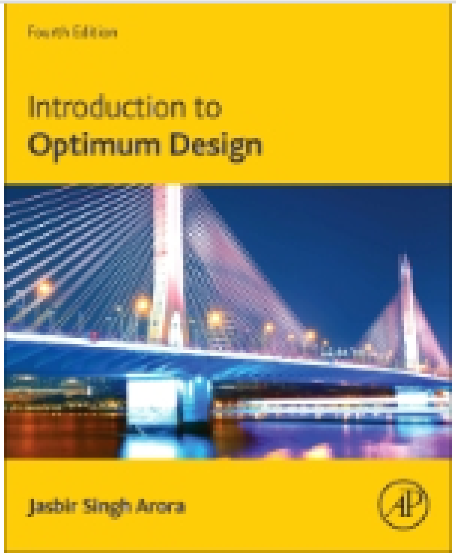
Textbook



View on ScienceDirect

Google Preview

Introduction to Optimum Design

4th Edition

☆☆☆☆☆ Write a review

Authors: Jasbir Singh Arora

Hardcover ISBN: 9780128008065
eBook ISBN: 9780128009185

Imprint: Academic Press
Published Date: 28th April 2016

Page Count: 968

https://www.elsevier.com/books/introduction-to-optimum-design/arora/978-0-12-800806-5
https://www.sciencedirect.com/book/9780128008065/introduction-to-optimum-design#book-info

Table of Contents (1)

U/G1: Undergraduate/First-Year Graduate Level Course
G1: First Graduate Level Course
G2 Second Graduate Level Course

Table of Contents (2)

Part II. Numerical Methods for Continuous Variable Optimization				
Ch	Title	U/G1	G1	G2
6	Optimum Design with Excel Solver	O		O
7	Optimum Design with MATLAB	O		O
8	Linear Programming Methods for Optimum Design	O	O	O
9	More on Linear Programming Methods for Optimum Design		O	O
10	Numerical Methods for Unconstrained Optimum Design	O	O	O
11	More on Numerical Methods for Unconstrained Optimum Design		O	O
12	Numerical Methods for Constrained Optimum Design	O	O	O
13	More on Numerical Methods for Constrained Optimum Design		O	O
14	Practical Applications of Optimization			O

Table of Contents (3)

Part III. Advanced and Modern Topics on Optimum Design				
Ch	Title	U/G1	G1	G2
15	Discrete Variable Optimum Design Concepts and Methods			O
16	Global Optimization Concepts and Methods			O
17	Nature-Inspired Search Methods			O
18	Multi-Objective Optimum Design Concepts and Methods			O
19	Additional Topics on Optimum Design			O

Introduction

- Engineer
  - Design devices and products that perform tasks in an efficient fashion
  - Constrained by the limitations of the physical world and must keep costs down
  - Confronting optimization problems that balance performance and limitations
- Mechanical Design
  - Selection of materials and geometry
  - which satisfies specified and implied functional requirements
  - while remaining within the confines of inherently unavoidable limitations

모델링

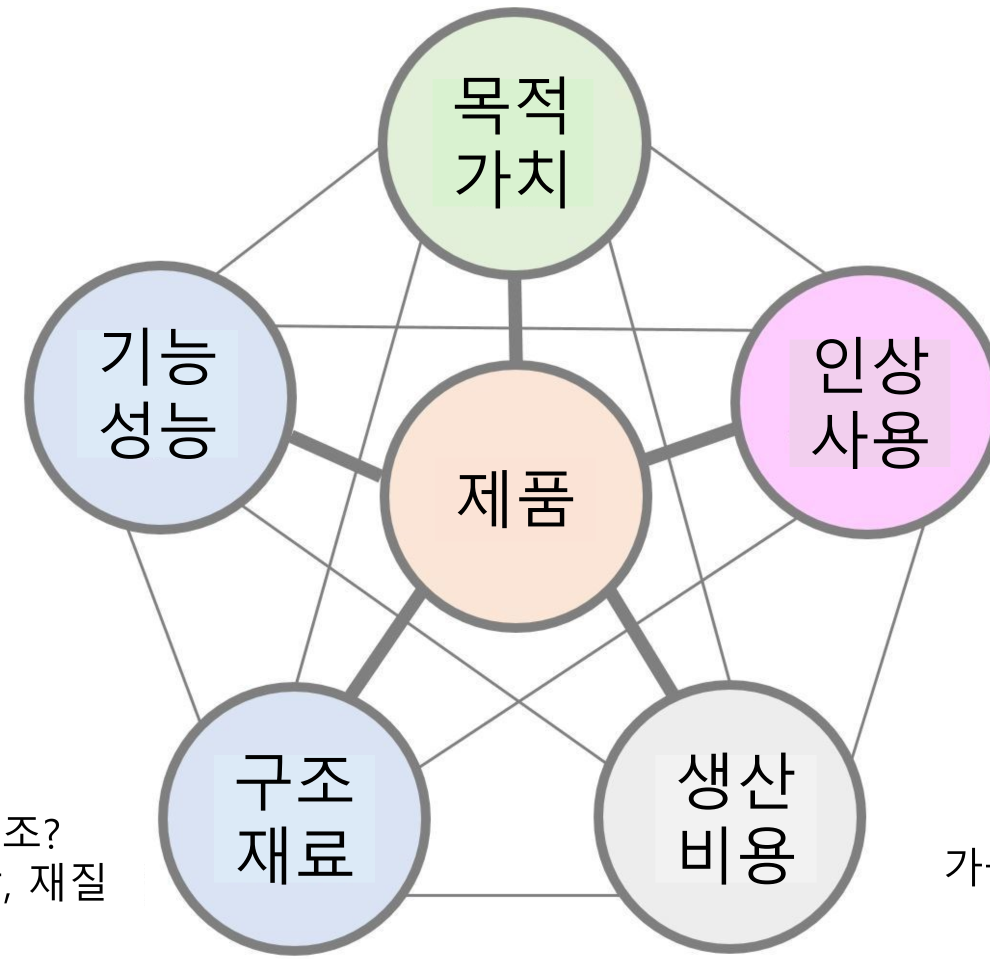
- 설계 시작부터 종료까지 프로세스를 통해 설계대상을 구성하는 파라미터와 이들간 관계를 각 프로세스로 이해가능한 형식으로 표현함으로써 각 설계결과를 평가 가능하도록 하는 것. 즉, 모델링의 결과가 모델임.
- 설계 자체를 제삼자가 이해 가능한 형식으로 표현하여 설계를 효율적으로 창조적인 것으로 하기 위한 프로세스를 가능한 이론적으로 표현하고 가시화하는 방법

