Lecture Note of Topics in Ship Design Automation

# Optimum Design

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## Contents

# Ch. 10 Case Study of Optimal Layout Design





# 10.1 Overview

# Optimal Layout Design for Ship
## - Determination of Optimal Bulkhead Layout of Naval Surface Ship

### Problem definition

- **Objective**
  - Minimization of liquid cargo space(maximization of space for armament) and maximization of stability
- **Input("Given")**
  - Required space for liquid cargos
  - Required damage stability by international rule
  - Required position(draft, trim, heel) at the damaged state
- **Output("Find")**
  - Optimal positions of bulkheads

### Proposal of an optimal layout algorithm

*Find* $x_k$ Position of each bulkhead — Design Variables

*Minimize* $F_1 = V_{FOT} + V_{FWT} + V_{WBT} + V_{LOT}$ *and* — Objective Functions

Sum of spaces for liquid cargos

*Maximize* $F_2 = \sum_{i=1}^{Q} GM_i$ Sum of GM at the damaged state

*Subject to* — Constraints

Constraints about the required space of each liquid cargo

$V_{FOT}^{\min} \le V_{FOT} \le V_{FOT}^{\max}$ $V_{FWT}^{\min} \le V_{FWT} \le V_{FWT}^{\max}$

$V_{WBT}^{\min} \le V_{WBT} \le V_{WBT}^{\max}$ $V_{LOT}^{\min} \le V_{LOT} \le V_{LOT}^{\max}$

Constraints about the shear force and bending moment at the intact state

$SF_j \le SF_j^{\max}$ $BM_j \le BM_j^{\max}$

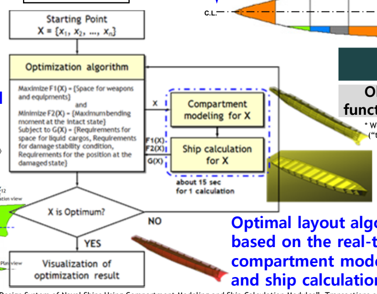
Constraints about the required damage stability condition

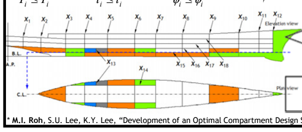
$\phi_{0,i} \le 15^\circ$ $1.4 \le A_{2,i} / A_{1,i}$

Constraints about the required position at the damaged state

$T_i \le T_i^{\max}$ $t_i \le t_i^{\max}$ $\phi_i \le \phi_i^{\max}$

Mathematical formulation

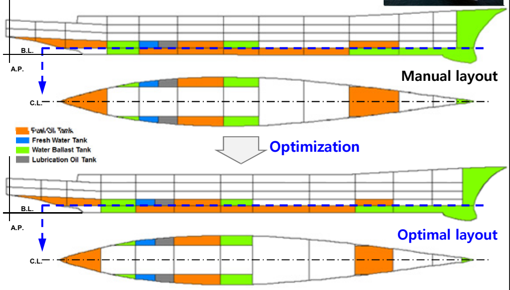




Optimal layout algorithm based on the real-time compartment modeling and ship calculation

### Application to an actual problem

- US Navy DDG-51 missile destroyer
- Number of design variables for bulkheads: 18




| | Manual layout [A] | Optimal layout [B] | Ratio (B/A) |
|---|---|---|---|
| Objective function value* | 12.80 | 12.54 | 98.0% |

* Weighted sum of objective function value (*the smaller, the better*)

2.0% improvement

* M.I. Roh, S.U. Lee, K.Y. Lee, "Development of an Optimal Compartment Design System of Naval Ships Using Compartment Modeling and Ship Calculation Modules", Transactions of the Society of Naval Architects of Korea, Vol. 46, No. 4, pp.424-434, 2009

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# Optimal Layout Design for Ship
## - Determination of Optimal Compartment Layout of Naval Surface Ship

### Problem definition

- **Objective**
  - Minimization of total cost of transporting materials and maximization of adjacency requirements
- **Input("Given")**
  - Total number of decks and compartments
  - Required area and aspect ratio of each compartment
  - Material flows and adjacency values between compartments
  - Number and positions of bulkheads
- **Output("Find")**
  - Optimal compartment layout of naval surface ship

### Proposal of an optimal layout algorithm

*Find* $(x_i, y_i)$ Position of each compartment — Design Variables

*Minimize* $F_1 = \sum_{i=1}^{M-1}\sum_{j=i+1}^{M}(f_{i,j} \times d_{i,j})$ *and* — Objective Functions

Total cost of transporting materials

*Maximize* $F_2 = \sum_{i=1}^{M-1}\sum_{j=i+1}^{M}(b_{i,j} \times c_{i,j})$ Adjacency requirements

*Subject to* — Constraints

Constraints about the required aspect ratio of each compartment

$g_1 = \alpha_k^{\min} - \alpha_k \le 0$ $g_2 = \alpha_k - \alpha_k^{\max} \le 0$

Constraints about the required area of each compartment

$g_3 = a_k^{\min} - a_k \le 0$ $g_4 = a_k - a_k^{\max} \le 0$

Constraints about the total area of all compartments

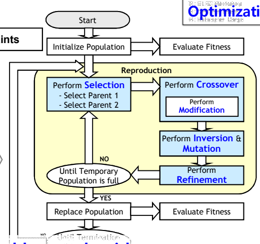
$g_5 = \sum_{k=1}^{M} a_k - A_{allowable} \le 0$

Mathematical formulation

Constraints about the position of each compartment

$g_6 = (x_k^t - x_i^{s,w})(x_i^{s,w} - x_k^t) \le 0$

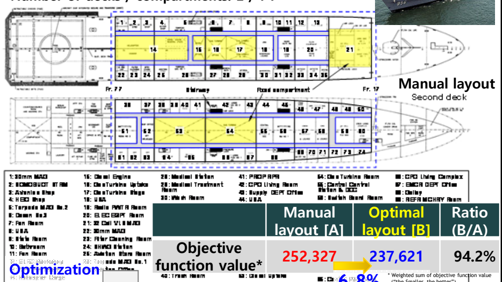
*for* $i, j, k = 1, \cdots, M$ and $s = 1, \cdots, P$




Optimal layout algorithm based on the genetic algorithm

### Application to an actual problem

- US Navy FF-21 multi-mission frigate
- Number of decks / compartments: 2 / 74




| | Manual layout [A] | Optimal layout [B] | Ratio (B/A) |
|---|---|---|---|
| Objective function value* | 252,327 | 237,621 | 94.2% |

* Weighted sum of objective function value (*the smaller, the better*)

6.8% improvement


* K.Y. Lee, S.N. Han, M.I. Roh, "Optimal Compartment Layout Design for a Naval Ship Using an Improved Genetic Algorithm", Marine Technology and SNAME News(SCIE/IF:0.419), Vol. 39, No. 3, pp.159-169, 2002
* K.Y. Lee, S.N. Han, M.I. Roh, "An Improved Genetic Algorithm for Facility Layout Problems Having Inner Structure Walls and Passages", Computers & Operation Research(SCIE/IF:1.984), Vol. 30, No. 1, pp. 117-138, 2003
* K.Y. Lee, M.I. Roh, H.S. Jeong, "An Improved Genetic Algorithm for Multi-Floor Facility Layout Problems Having Inner Structure Walls and Passages", Computers & Operations Research(SCIE/IF:1.984), Vol. 32, No. 4, pp.879-899, 2005

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# Optimal Layout Design for Offshore Plant
## - Optimal Layout Design of Topsides Modules

### Problem definition

- **Objective**
  - **Minimization of total flow volume and the distance between the center of gravity of total modules and the centerline of topsides**
- **Input("Given")**
  - Number, size, and weight of each module
  - Information on closeness factor among modules
- **Output("Find")**
  - **Optimal layout of modules on topsides**
- **Constraints**
  - Position constraints for some modules

### Proposal of an optimal layout algorithm

*Find* $(x_i, y_i)$ Position of each module — **Design Variables**

*Minimize* $F_1 = \sum_{i=1}^{M-1} \sum_{j=i+1}^{M} \left(q_{i,j} \times d_{i,j}\right)$ *and* — **Objective Functions**

Total flow volume

*Minimize* $F_2 = \left| \sum_{i=1}^{M} \left(w_i \times y_i\right) \Big/ \sum_{i=1}^{M} w_i \right|$ Weight balance requirements

*Subject to* — **Constraints**

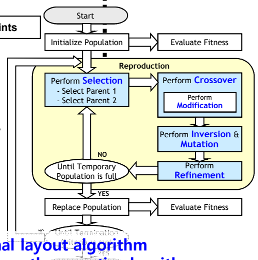
Constraints about the x-position of each module

