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Marine design application of design theory and methodology

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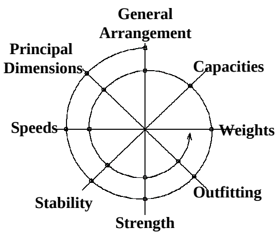
ICAD 2004
Seoul, June 21-24th
International Conference on Axiomatic Design

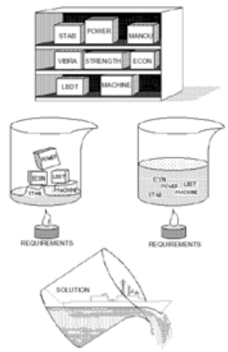
Contents

Ship design(Overview)

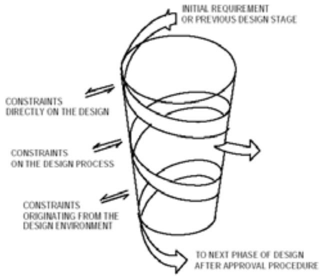
Paradigm for Ship Design



Evan's Design Spiral[1959]



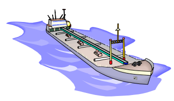
Mistress's Spiral Approach [1990]



Andrews's Overall Model[1981]

Ship design (Overview)

Ship Design Process



Owner's Req.
Class
Rule & Regulation
Flag Req.

Ship Marketing → Concept design → Preliminary design → Initial design → Detail design → Construction → Delivery

Basic design (Concept design, Preliminary design, Initial design)

Ship design (Overview)

Limitations of Ship Design

Parent(Basis) Ship based Design

In most shipyard designs, practical ship design is based on the parent or basis ship.

- Modifications of ship design are very little.
- Depends on empirical formulation.
- Case-Based Design more appropriates for ship design.

Burdens of Rules and Regulations

Owing to many Rules and Regulations, ship design is restricted.

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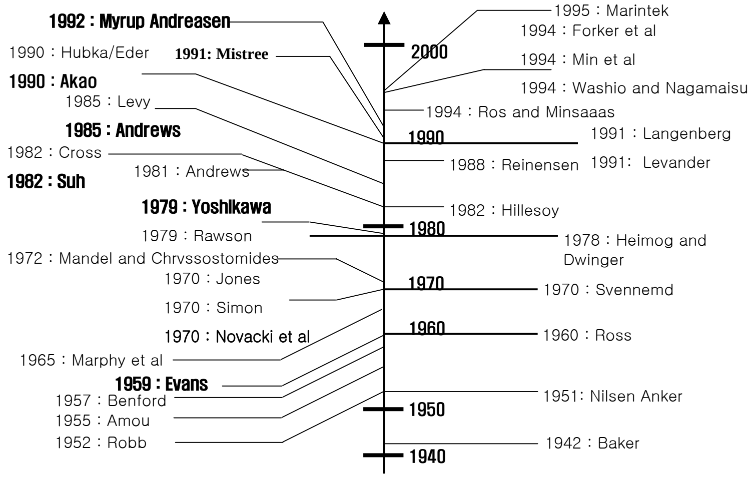
General Design Theory used in Ship Design



Papers on design theory and methodology & papers on practical design of ships

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New Design Methodology in Ship Design

• QFD

1967, Kobe Shipyard. QFD influenced the development of design theory in USA's Automobile Industry.

• F. Mistree et al (1991)

Design process considered as Decision based Design.

• Myrup Andreasen (1992,1987,1983)

Based on Hubka theory,

Process, function, organs and component, four domain concepts.

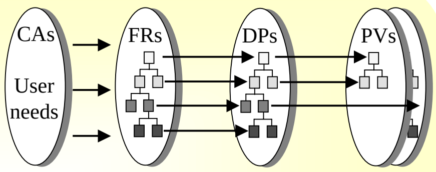
• David Andrews (1997)

Building block design methodology

Part 1. Axiomatic Design

Application of Design Axioms to Marine Design Problems

Contents



Introduction

The Design Axioms

Axiom 1 The Independence Axiom
Axiom 2 The Information Axiom

Application of the Design Axioms for Marine Design

Barge Design Example

- **The Independence and Information Axioms**

Conclusion

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Part 1. Axiomatic Design

Introduction

Motivation of Design Axiom

avoid intuitive way -> trial and error, empiricism, and know-how.

develop more systematic and rational approach.

Axiomatic design is

a scientific basis to the design process

a consistent set of analysis tools to assess each design decision

The roles of Design Axioms in Marine design are

Preliminary Barge design(redundant design, the similarity-based design)

selects which parameters should be changed and in what order they should be changed

Part 1. Axiomatic Design

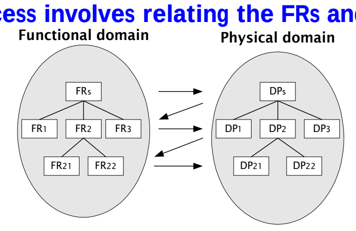
Axiomatic Design

Design tasks can be represented as a mapping between two domains.

Functional domain : "what we want to achieve" -> Functional Requirements (**FR**s)

Physical domain : "how we want to achieve it" -> Design Parameter (**DP**s)

The design process involves relating the FRs and the DPs in a logical way.