- 기술(記術)모델: 언어, 그림으로 표현, 의사 전달
- 해석(解析)모델: 식으로 표현, 계산 가능 (CAE)
- 형상(型狀)모델: 생산 가능한 형태로 표현 (CAD)

제품설계와 모델링

이 제품의 목적?
고객, 경제성, 환경, 성능, 가격

어떤 기능?
기능, 성능, 구매자극



고객에게 호소 방법?
오감, 브랜드, 사용감

어떤 구조?
구조, 형상, 재질

제작방법?
가공, 조립, 설치, 보수

모델링 사례: 가치 (헤어드라이어)

– QFD: 고객 요청 → 기능(공학적 지표) → 부품(구조) 으로 전개
  - 건조속도, 안전, 그립감, 소음, 신뢰도, 전기료, 휴대성, 조작성
  - 유량, 공기온도, 밸런스, 중량, 크기, 소음레벨, 소비전력, 스위치 개수
  - 모터, 팬, 히터, 스위치, 하네스, 관체

입력
[고객 요청]

		工学的指標（機能）								ベンチマーク				
顧客の声	重み付け	流量	空気温度	持ったバランス	重量	大きさ	騒音レベル	消費電力	スイッチの数	1 悪い	2	3	4	5 良い
早く乾く	9	9	9								C		B	A
安全である	3	1	9	3			1				A		B,C	
持ち易い	9		3	9	9	3					A	B		C
静かである	3	3					9			A		B		C
信頼できる	3	1	1				1				C	A	B	
電気代が安い	3							9				B	A,C	
携帯できる	1				9	9			3	C	B			A
操作が簡単	1			3	3					C	B			A
目標値		>1.2 m^3 / min	>90 °C	<10 Nm	< 500gram	< 300mmx300mmx100mm	< 60 dB	< 1500 W	< 4					
ベンチマーク	良い 5	A	B	C	A		C	A						
	4	B	A	B		A	B		A					
	3				B	B		B	C					
	2	C	C	A		C	A		B					
	悪い 1				C			C						
	積算値	96	138	93	93	36	33	27	3					
	正規化	0.18	0.27	0.18	0.18	0.07	0.06	0.05	0.01					

		部品（構造）					
工学的指標（機能）	正規化後の重み	モータ	ファン	ヒータ	スイッチ	ハーネス	筐体
流量	0.18	9	9	3			3
空気温度	0.27	3	3	9		1	
持ったバランス	0.18	9	3	1			9
重量	0.18	9	3	3	1	1	9
大きさ	0.07	3	3	3	1	1	9
騒音レベル	0.06	9	9				3
消費電力	0.05	3	3	9	1	1	
スイッチの数	0.01	3		3	9		
	積算値	6.64	4.47	4.36	0.35	0.57	4.60
	正規化	31.6%	21.3%	20.8%	1.7%	2.7%	21.9%
	材料費	30	6	4	2	2	2
	加工費		2	4		3	10
	開発費		1	1			1
	コスト	30	9	9	2	5	13
	正規化	44.1%	13.2%	13.2%	2.9%	7.4%	19.1%

출력
[가치, 비용]

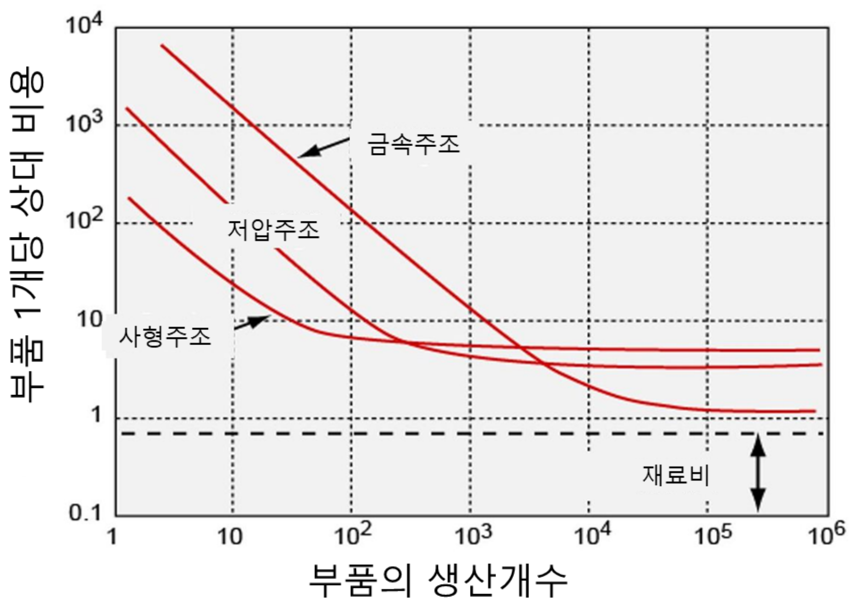
모델링 사례: 비용 (주조)