$g_1 = X_i - \varepsilon - x_i \le 0 \qquad g_2 = x_i - X_i - \varepsilon \le 0$

Constraints about the y-position of each module

$g_3 = Y_i - \varepsilon - y_i \le 0 \qquad g_4 = y_i - Y_i - \varepsilon \le 0$

**Mathematical formulation**



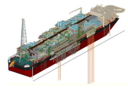

**Optimal layout algorithm based on the genetic algorithm**

### Application to an example

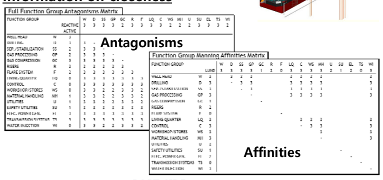
- **Number of modules: 12**

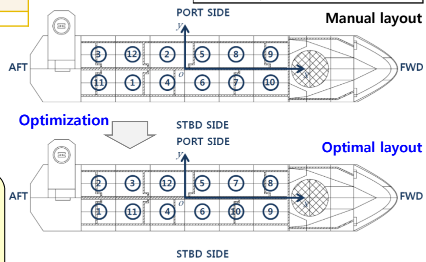
**Information on modules**

| ID | Name |
|---|---|
| 1 | Electrical BLD'G |
| 2 | Power generation |
| 3 | Water injection |
| 4 | Utilities area |
| 5 | Separation Train1 |
| 6 | Separation Train2 |
| 7 | Injection comp. |
| 8 | I/M metering |
| 9 | SDV platform |
| 10 | Recompressor |
| 11 | M/F dep. tower |
| 12 | Laydown area |



**Information on closeness**



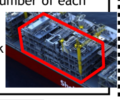

| | Manual layout [A] | Optimal layout [B] | Ratio (B/A) |
|---|---|---|---|
| Total flow volume | 463,010 | 393,050 | -15.1% |
| Transverse center of gravity | 2.7814m | 0.4395m | -84.2% |



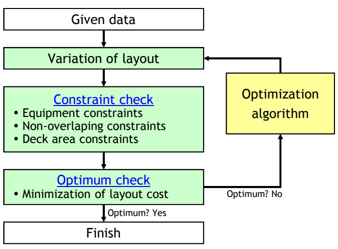
# Optimal Layout Design for Offshore Plant
## - Optimal Layout Design of Equipment in the Module

### Problem definition

- **Objective**
  - **Minimization of the layout cost(connectivity cost+construction cost) of liquefaction system**
- **Input("Given")**
  - Size of each equipment
  - Information of the connection among equipments
  - Number of decks
  - Clearance related with safety and maintenance
- **Output("Find")**
  - **Optimal layout of liquefaction system** (coordinate, orientation, and deck number of each equipment)
- **Constraints**
  - Equipment constraints for multi-deck
  - Non-overlapping constraints
  - Deck area constraints

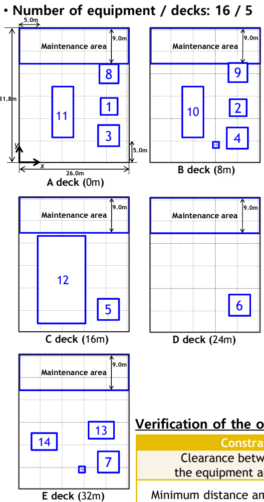


### Proposal of an optimal layout algorithm




### Application to an example

- **Number of equipment / decks: 16 / 5**




**Information on equipment**

| No. | Name | Dimension of the equipment | | |
|---|---|---|---|---|
| | | Length | Breadth | Height |
| 1, 2 | MR Separator | 4m | 4m | 13m |
| 3,4,5,6,7 | MCHE | 5m | 5m | 43m |
| 8, 9 | MR Comp. Suction Drum | 4.5m | 4.5m | 13m |
| 10 | MR Comp. | 5m | 12m | 6m |
| 11 | Cooler for MR Comp. | 5m | 12m | 6m |
| 12 | Overhead Crane | 12m | 19m | 6m |
| 13 | SW Cooler 5 | 4m | 6m | 5m |
| 14 | SW Cooler 4 | 4m | 6m | 5m |
| 15 | Valve 4 | 1m | 1m | 1m |
| 16 | Valve 5 | 1m | 1m | 1m |

**Optimal layout**

*Now, **total cost, weight, and layout of liquefaction system** can be estimated or determined.*

**Verification of the optimization result**

| Constraints | | Required | Result |
|---|---|---|---|
| Clearance between side of the equipment and deck side | | 3m | Satisfied (More than 3m) |
| Minimum distance among equipments | | 4m | Satisfied (More than 4m) |
| Working space area | A deck | 50% | Satisfied(57 %) |
| | B deck (Compressor) | 50% | Satisfied(57 %) |
| Emergency area | E deck | 60% | Satisfied(62 %) |

* J.H. Hwang, **M.I. Roh**, N.K. Ku, K.Y. Lee, "Optimal Module Layout for a Generic Offshore LNG Liquefaction Process of LNG FPSO", submitted to Ocen Engineering(SCI/IF:1.190), 2012

# 10.2 Determination of Optimal Bulkhead Layout of Naval Surface Ship



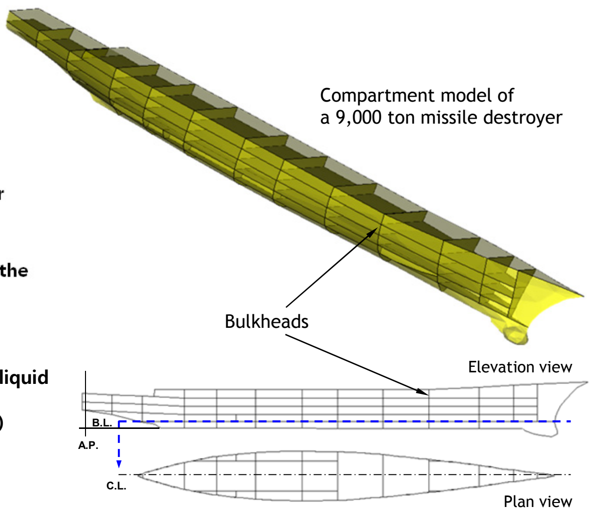
## Optimal Compartment Layout Design of a Naval Ship

☑ **Design variables (Output)**
- **Positions of transverse bulkheads**

☑ **Objective function**
- **Maximization of space for weapons and equipment (= Minimization of space for liquid cargos)**

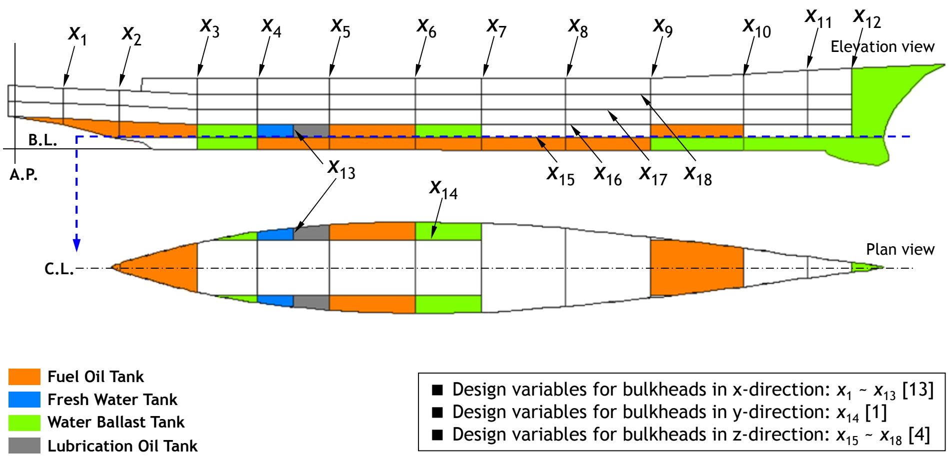
**and**
- **Maximization of stability at the damaged state**

☑ **Constraints**
- **Requirements for space for liquid cargos (fuel oil, fresh water, ballast water, lubrication oil)**
- **Requirements for damage stability condition by international regulations**
- **Requirements for the position (draft, trim, heel) at the damaged state**



## Design Variables of an Optimal Facility Layout Problem of a Naval Ship

General arrangement of a parent ship* and design variables




- Design variables for bulkheads in x-direction: $x_1$ ~ $x_{13}$ [13]
- Design variables for bulkheads in y-direction: $x_{14}$ [1]
- Design variables for bulkheads in z-direction: $x_{15}$ ~ $x_{18}$ [4]

* Missile destroyer of US Navy, "Arleigh Burke DDG-51"