Decomposition by zig-zagging

The design process progresses from a system level down to a more detailed level though **Zig-Zagging**.

High-level requirements are broken down into **sub-requirements**

Decomposition by zig-zagging to be satisfied by **sub-solutions**.

When selecting solutions, **Design Axioms** assists in evaluating **the quality of the solutions**.

Part 1. Axiomatic Design

Barge Design Example

In the early design stage of a complex product

difficulty in exactly specifying all requirements and constraints.

Similarity-based design

finds a good solution from past experience.

minimizes the risk of failure based on a verified solution with less effort.

In a preliminary structural design (Redundant Design)

many design variables compared to its simple functional requirements.

a functional requirement is usually associated with more than one design variable.

the Independence Axiom

finds which DPs should be changed and which change order is best for minimizing iterations.

the Information Axiom

selects a design point to have the largest probability of attaining the attributes.

Part 1. Axiomatic Design

Barge Design Example–Problem Definition

<u>*Original Problem definition*</u>

Minimize $Steel\ weight(Swt) = 2t(2DB + 1.9DL + LB)\rho_s$

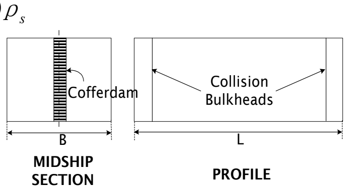
subject to

$Dead\ Weight(Dwt) \geq 1000\ ton,\ Metacentric\ Height(GM) \geq 0.3\ m$

$\frac{D}{T} \geq 1.2, \quad 2.0 \leq \frac{Z}{Z_{req}} \leq 3.0, \quad 5 \leq \frac{L}{B} \leq 7.5$

$Dwt = \rho_w LBT - 2t(2DB + 1.9DL + LB)\rho_s$

$Midship\ Section\ modulus\ (Z) = \{(2D^2t/3) + (t^3B/3D) + tDB\}$



Configuration of the barge

Find

$Length(L),\ Breadth(B),\ Depth(D),\ Draft(T),\ Effective\ thickness(t)$

<u>*The initial design point*</u>

L(m)	B(m)	D(m)	T(m)	t(m)	Dwt (ton)	$\frac{Z}{Z_{req}}$	Swt (ton)
41.94	7.54	4.09	3.37	0.005	1007.3	2.056	58.4

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Part 1. Axiomatic Design

Barge Design Example–Independence Axiom

Changed Definition

Minimize $\quad Steel\ weight(Swt) = 2t(2DB + 1.9DL + LB)\rho_s$

subject to $\quad Dwt \geq 1200\ ton,\ GM \geq 0.3\ m,\ \frac{D}{T} \geq 1.1$

- $\quad 2.156 \leq \frac{Z}{Z_{req}} \leq 3.0,\ 5 \leq \frac{L}{B} \leq 7.5$

Find $\quad Length(L),\ Breadth(B),\ Depth(D),\ Draft(T),\ Effective\ thickness(t)$

"Where the optimal design point should be moved to?"

Selecting partial DP sets using the Independence Axiom

$$\begin{Bmatrix} \Delta Dwt \\ \Delta Z \\ \Delta Swt \end{Bmatrix} = \begin{bmatrix} 0.316 & 0.323 & 0.010 & 0.333 & 0.018 \\ 0.0 & 0.245 & 0.422 & 0.0 & 0.333 \\ 0.304 & 0.179 & 0.184 & 0.0 & 0.333 \end{bmatrix} \begin{Bmatrix} \Delta L \\ \Delta B \\ \Delta D \\ \Delta T \\ \Delta t \end{Bmatrix} \qquad A_{ij} = \frac{\partial FR_i / \partial DP_j}{FR_0 / DP_0}$$

Part 1. Axiomatic Design

Barge Design Example–Independence Axiom

How to compute A_{ij} ?

$A_{ij} = \frac{\partial FR_i / \partial DP_j}{FR_0 / DP_0}$, is the chage rate in FR_i due to the change rate in DP_j at a design point.

$= \frac{\partial FR_i / FR_0}{\partial DP_j / DP_0}$ (because of the different scale of FR_i and the different scale of DP_j)

ex) $Dwt = \rho_w LBT - 2t(2DB + 1.9DL + LB)\rho_s$

$$\frac{\partial Dwt}{\partial L} = \rho_w BT - 2t(1.9D + B)\rho_s,\quad \frac{\partial Dwt}{\partial B} = \rho_w LT - 2t(2D + L)\rho_s,\quad \frac{\partial Dwt}{\partial D} = -2t(2B + 1.9L)\rho_s$$

$$A_{11} = \frac{\partial Dwt / \partial L}{Dwt_0 / L_0} = \frac{1.0 * 7.54 * 3.37 - 2 * 0.005 * (1.9 * 4.09 + 7.54) * 8.3}{1007.3 / 41.94} = 1.005$$

$$A_{12} = \frac{\partial Dwt / \partial B}{Dwt_0 / B_0} = \frac{1.0 * 41.94 * 3.37 - 2 * 0.005 * (2 * 4.09 + 41.94) * 8.3}{1007.3 / 7.54} = 1.026$$

$$A_{13} = \frac{\partial Dwt / \partial D}{Dwt_0 / D_0} = -0.0319,\quad A_{14} = \frac{\partial Dwt / \partial T}{Dwt_0 / T_0} = 1.058,\quad A_{15} = \frac{\partial Dwt / \partial t}{Dwt_0 / t_0} = -0.058$$

Normalize the absolute values of so that they add up to 1.