- 파라미터: 재료, 생산개수, 상각기간
- 선택 가능한 설계변수: 재료, 제조방법
- 정확도가 높지는 않지만 상대적 비교는 가능

재료비 공구비 설비비 간접비

부품 1개당 비용

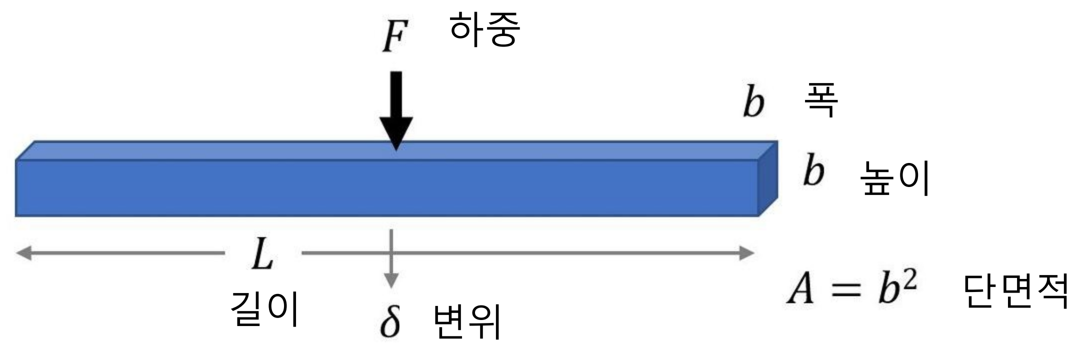
$$C = \left[\frac{mC_m}{1-f}\right] + \left[\frac{C_t}{n}\right] + \frac{1}{dn/dt}\left[\frac{C_c}{Lct}\right](1+d)^{ct} + \frac{dC_{oh}/dt}{dn/dt}$$



설비비: Cc
공구비: Ct
생산율: dn/dt
배치사이즈: n
원재료: m
상각기간: ct
할인율: d
간접비: dCoh/dt
손실율: f

모델링 사례: 성능 (경량보)

요구사항 가볍고 튼튼한 보(빔)



제약조건

- 길이 L은 고정
- 굽힘강성 > S*
- 면적 A에 관한 제약식

$$S = \frac{F}{\delta} = \frac{CEI}{L^3} = \frac{CEA^2}{12L^3}$$

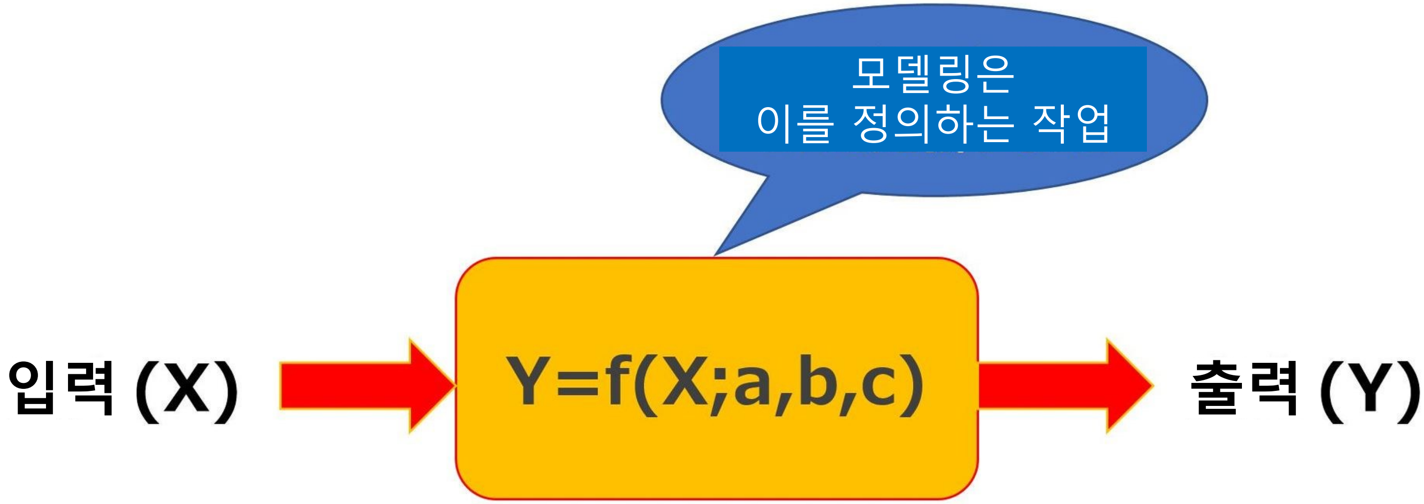
굽힘강성: S
밀도: ρ
경계조건에 따른 정수: C
(종)탄성계수: E
단면2차모멘트: I

목적함수 질량 m을 최소화 $m = AL\rho$

성능지표 $m = \left[\frac{12L^5S*}{C}\right]^{1/2}\left[\frac{\rho}{E^{1/2}}\right]$ → $M = \left[\frac{E^{1/2}}{\rho}\right]$ 설계지표: 이 값이 큰 재료를 선정

모델링이란?