## Mathematical Formulation of a Problem for Determining Optimal Compartment Layout of a Naval Ship

**Design Variables**

***Find*** $x_k \ (k=1,\ldots,18)$ Position of each bulkhead

**Objective Function**

***Minimize*** $F_1 = V_{FOT} + V_{FWT} + V_{WBT} + V_{LOT}$ ***and***

Sum of spaces for liquid cargos

***Maximize*** $F_2 = \sum_{i=1}^{Q} GM_i$ Sum of GM at the damaged state

**Constraints**

***Subject to***

Constraints about the required space of each liquid cargo

$V_{FOT}^{\min} \le V_{FOT} \le V_{FOT}^{\max}$ $V_{FWT}^{\min} \le V_{FWT} \le V_{FWT}^{\max}$

$V_{WBT}^{\min} \le V_{WBT} \le V_{WBT}^{\max}$ $V_{LOT}^{\min} \le V_{LOT} \le V_{LOT}^{\max}$

Constraints about the shear force and bending moment at the intact state

$SF_j \le SF_j^{\max}$ $BM_j \le BM_j^{\max}$

Constraints about the required damage stability condition

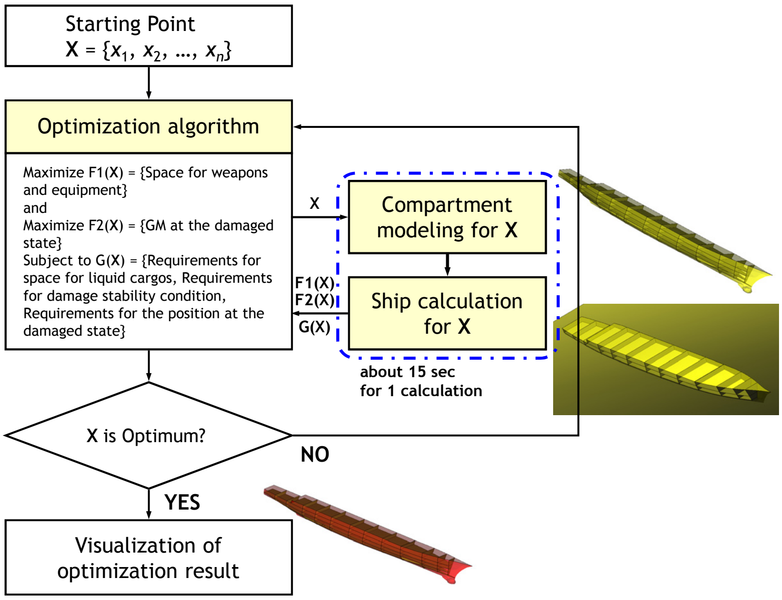
$\phi_{0,i} \le 15°$ $1.4 \le A_{2,i} / A_{1,i}$

Constraints about the required position at the damaged state

$T_i \le T_i^{\max}$ $t_i \le t_i^{\max}$ $\phi_i \le \phi_i^{\max}$

➡ **Optimization problem having 18 unknowns, 2 objective functions, and 11 inequality constraints**

## Process for Determining an Optimal Compartment Layout Design of a Naval Ship Using an Optimization Algorithm



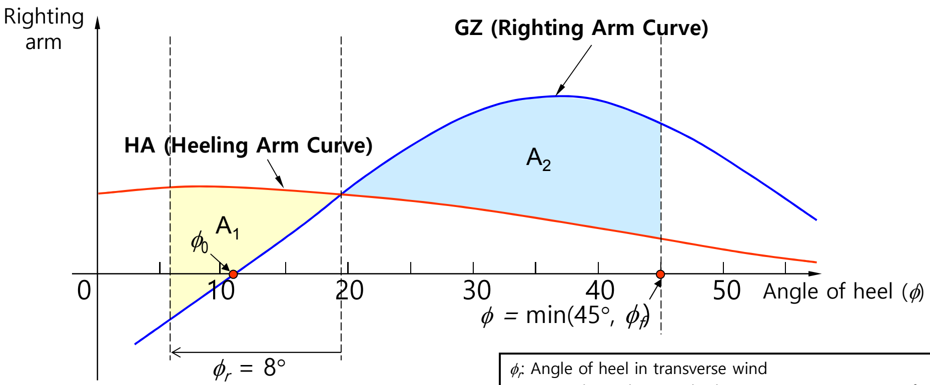

* F1(X), F2(X), G(X): Objective and constraints values for each design variables X



## Evaluation of the Required Damage Stability - Damage Stability Criteria in Battleship*

- **Regulation**

**$\phi_0$ (Initial Angle of Heel) $\le 15°$, $A_2 \ge 1.4 \cdot A_1$**




$\phi_r$: Angle of heel in transverse wind
(It varies depending on displacement, $\phi_r$ = 8° in case of battleship with displacement of 9,000 ton.)
$\phi_f$: An angle of heel at which openings in the hull submerge

* Surko, S.W., "An Assessment of Current Warship Damaged Stability Criteria", Naval Engineers Journal, 1994

## Optimization Result for the 9,000 ton Missile Destroyer - Comparison with a Parent Ship (1/2)

| Item | | Unit | Parent ship | | Optimization result | | Constraint |
|---|---|---|---|---|---|---|---|
| $V_{FOT}$ | | $m^3$ | 2,4466 | | 2,435 | | OK |
| $V_{FWT}$ | | $m^3$ | 87 | | 72 | | OK |
| $V_{WBT}$ | | $m^3$ | 896 | | 909 | | OK |
| $V_{LOT}$ | | $m^3$ | 100 | | 108 | | OK |
| Sum | | $m^3$ | 3,549 | | 3,523 | | - |
| $SF_1$ | $SF_2$ | $kN$ | 1,444 | 1,291 | 1,412 | 1,250 | OK |
| $BM_1$ | $BM_2$ | $kN{\cdot}m$ | 67,185 | 41,803 | 63,690 | 40,609 | OK |
| $\varphi_{0,1}$ | $\varphi_{0,2}$ | ° | 0.00 | 0.02 | 0.00 | 0.03 | OK |
| $A_{2,1}/A_{1,1}$ | $A_{2,2}/A_{1,2}$ | - | 40.50 | 40.49 | 40.62 | 40.80 | OK |
| $T_1$ | $T_2$ | $m$ | 6.85 | 6.81 | 6.87 | 6.82 | OK |
| $t_1$ | $t_2$ | $m$ | 1.35 | 1.51 | 1.33 | 1.44 | OK |
| $\varphi_1$ | $\varphi_2$ | $m$ | 0.00 | 0.04 | 0.00 | 0.05 | OK |

➡ Decrease of space for liquid cargos as compared with a parent ship
(= Increase of space for weapons and equipment)
& Increase of structural safety

* $V_{FOT}$, $V_{FWT}$, $V_{WBT}$, $V_{LOT}$: Total volume of fuel oil tank, fresh water tank, water ballast tank, and lubrication oil tank, respectively
* $BM_i$: Maximum bending moment at the $i$th loading condition
* $\phi_{0,j}$: Initial heel angle at the $j$th damage case
* $A_{1,j}$, $A_{2,j}$: Areas of the negative and the positive righting moment from a statistical stability curve and a heeling arm curve at the $j$th damage case
* $T_j$, $t_j$: Equivalent draft and trim at the $j$th damage case
* $\phi_j$: Equivalent heel angle considering beam wind at the $j$th damage case

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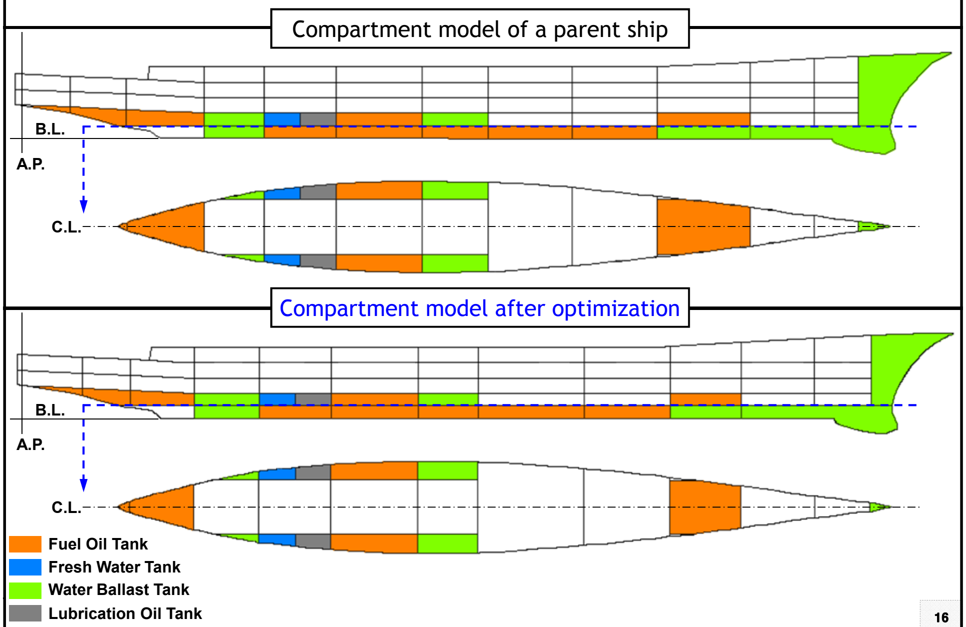
## Optimization Result for the 9,000 ton Missile Destroyer - Comparison with a Parent Ship (2/2)