Part 1. Axiomatic Design

Barge Design Example–Independence Axiom

Selecting partial DP sets using the Independence Axiom

$$\begin{Bmatrix} \Delta Dwt \\ \Delta Z \\ \Delta Swt \end{Bmatrix} = \begin{bmatrix} 0.316 & 0.323 & 0.010 & 0.333 & 0.018 \\ 0.0 & 0.245 & 0.422 & 0.0 & 0.333 \\ 0.304 & 0.179 & 0.184 & 0.0 & 0.333 \end{bmatrix} \begin{Bmatrix} \Delta L \\ \Delta B \\ \Delta D \\ \Delta T \\ \Delta t \end{Bmatrix}$$

choose three DPs for an **uncoupled** or **decoupled design matrix** type.
measure the independence by the reangularity (R) and the semangularity (S).

The two sets having the largest R and S.

① $\begin{Bmatrix} \Delta Z \\ \Delta Swt \\ \Delta Dwt \end{Bmatrix} = \begin{bmatrix} 0.422 & 0.0 & 0.0 \\ 0.184 & 0.304 & 0.0 \\ 0.010 & 0.316 & 0.333 \end{bmatrix} \begin{Bmatrix} \Delta D \\ \Delta L \\ \Delta T \end{Bmatrix}$ ② $\begin{Bmatrix} \Delta Z \\ \Delta Swt \\ \Delta Dwt \end{Bmatrix} = \begin{bmatrix} 0.333 & 0.0 & 0.0 \\ 0.333 & 0.304 & 0.0 \\ 0.018 & 0.316 & 0.333 \end{bmatrix} \begin{Bmatrix} \Delta t \\ \Delta L \\ \Delta T \end{Bmatrix}$

Part 1. Axiomatic Design

How to find a new solution for Case ① ?

① $\begin{Bmatrix} \Delta Z \\ \Delta Swt \\ \Delta Dwt \end{Bmatrix} = \begin{bmatrix} 0.422 & 0.0 & 0.0 \\ 0.184 & 0.304 & 0.0 \\ 0.010 & 0.316 & 0.333 \end{bmatrix} \begin{Bmatrix} \Delta D \\ \Delta L \\ \Delta T \end{Bmatrix}$

Minimize
$Steel\ weight(Swt) = 2t(2DB + 1.9DL + LB)\rho_s$

Subject to
$Dwt \geq 1200\ ton,\ GM \geq 0.3\ m,\ \frac{D}{T} \geq 1.1$

$2.156 \leq \frac{Z}{Z_{req}} \leq 3.0,\ 5 \leq \frac{L}{B} \leq 7.5$

Given $B = 7.54,\ t = 0.005$ *Find* D, L, T

i) change D in order to satisfy the constraint, $2.156 \leq Z/Z_{req} \leq 3.0$

$$Z = \{(2D^2t/3) + (t^3B/3D) + tDB\},\ Z_{req} = 0.1021m^4 \Rightarrow \boxed{D = 4.25\ m}$$

ii) in order to satisfy the constraint, $Dwt \geq 1200\ ton$
increase T which has little influence on the objective, Steel Weight and let $L = 41.94\ m$

$$Dwt = \rho_w LBT - 2t(2DB + 1.9DL + LB)\rho_s \quad \Rightarrow T = 3.983\ m$$

iii) since the constraint $D/T = 1.067$, is violated, decrease T. $\Rightarrow \boxed{T = 3.86\ m}$

iv) in order to satisfy the constraint, , increase L $\Rightarrow \boxed{L = 43.34\ m}$

$$Swt = 2t(2DB + 1.9DL + LB)\rho_s \quad \Rightarrow Swt = 61.45\ ton$$

Part 1. Axiomatic Design

Barge Design Example–Independence Axiom

Result ① is
a little inferior to the optimization result regarding objective function (Swt).
But, superior in aspect of the computational time.

The results of applying the Independent Axiom and optimization

	Initial Point	① {D,L,T}	② {t, L,T}	Optimization {L,B,D,T,t}
L	41.94	43.34	45.17	42.03
B	7.54	7.54	7.54	7.77
D	4.09	4.25	4.09	4.28
T	3.37	3.86	3.72	3.89
t	0.0050	0.0050	0.0053	0.0050
Dwt	1007.3	1200.3	1200.1	1209.4
Z/Z_{req}	2.056	2.159	2.180	2.233
Swt	58.4	**61.45**	66.27	**60.99**

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Part 1. Axiomatic Design

Barge Design Example–Information Axiom

The Information Axiom
assess the alternatives in the light of the attributes not considered by the Independence Axiom.
i) **cost** involving both steel weight and welding length.
ii) **the similarity** between the mother ship and the design ship.