- 알고 싶은 것(예: 부품 각 요소의 가치, 부품 한개당 비용, 설계지표)을 지배하는 지표를 명확히 하여 알고 있는 정보로부터 알고 싶은 것을 예측하는 행위



모델파라미터 : a、b、c

모델링 = 설계 (디자인)

Engineering Model (1)

- Model
  - Abstract description of the real world giving an approximate representation of more complex functions of physical systems
  - Increase our understanding of how a system works
  - Physical: scale model, prototype
  - Symbolic: drawings, verbalization, logic, mathematics
- Mathematical model
  - A model that represents a system by mathematical expressions of relevant natural laws, experience, and geometry
  - May contain many alternative designs, so criteria must be introduced in the model
  - Best, or optimum, design can be identified with the aid of mathematical methods

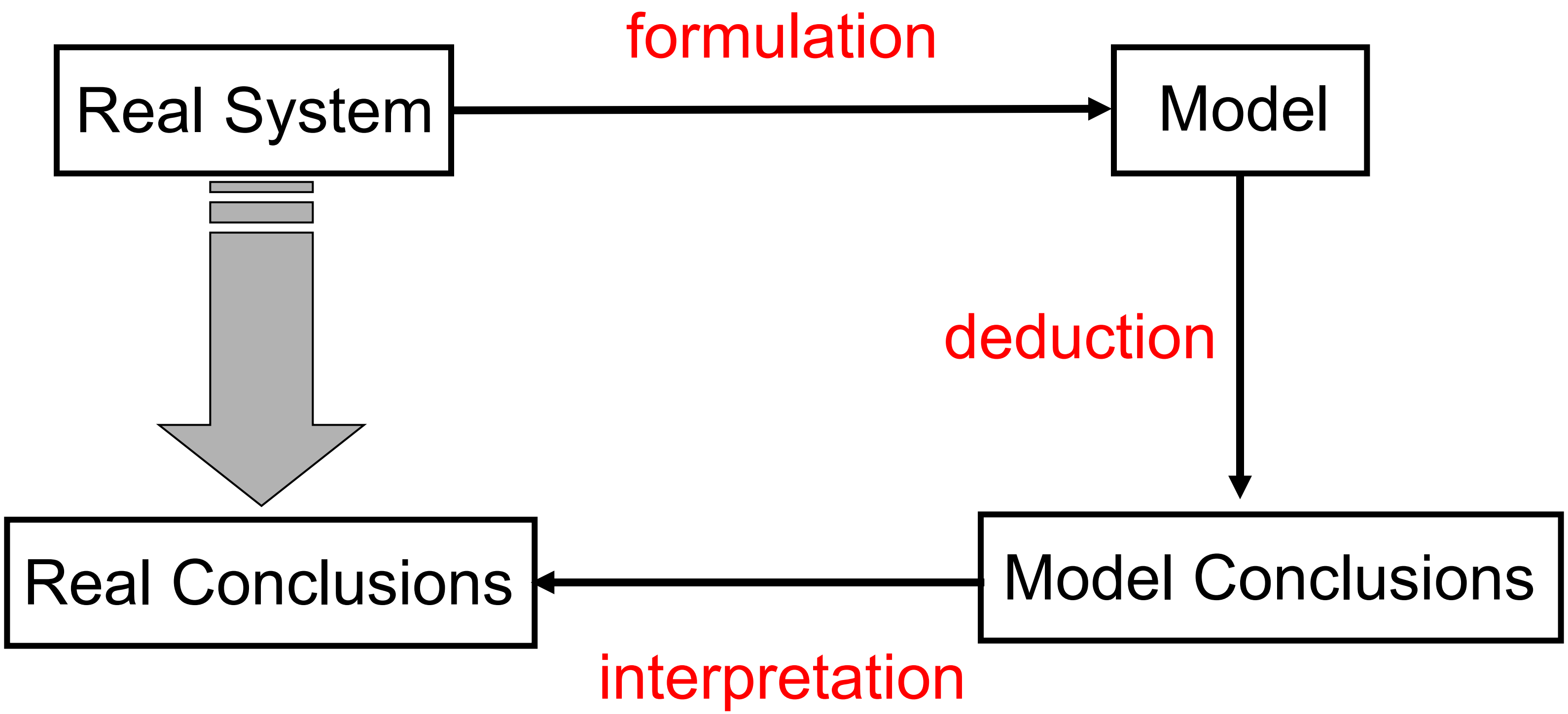
Engineering Model (2)

- Real-life engineering design problem
  - very unstructured
- Most difficult and challenging part
- Depends on experience as well as skill
- Thorough understanding of the first principles and fundamentals of engineering
- Describes the physical behavior of the system ▶ mathematical model

Engineering Model (3)

- Elements of models
  - Variables / Parameters / Constants / Mathematical relations
- Hierarchical levels
  - Every system is analyzed at a particular level of complexity
  - System → Subsystems → Components
  - "cut across" the links with environment, input/output characterization: free-body diagram, control volume

Modeling Process (1)



Modeling Process (2)

- Formulation
  - Often considered to be an art
  - What aspects of the real system should be included, which can be ignored?
  - What assumptions can and should be made?
- Deduction
  - Involves techniques that depend on the nature of the model
  - May involve solving equations, running a computer program, expressing a sequence of logical statements – whatever it takes to solve the problem of interest relative to the model
  - It should not be subject to differences of opinion, provided that the assumptions are clearly stated and identified
- Interpretation
  - Again involves a large amount of human judgment
  - The model conclusions must be translated to the real world conclusions, in full cognizance of possible discrepancies between the model and its real world