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# 10.3 Determination of Optimal Compartment Layout of Naval Surface Ship



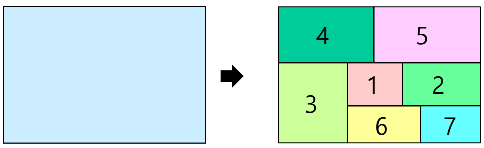
## Facility Layout Problem (FLP)

☑ Facility Layout Problem

- **Given**: Available area, the required area for each facility, material flow between facilities, etc.
- **Find**: Best facility layout which minimizes total cost of transporting materials between facilities
- Applications: Factory layout, equipment layout in the factory, office layout in the building, etc.

☑ Limitation of Existing Algorithms

- Limited to a rectangular boundary shape
- No consideration for inside side wall
- No consideration for passages between facilities



A given bounded area
Best layout of 7 facilities

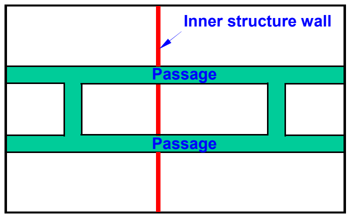
## Facility Layout Problem Having Inner Structure Walls and Passages

☑ **Given**

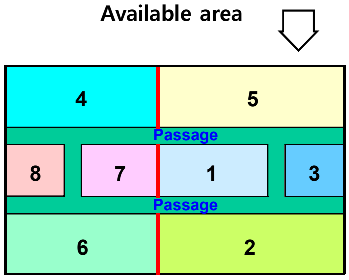
- Number of facilities to be allocated to the available area
- Available area and its boundary shape
- Number and positions of inner structure walls
- Number and widths of each vertical and horizontal passage
- Upper and lower bounds of the required area for each facility
- Upper and lower bounds of the required aspect ratio for each facility
- Material flows between facilities
- Upper and lower bounds of the position of each vertical and horizontal passage

☑ **Find**

- Best facility layout which minimizes total cost of transporting materials between facilities




Available area




Best layout plan of facilities (1-8)



## Formulation of the Optimal Facility Layout Problem Having Inner Structure Walls and Passages

*Minimize*

**Objective Function**

$$F = \sum_{i=1}^{M}\sum_{j=1}^{M} f_{ij} \times d_{ij}$$

Total cost of transporting materials

*Subject to*

**Constraints**

$$g_1 = \alpha_k^{\min} - \alpha_k \le 0$$
$$g_2 = \alpha_k - \alpha_k^{\max} \le 0$$

Constraints about the required aspect ratio of each compartment

$$g_3 = a_k^{\min} - a_k \le 0$$
$$g_4 = a_k - a_k^{\max} \le 0$$

Constraints about the required area of each compartment

$$g_5 = \sum_{k=1}^{M} a_k - A_{allowable} \le 0$$

Constraints about the total area of all compartments

$$g_6 = x_i^r - x_s^{i.s.w} \le 0$$
$$g_7 = x_s^{i.s.w} - x_j^l \le 0$$

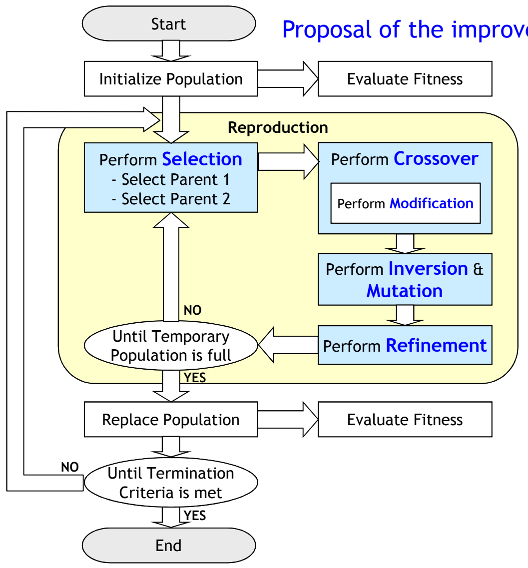
Constraints about the position of each compartment

$$for\ i, j, k = 1, \cdots, M\ \&\ s = 1, \cdots, P$$

$f_{ij}$: Material flow between the facility $i$ and $j$
$d_{ij}$: Distance between centroids of the facility $i$ and $j$

# Proposed Algorithm for the Facility Layout Problem Having Inner Structure Walls and Passages

Proposal of the improved genetic algorithm

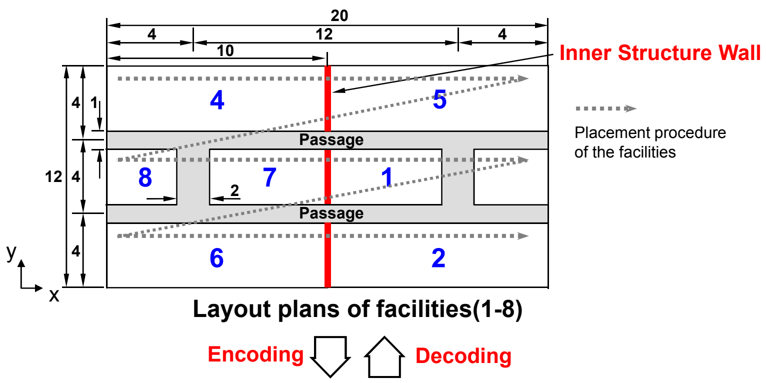



* 유전 알고리즘(Genetic Algorithm): 자연계에 있어서 생물의 유전과 진화의 메카니즘을 공학적으로 모델화하는 것에 의해 생물이 갖는 환경에서의 적응능력을 취급하는 것이고, 1975년에 John Holland 가 저서 "Adaptation on Natural and Artificial Systems"에 처음 소개한 자연 도태의 원리를 기초로 한 최적화 방법



# Representation of the Facility Layout

Four-segmented chromosome considering inner structure wall

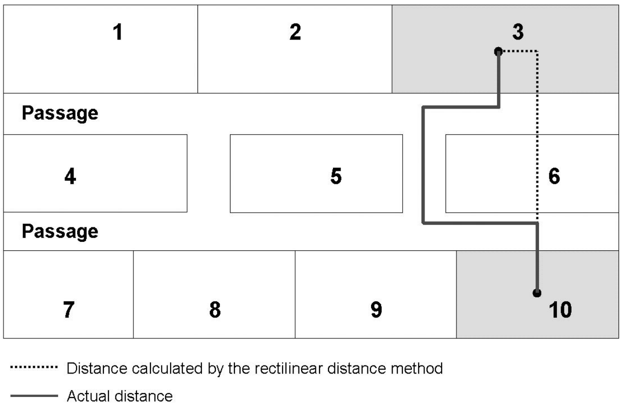



| Segment 1 | Segment 2 | Segment 3 | Segment 4 |
|---|---|---|---|
| 4, 5, 8, 7, 1, 3, 6, 2 | 35, 35, 9, 15, 15, 9, 35, 35 | 4, 4, 4 | 4,12, 4 |
| (facilities' sequence) | (Areas of the facilities) | (Location of passages) | |

Corresponding 4-segmented chromosome

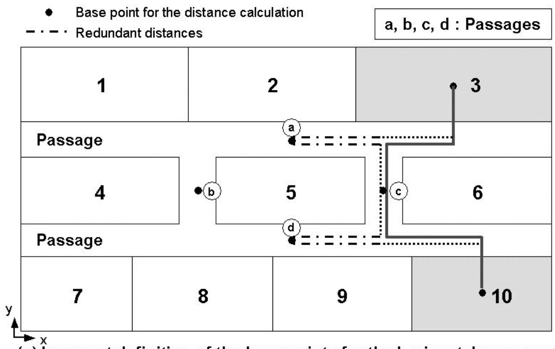
* 유전 알고리즘은 풀고자 하는 문제에 대한 가능한 해들을 정해진 형태의 자료 구조("염색체")로 표현한 다음, 이들을 점차적으로 변형함으로써 점점 더 좋은 해들을 생성하게 됨