Information content of the Cost
less cost preferred

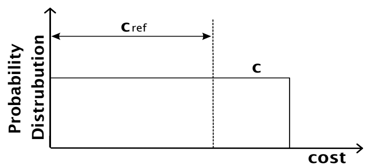
$$I_{\cos t} = \frac{C}{C_{ref}}$$

$$C_{ref} = steel\ weight_{ref} \times c_1$$

$$C = steel\ weight \times c_1 + welding\ length \times c_2$$

$$c_1\ :\ a\ unit\ \cos t\ of\ steel\ weight$$

$$c_2\ :\ a\ unit\ \cos t\ of\ welding\ length$$



The information content of Cost

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Part 1. Axiomatic Design

Barge Design Example–Information Axiom

Information content of Similarity

the more similar to mother ship, less information content the design ship has

$$I_{Similarity} = (\frac{L_b}{B_b} - \frac{L_c}{B_c})^2 + (\frac{L_b}{D_b} - \frac{L_c}{D_c})^2 + (\frac{B_b}{D_b} - \frac{B_c}{D_c})^2 \qquad (L_b : mother\ ship,\ L_c : design\ ship)$$

Final Results

The result of applying the Information Axiom

	$I_{\cos t}$	$I_{similarity}$	I_{total}
① {D, L, T}	2.144	0.097	2.241
② {t, L, T}	2.279	0.807	3.086

Part 1. Axiomatic Design

Conclusion

investigate the possibility of applying of the Design Axioms to marine design examples

the Independence Axiom

guides for checking the correctness the decomposition process.
assists in deciding what to change and what order in similarity-based design.
leads less iteration and effective changes in redundant design.

the Information Axiom

a good criterion for a probabilistic estimation under the uncertain condition.

However,

Further research on the application of Axiom Design to structural design.
(redundant design)

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Part 2. QFD (Quality Function Deployment)

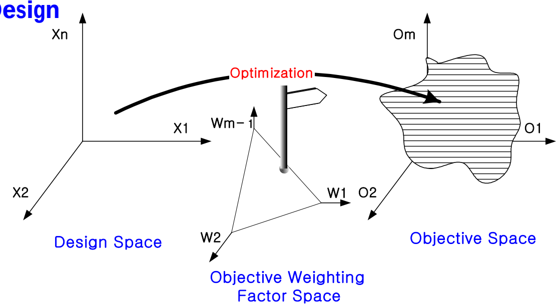
Design Optimization using QFD

Contents

Part 2. QFD (Quality Function Deployment)

Traditional Methods

Preference based Design



- Transforms to a single optimization problem with **weighting factors**
  - AHP technique ▶ systematic determination of weighing factors through individual comparison
  - HOQ(House of Quality) ▶ determination of weighting factors based on Customer demands
- Advantage : Simple
- Disadvantage : No information about correlations among Design Objectives
  ▶ **Difficulty in Trade-off**

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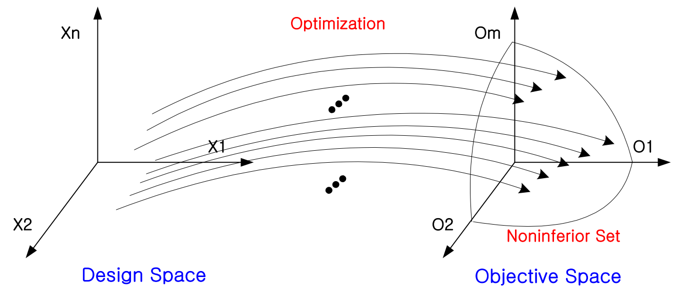
Part 2. QFD (Quality Function Deployment)

Traditional Methods

Generating Method



✓Generate **Inferior Set(Pareto Set)** with Constraint Method or Weighting Method
- Advantage : Understanding correlations among Design Objectives
- Disadvantage : **Exhaustive computation**

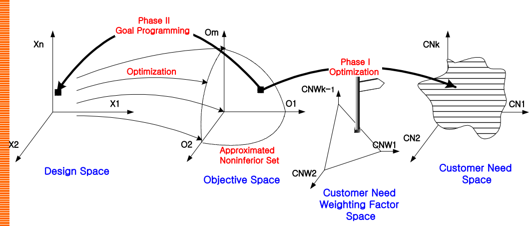
Part 2. QFD (Quality Function Deployment)

Design Optimization using QFD

Design optimization using QFD

Phase I : Maximize Overall Customer Satisfaction Level
◇ Analysis of correlations among Design Objectives using RSM for Pareto Set
◇ determine Design Objective values maximizing Customer Satisfaction Level and satisfying their correlations

Phase II : Goal Programming
◇ determine Design Variables accomplishing the Design Objective values



◇ Advantage
- Customer oriented decision
- Effective analysis of correlations
- Flexible reflection of design environment
- Support for exploration for uncertainty

◇ Computational time
Preference based Method < QFD Optimization < Generating Method

Part 2. QFD (Quality Function Deployment)

Design Optimization using QFD

Formulation

Maximize Overall Customer Satisfaction Level. $OCSL = \sum_{i=1}^{m} w_i y_i$

$y_i = \sum_{j=1}^{n} f_{ij} \Delta x_j$, Individual Customer Satisfaction

f_{ij} ; Relationship coefficients

w_i ; Relative Importance

$x_j^0, x_j^{\min}, x_j^{\max}$: Current,min,max value of DOj

$$\left(\Delta x_j = \frac{x_j^* - x_j^0}{x_j^{\max} - x_j^{\min}} \right)$$

Find x_j^* DO values

Satisfy Regression Model

$$x_n' = b_0 + \sum_{i=1}^{n-1} b_i x_i + \sum_{i=1}^{n-1} b_{ii} x_i^2 + \sum_{i=1}^{n-2} \sum_{j=i+1}^{n-1} b_{ij} x_i x_j$$

$$x_n'(1-f) \le x_n \le x_n'(1+f), f = flexibility(0.01 \sim 0.03)$$

Regression Model

Design Objectives(DOs)