Analysis vs. Design

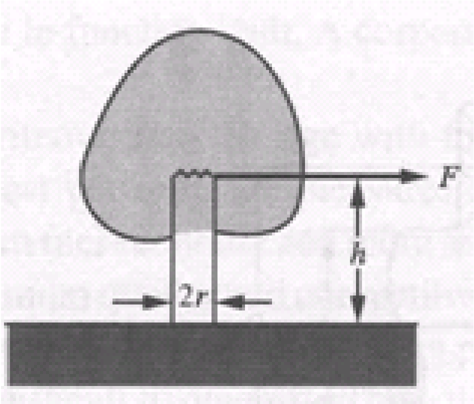
- Engineering analysis
  - To determine the behavior of an existing system
  - Sizes and configurations are given
- Engineering design
  - To calculate sizes and shapes of various parts to meet performance requirements
- ▶ estimate a design and analyze it to see if it performs according to the specifications

Analysis and Design Model

- Analysis model
  - Based on the principles of engineering science
    - Maximum wind force the tree can withstand before it breaks (*F*) if we take the tree as given (σ_{max}, *h, r* : parameters)
- Design model
  - Constructed from the analysis models for specific prediction tasks
    - Protect the tree from high winds by appropriately trimming the foliage to decrease *F* and *h* (variables)

Trunk of a tree subject to a wind force *F* at a height *h*

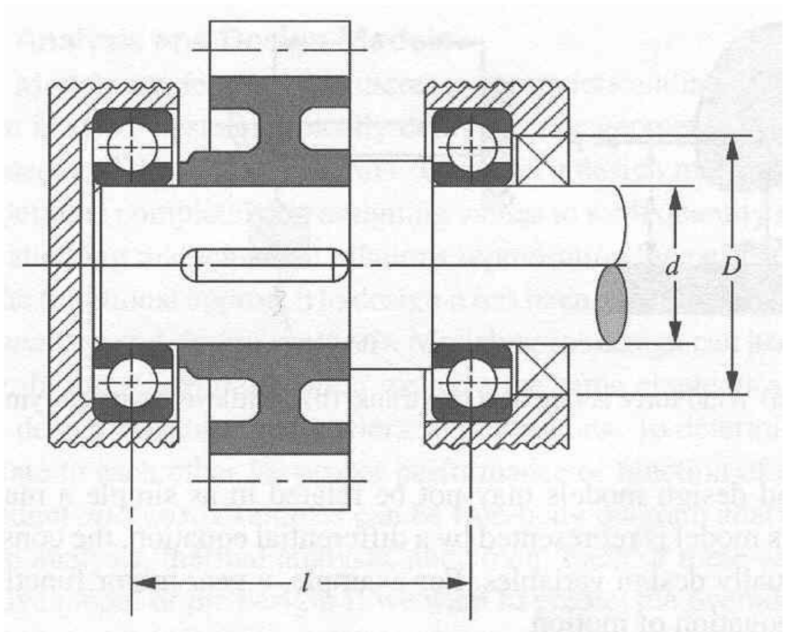
$$\sigma = \frac{My}{I} \xrightarrow{I=\frac{\pi r^4}{4}} \sigma_{\max} = \frac{4Fh}{\pi r^3}$$



Example: Shaft Design

- Influence of a given viewpoint on the design model

	d	*l*	*materials*
Shaft designer	variable	parameter	parameter
Housing designer	variable	variable	parameter
Project manager	variable	variable	variable



Decision Making

- Criterion: evaluating alternatives and choosing the "best" one
  - Not unique, influenced by many factors
    - Design application, timing, point of view, judgment of the designer
  - May change with time
    - Automobile design: maximum power and comfort → fuel economy
- Decision-making (Optimization) model
  - A design model that includes an evaluation criterion (*objective*)
- Shaft design example

Criterion	
Weight	
Rigidity	Best meshing of the attached gear
Material and manufacturing costs	Shop manager, ease of manufacturing
Cost	Project or plant manager

Design Optimization

- Goal of engineering
  - To improve the design so as to achieve the best way of satisfying the original need within the available means
- Elements in the design process
  - Recognition of need / act of creation / selection of alternatives
- Design optimization: selection of the “best” alternative
  - How do we describe different designs ? (design model)
  - What is our criterion for “best” design ? (objective)
  - What are the “available means” ? (set of requirements)

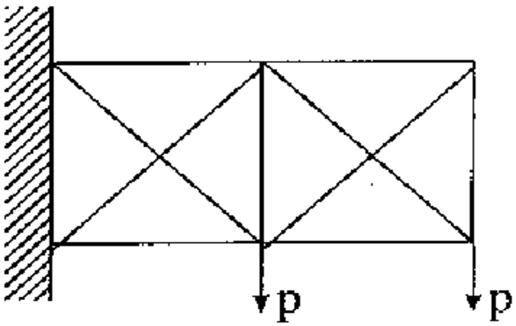
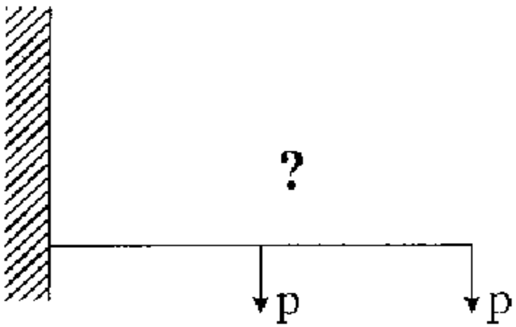
Optimum Design

- Undesirable effects
  - Stress, deflection, vibration, space occupancy, weight, cost
  - Dependent of the application (degree of significance)
  - Tolerable limit
- Desirable effects
  - Power transmission/ energy absorption/ momentary overload/ speed capacity, usable length of life, factor of safety
- Optimum design
  - Best possible one from the standpoint of the most significant effect
  - Minimize/Maximize the most significant undesirable/desirable effect