## Distance Calculation Method between the Facilities
## - Distance Calculated by the Rectilinear Method and Actual Distance





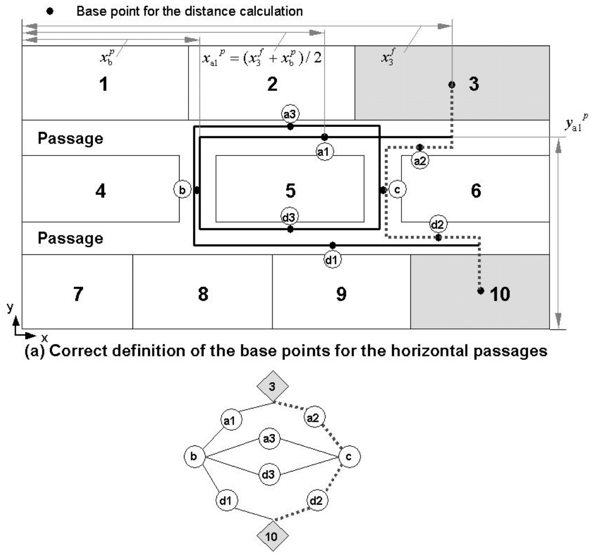

## Distance Calculation Method between the Facilities
## - Redundant Distances by Incorrect Definition of the Base Points




(a) Incorrect definition of the base points for the horizontal passages

(b) Original adjacency graph

## Distance Calculation Method between the Facilities
## - Correct Definition of the Base Points




(a) Correct definition of the base points for the horizontal passages

(b) Modified adjacency graph



## Improved Genetic Operations
## - Crossover Operation: Modified Crossover Operation (1/2)

- ☑ **The modified crossover is applied to the first and second segments of the parents.**
- ☑ **Initially s1 positions in the first and second segments of the first parent are randomly selected.**

$$s1 = \frac{\{Ft(p1) + Ft(p2)\} - Ft(p1)}{Ft(p1) + Ft(p2)} \times n \quad \text{(discard decimals)} \qquad s2 = n - s1$$

where, s1: the number of genes of the first parent to be replaced with those of the second parent,
s2: the number of genes of the first parent to be transmitted to the first child,
n: the number of the genes in the first or second segments

- ☑ **Next step is for the genes in the s2 positions of the first parent to be transmitted to the corresponding positions of the first child.**
- ☑ **Finally, the genes in the s1 positions are reordered according to the order of the corresponding genes in the second parent and then they are transmitted to the corresponding positions of the first child.**
- ☑ **These similar steps are applied to the second parent to also generate the first and second segments of the second child.**

## Improved Genetic Operations
## - Crossover Operation: Modified Crossover Operation (2/2)

| Segment 1 | Segment 2 | Segment 3 | Segment 4 |
|---|---|---|---|
| 4, 5, 8, 7, 1, **6**, **3**, **2** | 20, 30, 8, 9, 15, **9**, **24**, **28** | 4, 5, 3 | 4, 13, 3 |

**1st PARENT(fitness : 200) ➡ s1 = {6, 3, 2}, s2 = {4, 5, 8, 7, 1} for Segment 1**

| | | | |
|---|---|---|---|
| 7, **3**, 5, **6**, 8, **2**, 4, 1 | 20, **13**, 15, **12**, 25, **24**, 20, 30 | 3, 4, 5 | 5, 12, 3 |

**2nd PARENT(fitness : 120)**

| | | | |
|---|---|---|---|
| 4, 5, 8, 7, 1, **3**, **6**, **2** | 20, 30, 8, 9, 15, **13**, **12**, **24** | -, -, - | -, -, - |

**1st CHILD**

**(a) Modified crossover for the 1st CHILD**

| Segment 1 | Segment 2 | Segment 3 | Segment 4 |
|---|---|---|---|
| 4, **5**, 8, **7**, **1**, 6, **3**, **2** | 20, **30**, 8, **9**, **15**, 9, **24**, **28** | 4, 5, 3 | 4, 13, 3 |

**1st PARENT(fitness : 200)**

| | | | |
|---|---|---|---|
| **7**, **3**, **5**, 6, 8, **2**, 4, **1** | **20**, **13**, **15**, 12, 25, **24**, 20, **30** | 3, 4, 5 | 5, 12, 3 |

**2nd PARENT(fitness : 120) ➡ s1 = {7, 3, 5, 2, 1}, s2 = {6, 8, 4} for Segment 1**

| | | | |
|---|---|---|---|
| **5**, **7**, **1**, 6, 8, **3**, 4, **2** | **30**, **9**, **15**, 12, 25, **24**, 20, **28** | -, -, - | -, -, - |

**2nd CHILD**

**(b) Modified crossover for the 2nd CHILD**



## Improved Genetic Operations
## - Crossover Operation: One-Point Crossover Operation

- ☑ **The one-point crossover is applied to the third and fourth segments of the parents.**
- ☑ **A split line is randomly determined in these segments, and then genes behind the split line are exchanged between the parents.**

| Segment 1 | Segment 2 | Segment 3 | Segment 4 |
|---|---|---|---|
| 4, 5, 8, 7, 1, 6, 3, 2 | 20, 30, 8, 9, 15, 9, 24, 28 | 4, **5**, **3** | 4, **13**, **3** |

**1st PARENT**

| | | | |
|---|---|---|---|
| 7, 3, 5, 6, 8, 2, 4, 1 | 20, 13, 15, 12, 25, 24, 20, 30 | 3, **4**, **5** | 5, **12**, **3** |

**2nd PARENT**

Split Line

| | | | |
|---|---|---|---|
| -, -, -, -, -, -, -, - | -, -, -, -, -, -, -, - | 4, **4**, **5** | 4, **12**, **3** |

**1st CHILD**

| | | | |
|---|---|---|---|
| -, -, -, -, -, -, -, - | -, -, -, -, -, -, -, - | 3, **5**, **3** | 5, **13**, **3** |

**2nd CHILD**

## Improved Genetic Operations - Inversion Operation

- ☑ The inversion operation, which can be considered as self-crossing, is used to increase population diversity together with the mutation operation.
- ☑ The inversion operation is simultaneously applied to the first and second segments of the first child generated from the crossover operation.
- ☑ The inversion operation occurs with very low probability (typically $p_{inversion} = 0.01$ from Grefenstette's study).
- ☑ In the inversion operation, two genes in the first and second segments of the first child are randomly selected and are exchanged with each other.

| Segment 1 | Segment 2 | Segment 3 | Segment 4 |
|---|---|---|---|
| 4, 5, 8, **7**, 1, **3**, 6, 2 | 20, 30, 8, **9**, 15, **13**, 12, 24 | 4, 4, 4 | 4, 12, 4 |

1st CHILD – Before Inversion

| Segment 1 | Segment 2 | Segment 3 | Segment 4 |
|---|---|---|---|
| 4, 5, 8, **3**, 1, **7**, 6, 2 | 20, 30, 8, **13**, 15, **9**, 12, 24 | 4, 4, 4 | 4, 12, 4 |

1st CHILD – After Inversion



## Improved Genetic Operations - Mutation Operation

- ☑ The mutation operation is applied to the second segment of the second child generated from the crossover operation and occurs with very low probability (typically $p_{mutation} = 0.01$ from Grefenstette's study).
- ☑ In this operation, two genes in the second segment of the second child are randomly selected and a difference value is also randomly determined.
- ☑ The difference value is then added to the first gene and at the same time, subtracted from the second gene.

| Segment 1 | Segment 2 | Segment 3 | Segment 4 |
|---|---|---|---|
| 5, 7, 1, 6, 8, 3, 4, 2 | 30, 9, 15, **12**, 25, **24**, 20, 28 | 3, 4, 5 | 5, 13, 2 |

2nd CHILD – Before Mutation

Difference Value = 3

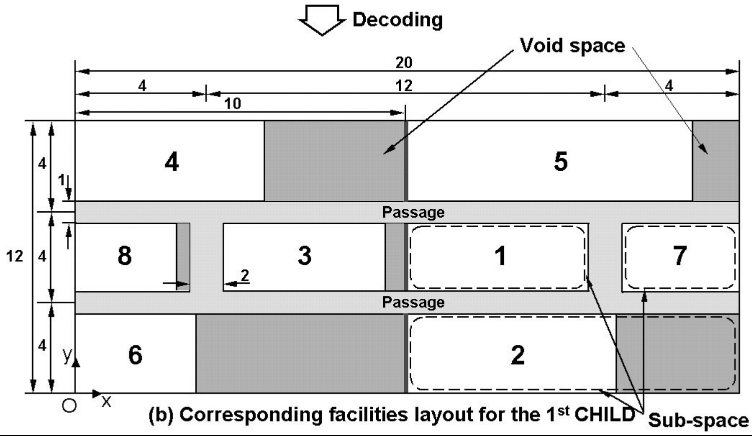
| Segment 1 | Segment 2 | Segment 3 | Segment 4 |
|---|---|---|---|
| 5, 7, 1, 6, 8, 3, 4, 2 | 30, 9, 15, **15**, 25, **21**, 20, 28 | 3, 4, 5 | 5, 13, 2 |