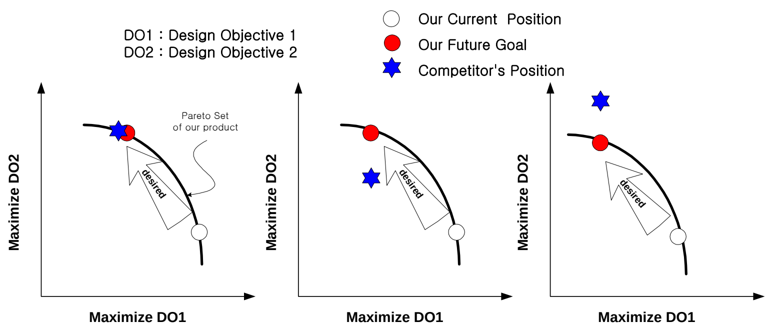
		x_1	x_2	...	x_{n-1}	x_n	
Customer Needs (CNs)	y_1	f_{11}	f_{12}	...	f_{1n-1}	f_{1n}	w_1
	y_2	f_{21}	f_{22}	...	f_{2n-1}	f_{2n}	w_2
	⋮	⋮	⋮	⋮	⋮	⋮	⋮
	y_{m-1}	f_{m1}	f_{m-12}	...	f_{m-1n-1}	f_{m-1n}	w_{m-1}
	y_m	f_{m-11}	f_{m2}	...	f_{mn-1}	f_{mn}	w_m
	Current	x_1^0	x_2^0	...	x_{n-1}^0	x_n^0	
	Maximum	$x_1^{\max}$	$x_2^{\max}$	...	$x_{n-1}^{\max}$	$x_n^{\max}$	
	Minimum	$x_1^{\min}$	$x_2^{\min}$	...	$x_{n-1}^{\min}$	$x_n^{\min}$	

Part 2. QFD (Quality Function Deployment)

Correlations among Design Objectives(Dos) – RSM for Pareto Set

An effective approach for indirect correlations among DOs

- Approximation with Quadratic Regression model due to a convex characteristic of Pareto Set
- Support for direct Trade-off among DOs
- Identification of the relative position of our product w.r.t. competitor's product



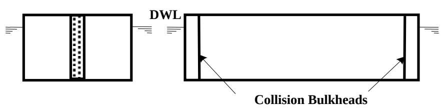
(a) Noninferior Position (b) Superior Position (c) Inferior Position

Part 2. QFD (Quality Function Deployment)

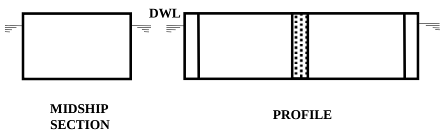
Barge Example

A barge should carry 500 ton of fresh water and 500 ton of distilled water

Our Product



Competitor's Product



Design Objectives

- Minimize Steel Weight
- Maximize Strength (Midship Section Modulus)
- Minimize Welding Length
- Minimize Inertia of Tank

Satisfy

Stability, Displacement, Volume, Form ratio

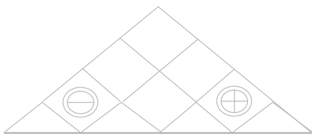
Design Variable

Length(L), Breadth(B), Depth(D), Draft(T), Effective plate thickness(t)

	L(m)	B(m)	T(m)	D(m)	t(m)	Steel Weight (ton)	Strength (m^3)	Welding Length (m)	Inertia of Tank (m^4)
Our Product	52.63	10.32	2.00	4.00	0.005	85.738	0.262	514.503	398.927
Competitor's Product	52.98	9.75	2.62	4.00	0.025	350.823	1.108	376.895	1801.940

Part 2. QFD (Quality Function Deployment)

QFD Optimization – HOQ of Barge



	Importance	Steel Weight	Strength	Welding Length	Inertia of Tank	
Low Life Cycle Cost	0.3		0.43	−0.57		
Purchase Cost	0.1	−1.0				
High Reliability	0.4		0.57	−0.14	−0.29	
Productivity	0.2	−0.20		−0.80		
	Measurement Unit	ton	Z(m^3)	m	m^4	
	Minimum Level	61.147	0.174	422.304	111.657	
	Maximum Level	586.989	1.467	639.228	839.364	OCSL
	Current Level of Our Product	85.738	0.262	514.503	398.927	0
	Competitor's Product	350.823	1.108	376.895	1801.940	+0.185

※ OCSL = Overall Customer Satisfaction Level w. r. t. Current Level
Our Product : L=52.63 B=10.32 T=2.00 D=4.00 t=0.005
Competitor's Product : L=52.98 B= 9.75 T=2.62 D=4.00 t=0.025

Part 2. QFD (Quality Function Deployment)