Problem Formulation Steps

- Identification of *design variables*
  - Parameter chosen to describe the design
  - Independent of each other, minimum number
- Identification of an *objective (cost) functions*
  - Criterion to compare various designs
  - as a function of the design variables
  - Single/Multi-objective
- Identification of all *design constraints*
  - All restrictions placed on a design
  - Explicit/Implicit, Linear/Nonlinear, Equality/Inequality
  - Feasible/Infeasible

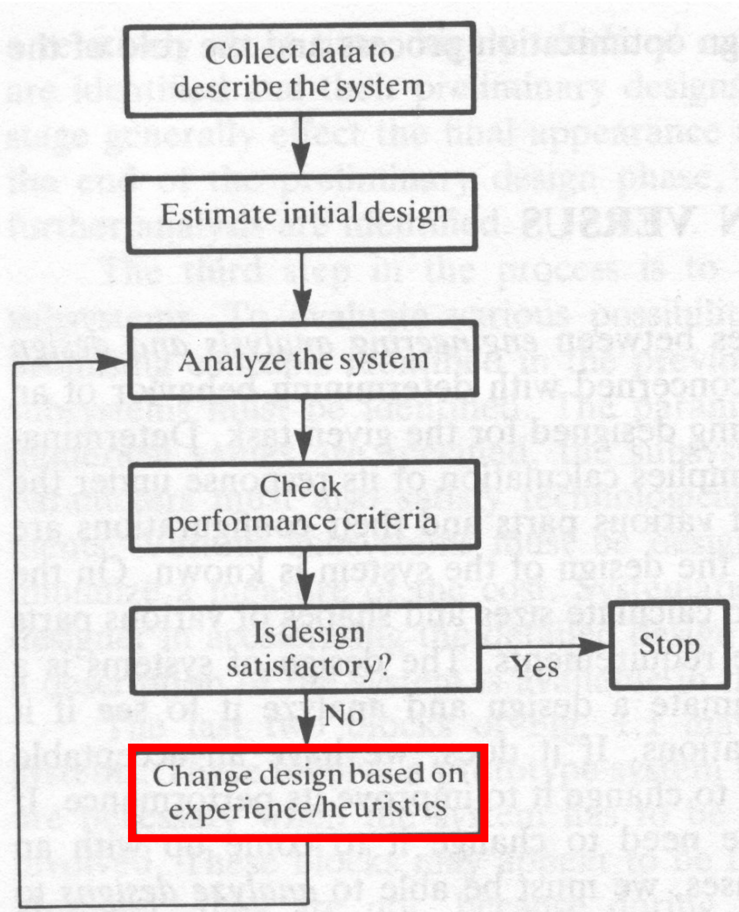
10 Bar Truss Design

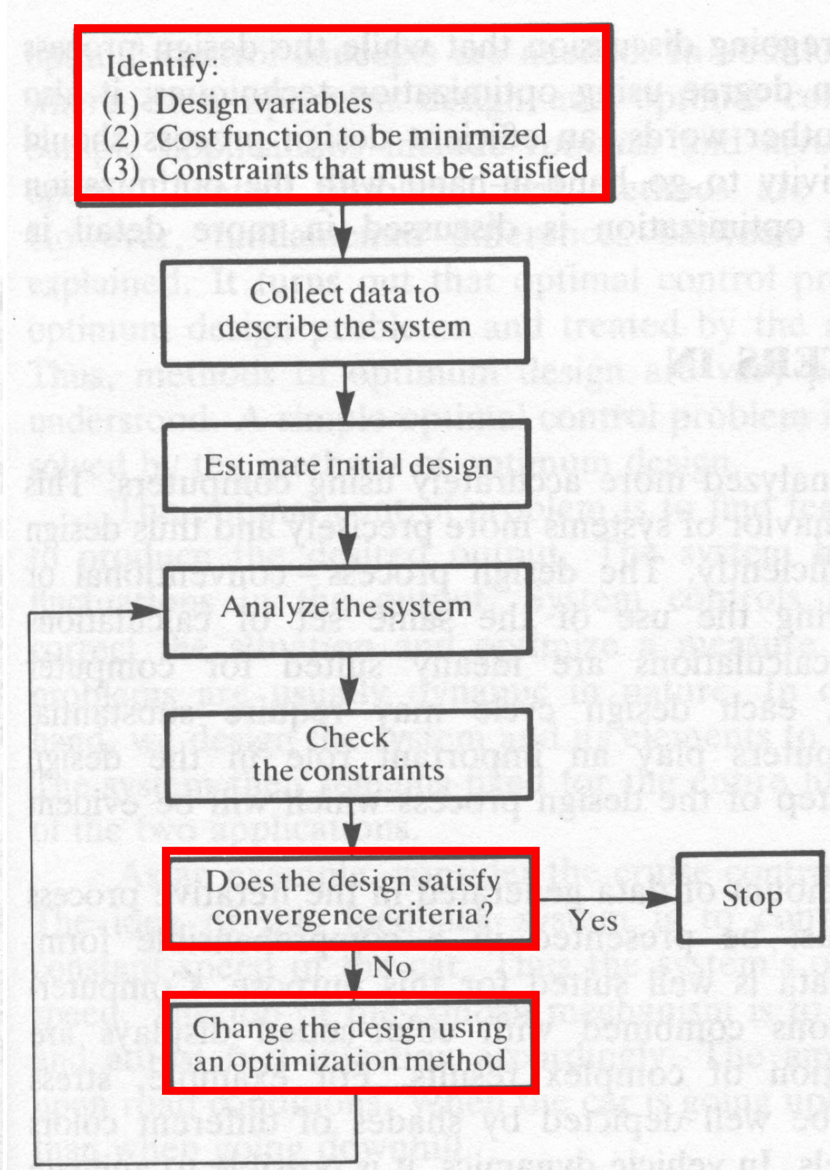
해석 (Analysis)	설계 (Design)
	