2nd CHILD – After Mutation

## Improved Genetic Operations
## - Representation of Facilities Layout by Decoding Process

| Segment 1 | Segment 2 | Segment 3 | Segment 4 |
|---|---|---|---|
| 4, 5, 8, 3, 1, 7, 6, 2 | 20, 30, 8, 13, 15, 9, 12, 24 | 4, 4, 4 | 4,12, 4 |
| (sequence of the facilities) | (Areas of the facilities) | (Location of passages) | |

(a) Four-segmented chromosome for the 1st CHILD

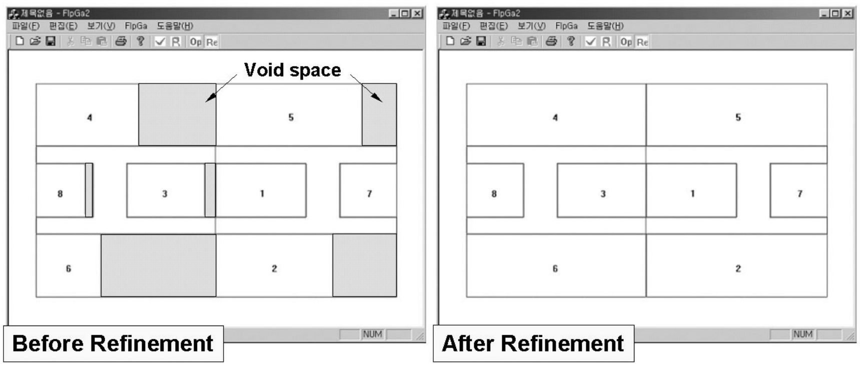



(b) Corresponding facilities layout for the 1st CHILD



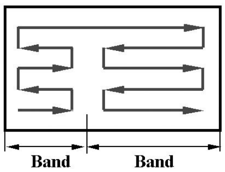
## Improved Genetic Operations
## - Refinement Operation

- ☑ Void spaces are generated while converting a chromosome into a facility layout during the decoding process.
- ☑ The refinement operation is performed to eliminate the void spaces and for efficient utilization of the available area.



## Comparison with Existing Algorithm
## - Islier's Algorithm

"xy-oscillatory"




(a) Placement procedure

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 4 | 4 | 4 | 4 | 4 | 4 | 4 | 7 | 7 | 7 |
| 4 | 4 | 4 | 4 | 4 | 4 | 4 | 7 | 7 | 7 |
| 4 | 4 | 4 | 4 | 4 | 4 | 4 | 7 | 7 | 7 |
| 4 | 4 | 4 | 4 | 3 | 3 | 3 | 7 | 7 | 7 |
| 2 | 2 | 2 | 2 | 3 | 3 | 3 | 7 | 7 | 7 |
| 2 | 2 | 2 | 2 | 3 | 3 | 3 | 7 | 6 | 6 |
| 1 | 1 | 2 | 2 | 5 | 5 | 5 | 6 | 6 | 6 |
| 1 | 1 | 1 | 1 | 5 | 5 | 5 | 6 | 6 | 6 |
| 1 | 1 | 1 | 1 | 5 | 5 | 5 | 6 | 6 | 6 |

(b) Layout plan by xy-oscillatory

Decoding Encoding

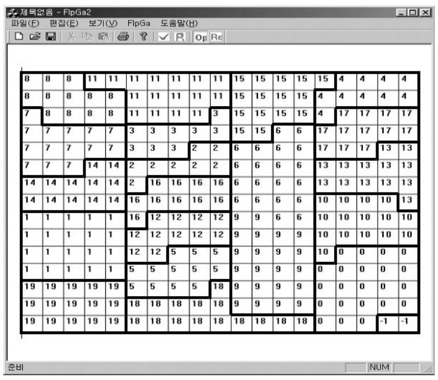
| | | |
|---|---|---|
| 1, 2, 4, 3, 5, 6, 7 | 10, 10, 25, 9, 9, 11, 16 | 4, 3, 3 |
| (Sequence of the facilities) | (Areas of the facilities) | (Band widths) |

(c) Corresponding 3-segmented Chromosome representation



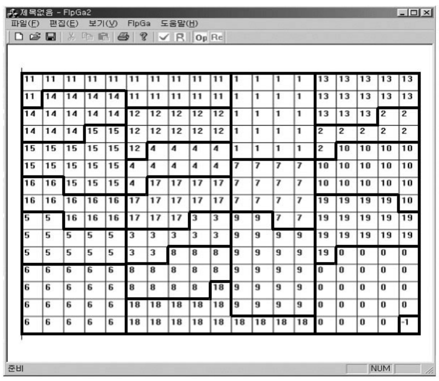
## Comparison with Existing Algorithm
## - Result

**Islier's Algorithm**



Objective Function Value = 37.698
Computation Time = 5.5 min

**Proposed Algorithm**



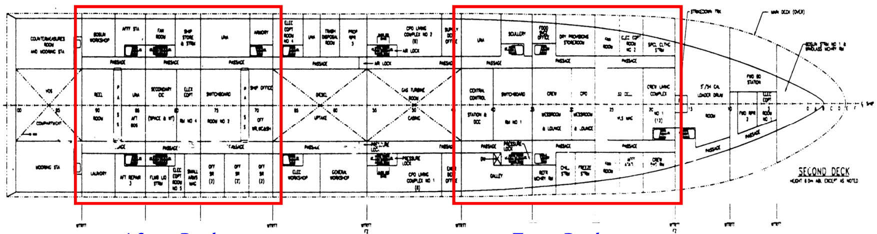
Objective Function Value = 37.198
Computation Time = 4 min

**Final layouts of 20 facilities**

# Optimal Facility Layout Problem of a Naval Ship

- ☑ After body (Fr. no. 68~92)
  - Rectangular boundary shape
  - 20 compartments, 2 watertight transverse bulkheads, 2 vertical passages, 2 horizontal passages
- ☑ Fore body (Fr. no. 17~44)
  - Curved boundary shape
  - 20 compartments, 2 watertight transverse bulkheads, 1 vertical passage, 2 horizontal passages

2nd Deck of the FF-21




After Body
(Fr. no. 68~92)

Fore Body
(Fr. no. 17~44)

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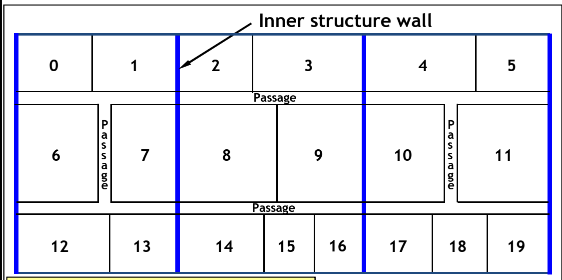
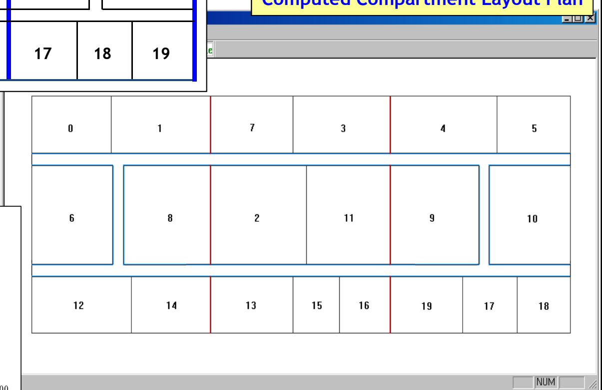
# Optimal Facility Layout Problem of a Naval Ship - Optimization Result of the After Body