QFD Optimization – Response Surface Method for Pareto Set

Experiment Set built by Central Composite Design

		Input(×1)	Input(×2)	Input(×3)	Response(Y)
Objective Function		Max(2.0) - Strength(Z)	Welding Length	Inertia of Tank	Steel Weight
Min(Ximin)		0.53332	422.304	111.657	61.147
Max(Ximax)		1.82554	639.228	839.364	586.989
Actually Observed (Expected)	1	-0.975(-1.000)	-0.856(-1.000)	-1.000(-1.000)	371.338
	2	1.000(1.000)	-0.889(-1.000)	-1.000(-1.000)	135.571
	3	-0.976(-1.000)	-0.864(1.000)	-1.000(-1.000)	370.913
	4	1.000(1.000)	-0.293(1.000)	-1.000(-1.000)	168.565
	5	-1.000(-1.000)	0.190(-1.000)	0.334(1.000)	432.704
	6	1.000(1.000)	0.668(-1.000)	1.000(1.000)	159.135
	7	-1.000(-1.000)	0.986(1.000)	1.000(1.000)	493.577
	8	1.000(1.000)	1.067(1.000)	1.000(1.000)	174.346
	9	-1.363(-1.682)	-0.001(0.000)	0.000(0.000)	449.720
	10	1.682(1.682)	-0.028(0.000)	0.000(0.000)	78.458
	11	-0.000(0.000)	0.030(-1.682)	-0.001(0.000)	278.107
	12	-0.000(0.000)	1.012(1.682)	0.000(0.000)	326.474
	13	0.000(0.000)	-0.675(0.000)	-1.593(-1.682)	284.007
	14	-0.000(0.000)	1.497(0.000)	1.682(1.682)	471.487
	15	-0.000(0.000)	0.778(0.000)	0.000(0.000)	309.476

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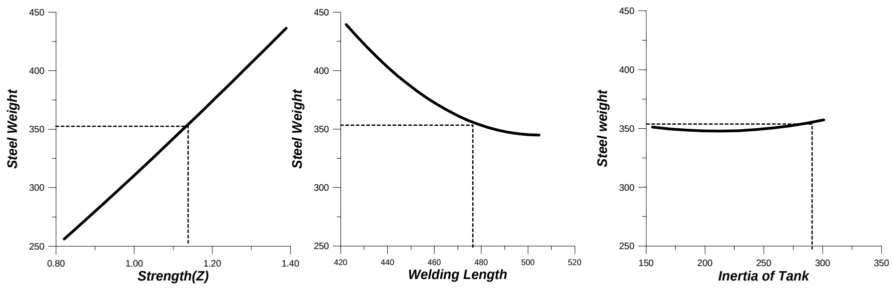
Part 2. QFD (Quality Function Deployment)

Regression Model

$$Y = 262.08 - 132.484x_1 + 5.760x_2 + 37.669x_3$$
$$+ 5.192x_1^2 + 58.634x_2^2 + 53.264x_3^2 + 17.993x_1x_2 - 42.204x_1x_3 - 68.609x_2x_3$$

"We can identify associations among Design Objectives using Regression Model"



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Part 2. QFD (Quality Function Deployment)

Identification of Relative Position

	L(m)	B(m)	T(m)	D(m)	t(m)	Steel Weight (ton)	Strength (m^3)	Welding Length (m)	Inertia of Tank (m^4)
Our Product	52.63	10.32	2.00	4.00	0.005	85.738	0.262	514.503	398.927
Competitor's Product	52.98	9.75	2.62	4.00	0.025	350.823	1.108	376.895	1801.940

Steel Weight(Y)
Strength(X_1)
Welding Length(X_2)
of Competitor's Product

→ Regression Model of Our Product

→ Compare Inertia of Tank(X_3) with Competitor's

	Steel Weight (ton)	Strength (m^3)	Welding Length (m)	Inertia of Tank (m^4)
Our Product	350.823	1.108	376.895	287.245(m4) (est.) < 1801.840(m4)
Competitor's Product	350.823	1.108	376.895	1801.940

Part 2. QFD (Quality Function Deployment)

Comparisons of three methods

	L	B	T	D	t	Steel Weight	Strength	Welding Length	Inertia of Tank	OCSL
Current Level	52.63	10.32	2.00	4.00	0.005	85.738	0.262	514.503	398.927	0
Competitor's Product	52.98	9.75	2.62	4.00	0.025	350.823	1.108	376.895	1801.940	+0.185
Preference Method with AHP	48.58	9.70	2.95	4.00	0.025	381.001	1.237	478.820	300.002	+0.139
Preference Method with HOQ	45.20	9.00	3.31	4.00	0.025	341.344	1.167	447.561	217.210	+0.238
QFD Optimization	48.13	9.58	2.94	4.00	0.0234	351.47	1.148	474.46	285.258	+0.264

Part 2. QFD (Quality Function Deployment)

Conclusion

Suggest a method determining DO values maximizing Customer Satisfaction

Build a regression model for Pareto Set ▶ Identify optimal relationships among Dos(Design Objectives)

- decide whether DOs values are feasible or not
- support Trade-off among various perspectives
- reflect designer's thoughts and design environment flexibly
- help designer understand a feature of correlations among DOs
- make it possible to explore Design Objective space for uncertainty