$\delta = ?$ $\sigma = ?$	$\delta \le \delta_{allow}$ $\sigma \le \sigma_{allow}$
• to obtain the response of a given system • # of unknown = # of equations	• to determine specifications of the system satisfying requirements • # of unknown > # of equations

Conventional vs. Optimum (1)

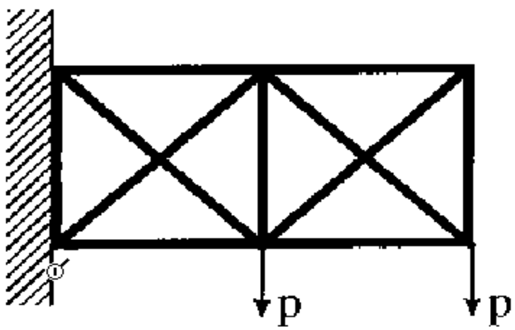
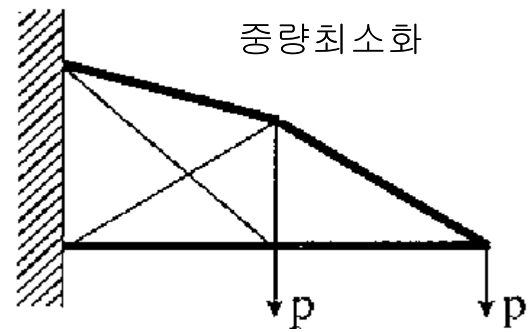
- Conventional design
  - Depends on designer's intuition, experience, and skill
  - Merits in making conceptual changes/additional specs
  - Difficulties in detailed design (complex constraints)
  - Less formal, no objective function/trend information
- Optimum design
  - Identify explicitly a set of design variables, cost function to be minimized, and constraint functions
  - More organized using trend information

Conventional vs. Optimum (2)





Conventional vs. Optimum (3)

Conventional Design	Optimum Design
	
$\delta \le \delta_{allow}$ $\sigma \le \sigma_{allow}$	$\delta \le \delta_{allow}$ $\sigma \le \sigma_{allow}$

Optimization Problems in Engineering (1)

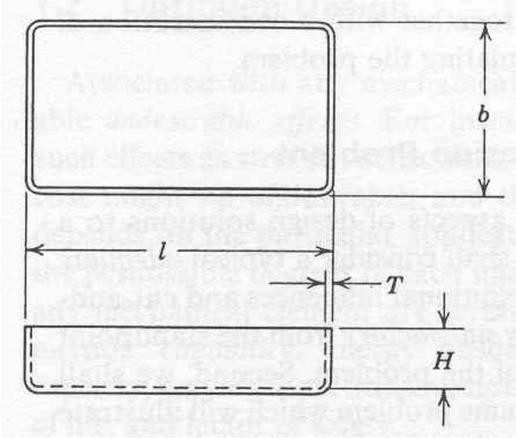
- Design aircraft for minimum weight and maximum strength
- Optimal trajectories of space vehicles
- Design civil engineering structures for minimum cost
- Design water-resource projects like dams to mitigate flood damage while yielding maximum hydropower
- Predict structural behavior by minimizing potential energy
- Material-cutting strategy for minimum cost
- Design pump and heat transfer equipment for maximum efficiency
- Maximize power output of electrical networks and machinery while minimizing heat generation
- Shortest route of salesperson visiting various cities during one sales trip
- Optimal planning and scheduling

Optimization Problems in Engineering (2)

- Statistical analysis and models with minimum error
- Optimal pipeline networks
- Inventory control
- Maintenance planning to minimize cost
- Minimize waiting and idling times
- Design waste treatment systems to meet water-quality standards at least cost

Plastic Tray Design (1)

- Basic design problem
  - Design a plastic tray capable of holding a specified volume of liquid, V, such that the liquid has a specified depth H, and the wall thickness of the tray is to be a specified thickness, T. The tray is to be manufactured in large quantities.
- Adequate design solution
  - Geometry
    - Intuition: rectangular ?



    - Infinite number of possible solutions
  - Material: experience?
    - Possible manufacturing techniques: vacuum forming
    - Possible chemical reactions w/ liquid: acrylic thermoplastic sheet

Plastic Tray Design (2)

- Optimum design solution
  - "manufactured in large quantities": cost (most significant undesirable effect)
  - Primary design equation: $C = \underbrace{C_o}_{\text{overhead}} + \underbrace{C_t}_{\text{tooling}} + \underbrace{C_l}_{\text{labor}} + \underbrace{C_m}_{\text{material}}$
  - C_o, C_t, C_l : independent of
    - Reasonable geometrical shapes / Feasible plastic materials
  - Objective: minimize cost C_m
    - selecting the best feasible material and the best values for *b* and *l*