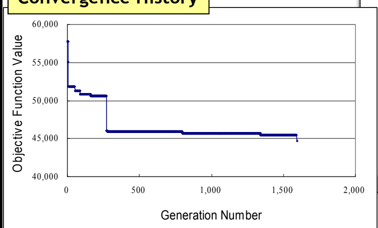



Actual Compartment Layout Plan

Computed Compartment Layout Plan




Convergence History

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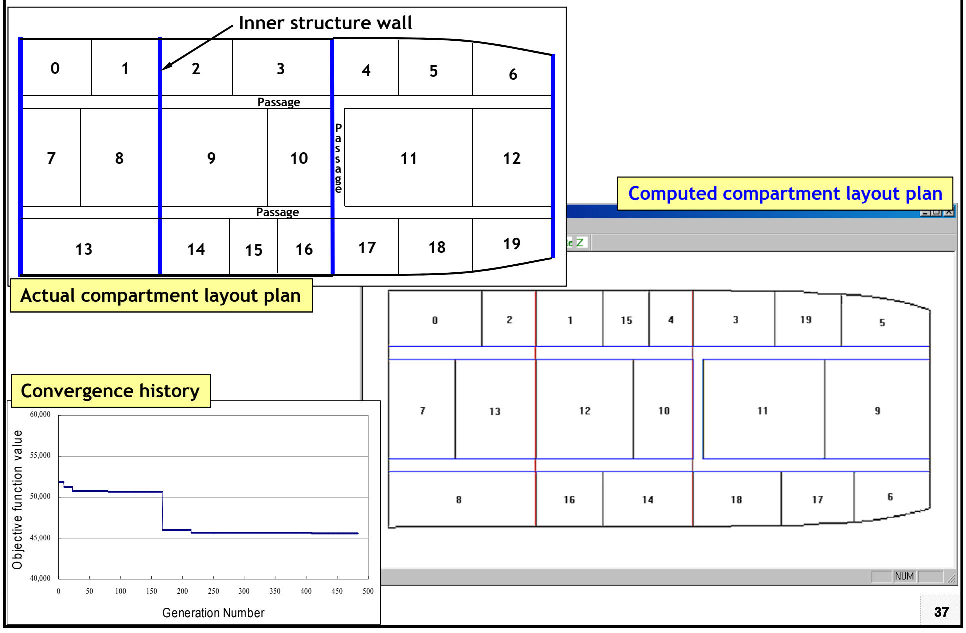
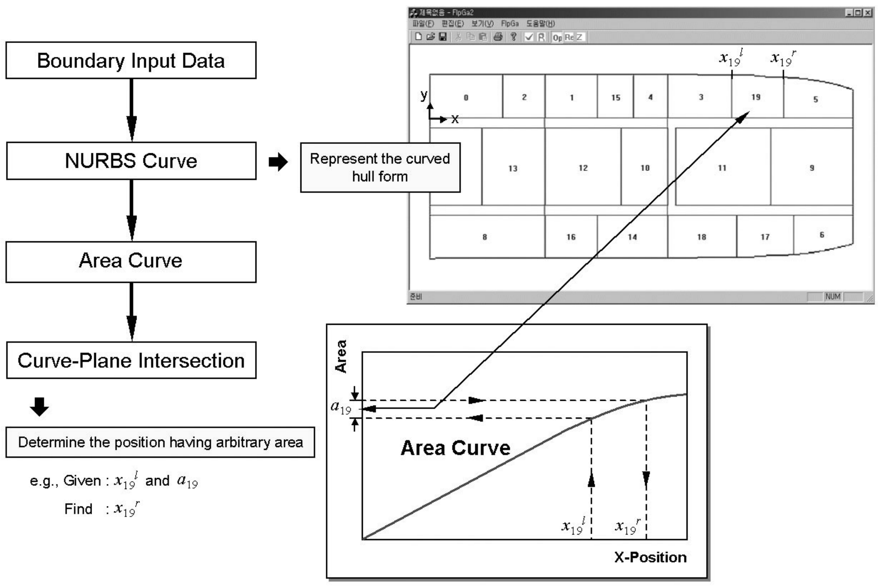
## Optimal Facility Layout Problem of a Naval Ship - Optimization Result of the Fore Body






## Calculation of the Right Boundary for the Compartment with Arbitrary Area

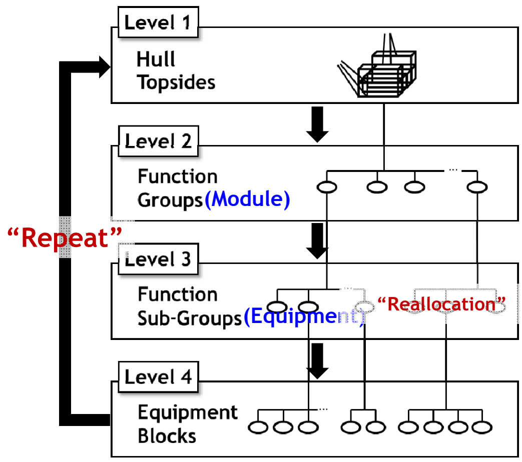


# 10.4 Determination of Optimal Layout of Topsides of Offshore Plant



## Existing Method for Topsides Layout (1/2)

**Hierarchical Approach (Top-Down Approach)**

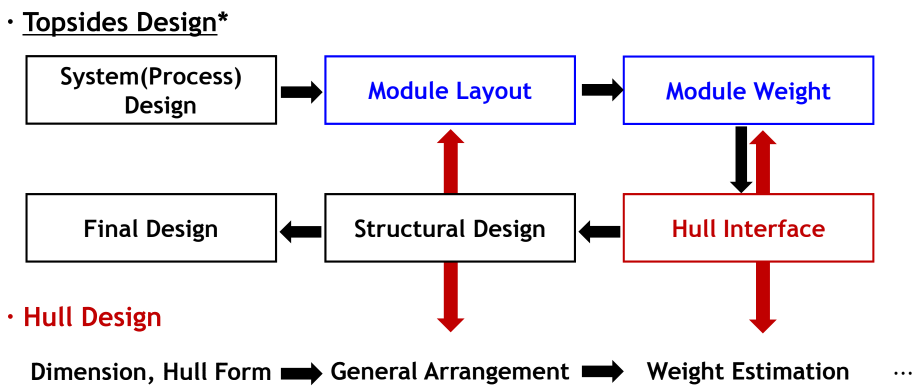



Considerations for layout
- Antagonisms
- Affinities
  - Engineering affinities
  - Manning affinities

Example of Modules of Guara FPSO(Modec/Toyo's) fabricated by Aibel

* Reference: PETRONAS, "Layout Considerations for Offshore Topsides Facilities", 1990

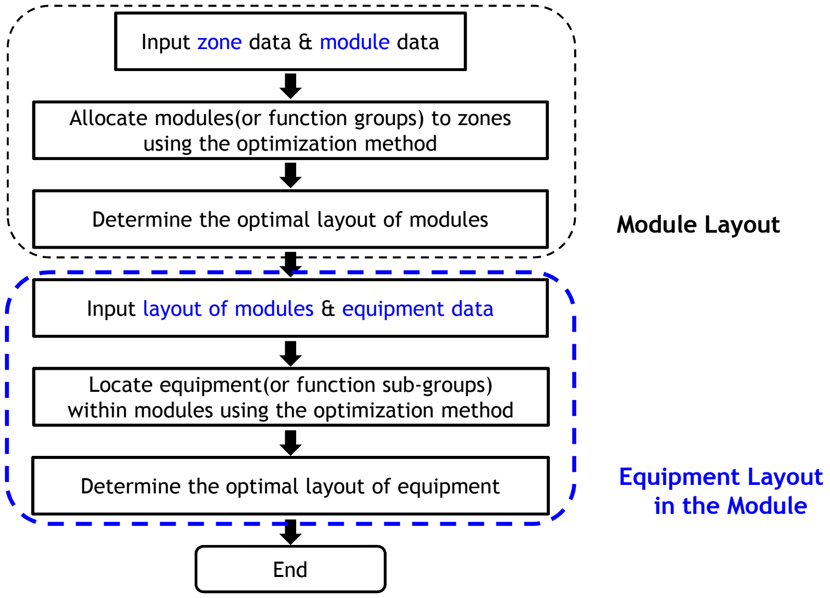
## Existing Method for Topsides Layout (2/2)




* Terpstra, T., et al, "FPSO Design and Conversion: A Designer's Approach", Offshore Technology Conference, 30 April-3 May 2001, Houston, Texas