Part 3. FBS

Application of FBS Design Model in Preliminary Ship Design

Contents

Introduction

The Need of Systematic Design

FBS(Function–Behavior–Structure) Overview

Examples - 330K VLCC

Conclusion

Part 3. FBS

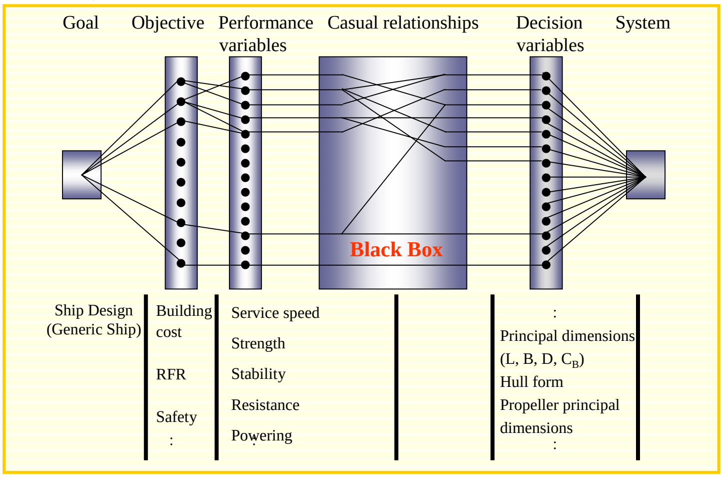
Introduction

- ✓FBS(Function-Behavior-Structure) based Representation System
  - Gero(1990)
  - Yoshikawa(1990)
- ✓SFB(Structure, Function, Behavior) based Representation System
  - Linda(2000)
- ✓F(Function) based Representation System
  - Pahl & Beitz(1977 and 1996)
  - Chakrabarti(1994)
- ✓Function based early stage ship design – "SURFCON"
  - Traditional Ship Design : based ship sizing tools
  - SURFCON : based Function

Part 3. FBS

The Need of Systematic Design

The relationships among goals, objectives, performance variables, and decision variables in optimization



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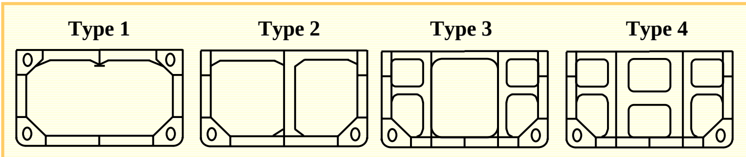
The Need of Systematic Design

– Midship section Optimization

find ***plate & stiffener space***, which minimizes ***midship area***
subject to ***class rule based***
plate required thickness
section modulus
buckling



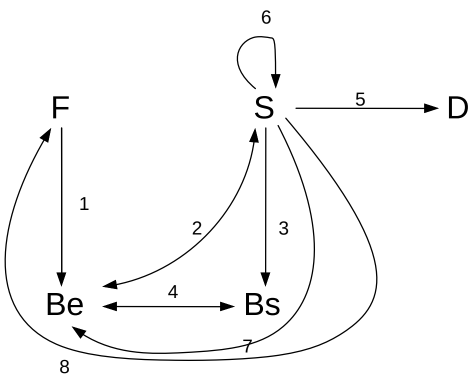
✓ Design problems are formulated in terms of objective and constraint functions based on the mathematical concepts of Operation Research

Part 3. FBS

FBS Overview

✓FBS(Function-Behavior- Structure)

- J.S. Gero(Sidney University)
- The Purpose, Function(F), of designing is to transform Design Description(D)



1. Formulation	**F -> Be**
2. Synthesis	**B -> S via Bs**
3. Analysis	**S -> Bs**
4. Evaluation	**Bs <-> Be**
5. Documentation	**S -> D**
6. Reformulation	**S -> S**
7. Reformulation	**S -> Be**
8. Reformulation	**S -> F via Be**

The FBS Framework[Gero 2002]

Part 3. FBS

The Need of Systematic Design

– Comparisons of Optimization and FBS

Optimization :

Formulation

: Explicit function

Min/Max : $F(x), x \in \Omega$

where $\Omega = \{ x : g \le 0, h = 0 \}$

Final Results

L : 310.0m

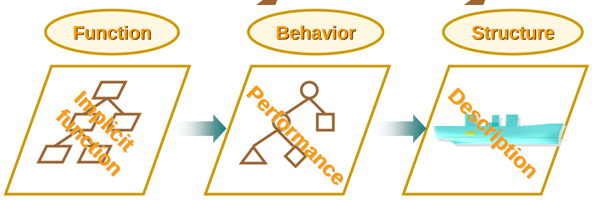
B : 60.6 m

D : 29.6m

C_B : 0.8449

:

FBS Model :



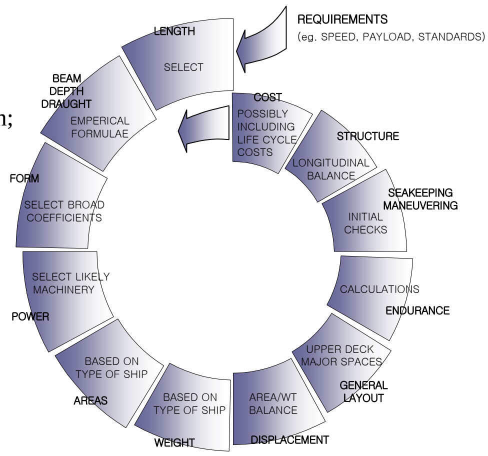
Part 3. FBS

The Need of Systematic Design

✓Characteristics of Ship Design

- Iterative process in nature;
- limitations on rules and regulations;
- occurs large accident by fault design;
- dependent on human's knowledge & experience