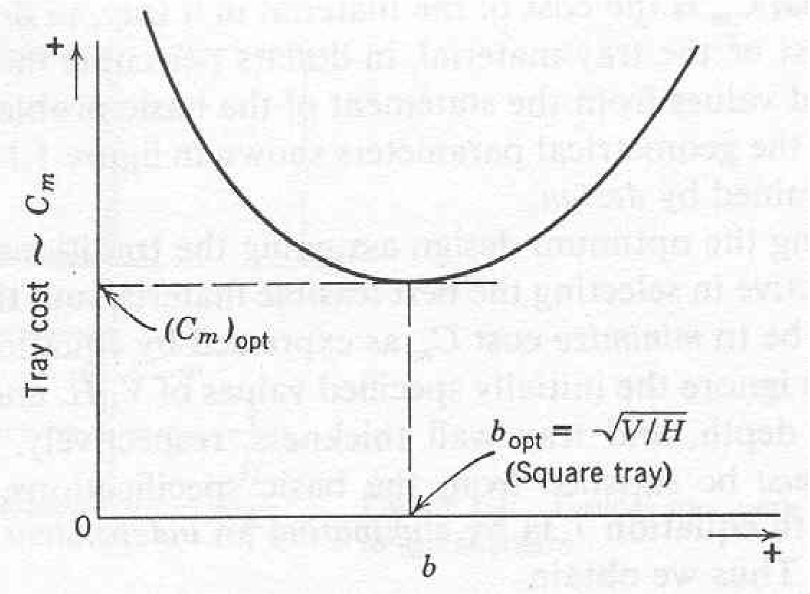
c : unit volume cost of the tray material

  - Optimum feasible material
    - *c*: polystyrene

	c ($\$/in^3$)	c ($\$/m^3$)
Acrylic	0.030	1831
Polystyrene	0.012	732

Plastic Tray Design (3)

– Optimum geometry for the rectangular tray

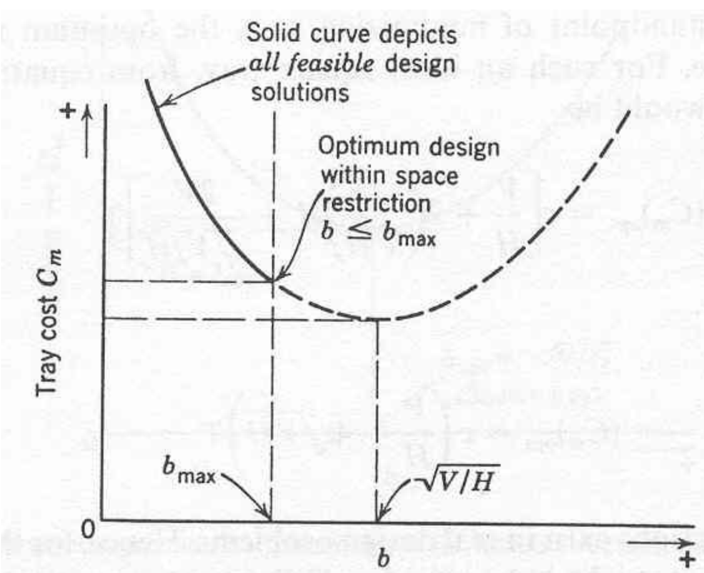


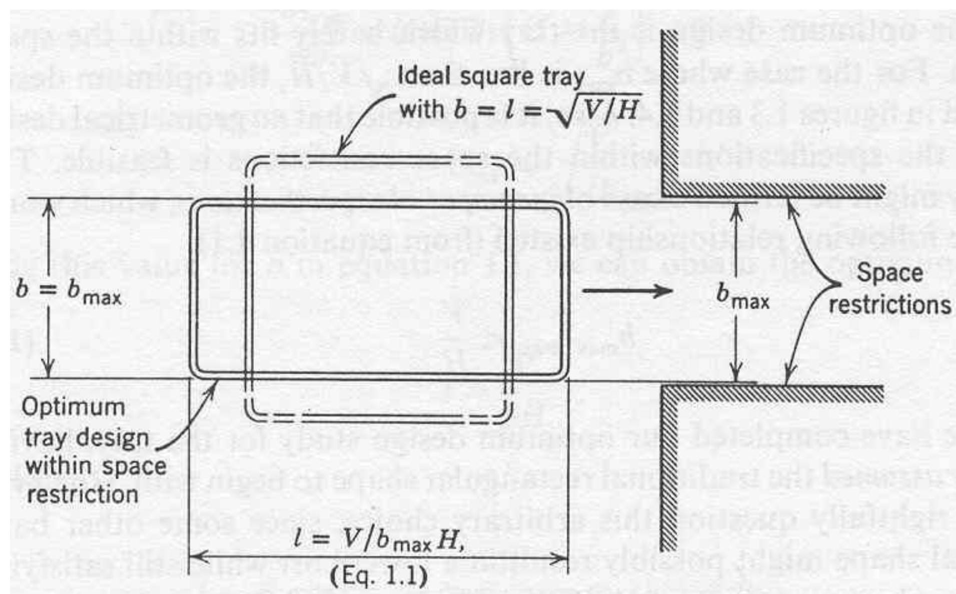
Plastic Tray Design (4)

- Space restrictions: $b \le b_{\max},\ \ l \le l_{\max}$

$$\begin{cases} b_{\max} \ge \sqrt{V/H} \ \text{ and } \ l_{\max} \ge \sqrt{V/H} : \text{ideal square tray is still the optimum design} \\ b_{\max} < \sqrt{V/H} \ \text{ or } \ l_{\max} < \sqrt{V/H} : \text{the tray which barely fits within the space restriction} \end{cases}$$

$$\text{incompatible specifications} : b_{\max} l_{\max} < \frac{V}{H}$$





Plastic Tray Design (5)

- Other basic geometrical shape ?
  - Circle: lowest C_m from the calculus of variations