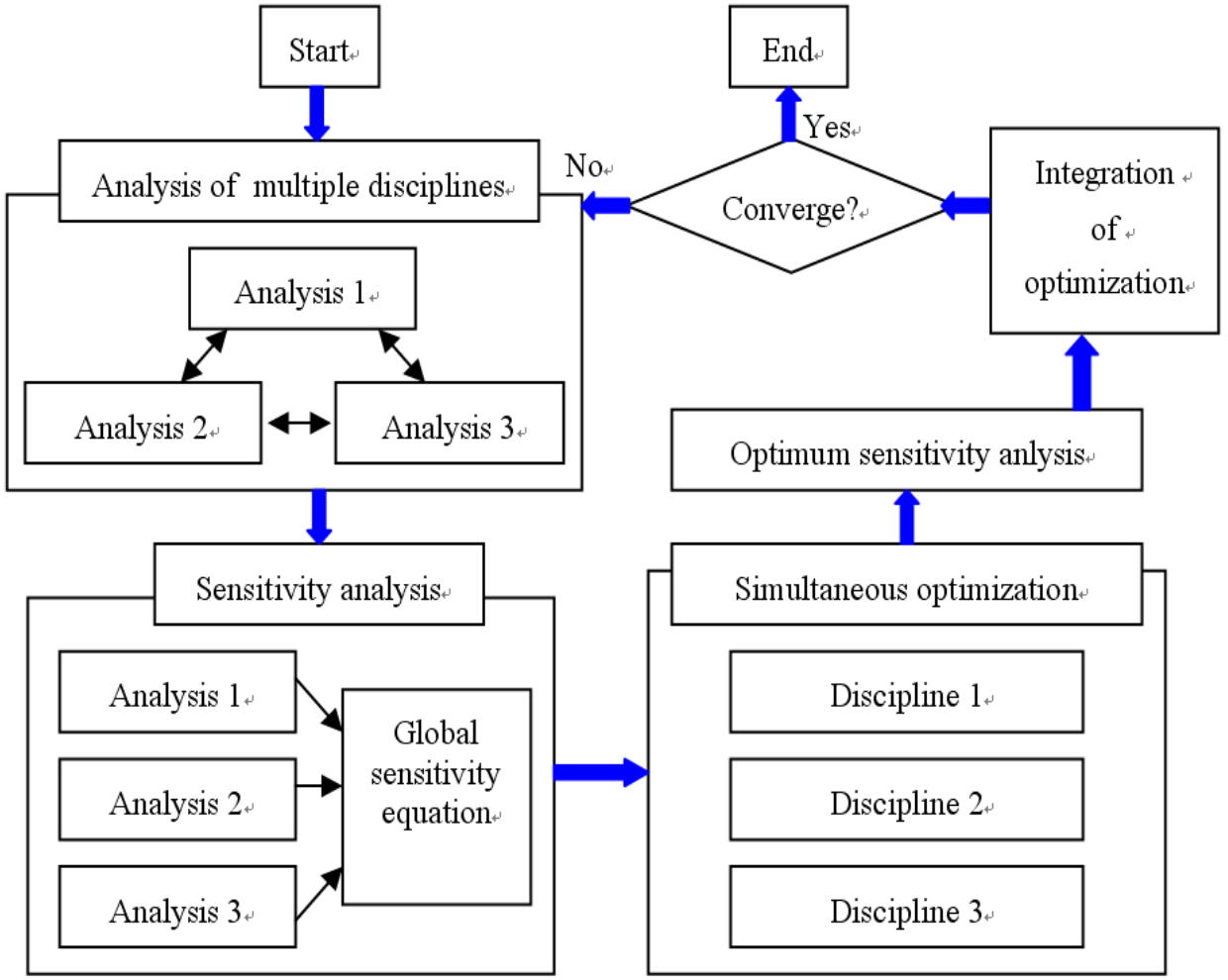
1.7 Multidisciplinary Design Optimization (MDO)

- Multiple disciplines are involved in MDO.
- The coupled relationship between disciplines is important.
- Various methods are proposed but no method can solve all the MDO problems.



Typical coupling relationship between various analysis methods

❑ Multidisciplinary Design Optimization (MDO)



An example of a definition for MDO

❑ Homework

1. **Read Chapter 1 and summarize it.**
2. **Read Sections 3.1-3.2 and summarize them in 1-2 pages.**