Exxon Valdez Spill



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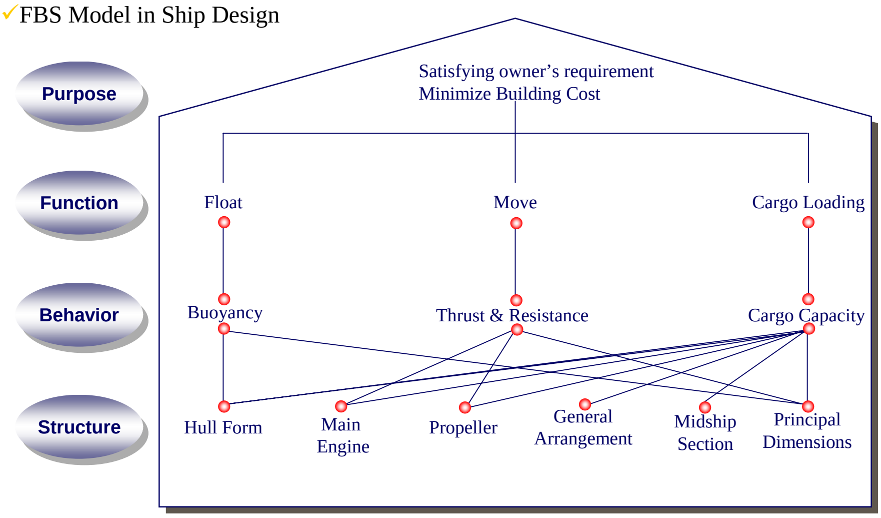
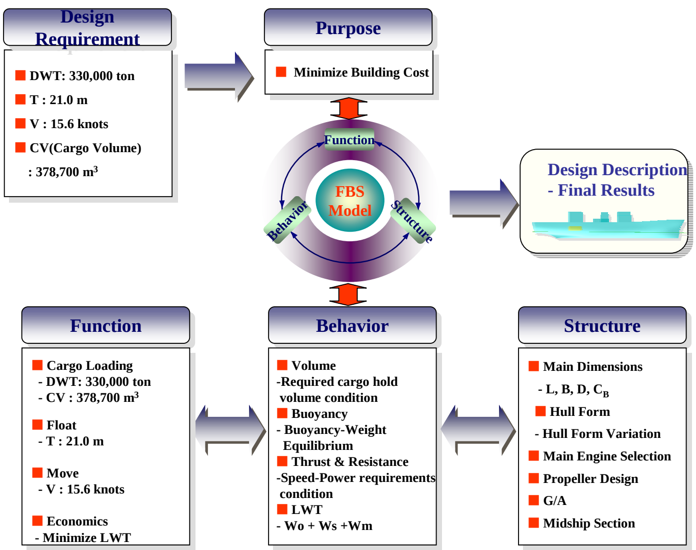
FBS Overview

✓FBS Model in Ship Design



Part 3. FBS

FBS Example – 330K VLCC



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FBS Example – 330K VLCC

- Minimize *Building Cost*
- Given
  - DWT(DeadWeight) : 330,000ton
  - T(draft) : 21.0m
  - V(Service Speed) : 15.6knots
  - CV(Cargo Volume) : 378,700m^3
- Basis Ship(Parent Ship)
  - 278K VLCC / 300K VLCC

Part 3. FBS

FBS Example – 330K VLCC

		Units	Traditional Design	F B S (Optimization)	
				WO/Hullform	W/Hullform
Object (Build Cost)		$	1.11913×10^8	9.94635×10^7	9.91975×10^7
Results	L	m	325.8	310.0	310.0
	B	m	60.4	60.6	57.3
	D	m	31.6	29.6	29.4
	C_i	-	-	-	0.99
	C_B	-	0.8087	0.8499	0.8112
	V	knots	15.6	15.6	15.6
	DMCR	PS	40006.10	35433.97	35159.70
	D_P	m	9.83	9.61	10.39
	Pi	-	7.07	6.82	7.17
	A_E/A_O	-	0.44	0.44	0.56
	CV	m^3	378700.0	420702.4	396745.7
	DWT	ton	330,000	330,000	330,000
	LWT	ton	**39957.7**	36969.3	**35441.9**
System Iteration		-	-	5	7
Function Call		-	-	70	141

Part 3. FBS

Conclusion

- ✓ Design becomes more complex recently.
- ✓ It is necessary that designer can handle his design problems systematically.
- ✓ Optimal design method cannot be used effectively at the early design stage

  design problems must be formulated in terms of objective and constraint functions based on the mathematical concepts

- ✓ FBS design model is introduced to help the novice designer formulate the complex design problems systematically into a more clear and easy understandable relationship.

  Function(F) ☞ designer's new intents which designer wants to create for
  Structure(S) ☞ a final product configuration
  Behavior(B) ☞ a product's performance

- ✓ FBS design model is thus rather totally different concept used for formulating design problem, compared with conventional optimal design method.
- ✓ To validate this new FBS model, 330K VLCC design case is performed.