## Optimal Layout of Topsides Using Optimization Technique

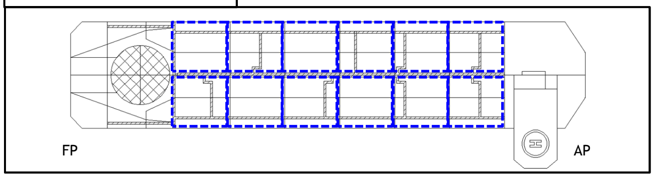


# Optimal Module Layout of Topsides of Offshore Plant



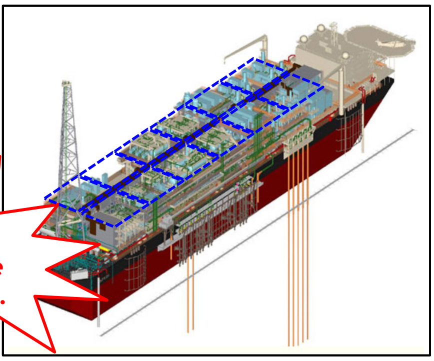
## Necessity of Optimal Module Layout

**Plan view of the FPSO***



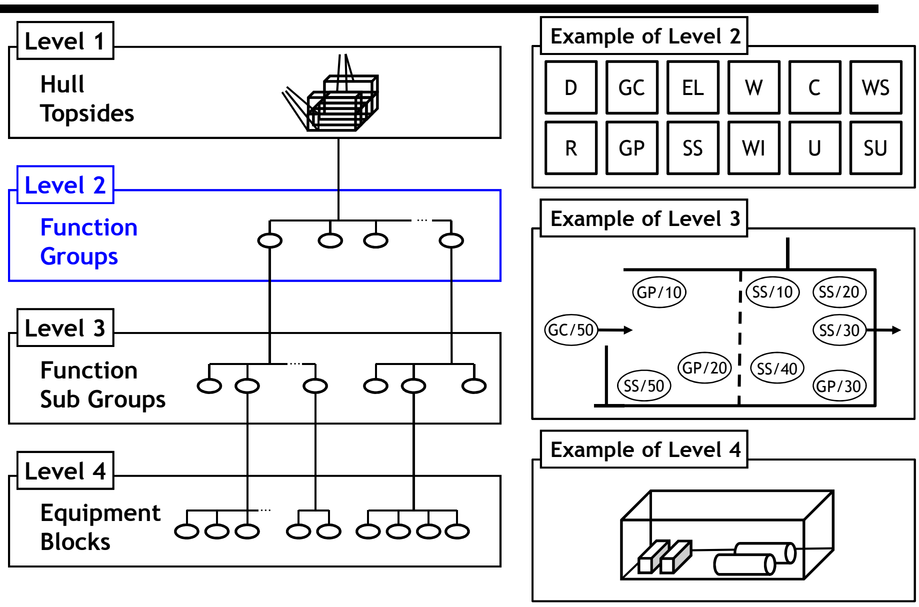

| No of modules | No of design alternatives |
|---|---|
| 8 | 40,320 |
| 10 | 3,628,800 |
| 12 | 479,001,600 |
| 14 | $8.72 \times 10^{10}$ |
| 16 | $2.09 \times 10^{13}$ |
| 18 | $6.40 \times 10^{15}$ |
| … | ⋮ |

Too many cases to be considered.



* **Reference:** (Article) MBN, 2007.12, The DSME receives an order of FPSO of 2 billion.

## Hierarchical Approach of Module Layout of Topsides of Offshore Plant




* Reference: PETRONAS, "Layout Considerations for Offshore Topsides Facilities", 1990



## Example of Topsides Modules (Function Groups, Function Sub Groups)

| Wellhead | W |
|---|---|
| Xmas Trees | W/10 |
| Manifold | W/20 |
| Well Control | W/30 |
| Conductors | W/40 |

| Drilling | D |
|---|---|
| BOP | D/10 |
| Drilling Derrick | D/20 |
| Drilling Support | D/30 |
| Mud Systems (Active) | D/40 |
| Drilling Control | D/50 |

| Separation/Stabilization | SS |
|---|---|
| Separation | SS/10 |
| Stabilization | SS/20 |
| Test Separation | SS/30 |
| Produced Water Treatment | SS/40 |
| Oil Export Pumping | SS/50 |
| Oil Metering | SS/60 |

| Gas Processing | GP |
|---|---|
| Gas Processing | GP/10 |
| Condensate Processing | GP/20 |
| Dehydration | GP/30 |
| Fuel Gas | GP/40 |

| Gas Compressing | GC |
|---|---|
| Compression Train | GC/10 |
| Scrubber | GC/20 |
| Coolers | GC/30 |
| Lube Oil/Seal Oil | GC/40 |
| Gas Metering | GC/50 |

| Risers | R |
|---|---|
| Risers/Manifolds | R/10 |
| ESD Valves | R/20 |
| Pigging Facilities | R/30 |
| Subsea Sat. Facilities | R/40 |

| Flare System | F |
|---|---|
| Flare Knockout | F/10 |
| Tower (incl. tip) | F/20 |

| Living Quarter | LQ |
|---|---|
| Living Quarters | LQ/10 |
| Living Quarters Utilities | LQ/20 |
| Sheltered Area | LQ/30 |
| Helideck | LQ/40 |

| Control | C |
|---|---|
| Central Control | C/10 |
| Local Control | C/20 |

| Workshop/Stores | WS |
|---|---|
| Workshop - Mechanical | WS/10 |
| Workshop - Electrical | WS/20 |
| Stores | WS/30 |
| Laboratory | WS/40 |
| Storage - Standby Fuel | WS/50 |
| Storage - Jet Fuel | WS/60 |
| Storage - Flamm./Comb. Liquids | WS/70 |
| Storage - Process Consumables | WS/80 |

| Material Handling | MH |
|---|---|
| Cranes | MH/10 |
| Laydown Areas | MH/20 |

| Utilities | U |
|---|---|
| Seawater System | U/10 |
| Instrument Air System | U/20 |
| Diesel System | U/30 |
| HVAC | U/40 |
| Potable Water | U/50 |
| Sewage Systems | U/60 |
| Heating Systems | U/70 |
| Cooling Systems | U/80 |

| Safety Utilities | SU |
|---|---|
| Fire Water Pumps | SU/10 |
| Emergency Generator | SU/20 |
| Emergency Switchgear | SU/30 |
| UPS | SU/40 |
| Survival Craft | SU/50 |
| Bridges | SU/60 |

| Electrical Power Generation | EL |
|---|---|
| Driver / Power Generator | EL/10 |
| Switchgear | EL/20 |

| Transmission Systems | TS |
|---|---|
| Relief and Blowdown | TS/10 |
| Drains - Open | TS/20 |
| Drains - Closed | TS/30 |
| Piping - Process | TS/40 |
| Piping - Safety | TS/50 |
| Piping - Utilities. | TS/60 |
| Cables - Instrumentation | TS/70 |
| Cables - Electrical | TS/80 |
| Ducting - HVAC | TS/90 |

| Water Injection | WI |
|---|---|
| Injection | WI/10 |
| Treatment | WI/20 |

* Reference: PETRONAS, "Layout Considerations for Offshore Topsides Facilities", 1990

## Characteristics for the Representation of Relationship between Topsides Modules

☑ **Antagonisms**: Characteristics which preclude an module being safely located near another specific module unless mutually protected (e.g., "two modules should be distant from each other.")

☑ **Affinities**: Characteristics which make it particularly advantageous to locate one module close to another specific module (e.g., "two modules should be adjacent to each other.")



## Relationship between Topside Modules - Antagonisms

☑ Characteristics for defining antagonisms

- Active behavior characteristics: Probability of a module initiating major incidents
- Reactive behavior characteristics: Propensity for a module to escalate major incidents initiated elsewhere.

Antagonisms Matrix

| FUNCTION GROUP | | | W | D | SS | GP | GC | R | F | LQ | C | WS | MH | U | SU | EL | TS | WI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | REACTIVE | 3 | 3 | 3 | 3 | 2 | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 3 | 3 | 3 | 2 |
| | | ACTIVE | | | | | | | | | | | | | | | | |
| WELL HEAD | W | 3 | - | | | | | | | | | | | | | | | |
| DRILLING | D | 3 | 3 | - | | | | | | | | | | | | | | |
| SEP./STABILIZATION | SS | 2 | 3 | 3 | - | | | | | | | | | | | | | |
| GAS PROCESSING | GP | 2 | 3 | 3 | 3 | - | | | | | | | | | | | | |
| GAS COMPRESSION | GC | 3 | 3 | 3 | 3 | 3 | - | | | | | | | | | | | |
| RISERS | R | 3 | 3 | 3 | 3 | 3 | 3 | - | | | | | | | | | | |
| FLARE SYSTEM | F | 2 | 3 | 3 | 3 | 3 | 3 | 3 | - | | | | | | | | | |
| LIVING QUARTER | LQ | 0 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | - | | | | | | | | |
| CONTROL | C | 0 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 1 | - | | | | | | | |
| WORKSHOP/STORES | WS | 0 | 3 | 3 | 2 | 2 | 3 | 3 | 2 | 1 | 1 | - | | | | | | |
| MATERIAL HANDLING | MH | 1 | 3 | 3 | 2 | 2 | 3 | 3 | 2 | 2 | 2 | 1 | - | | | | | |
| UTILITIES | U | 1 | 3 | 3 | 2 | 2 | 3 | 3 | 2 | 2 | 2 | 1 | 1 | - | | | | |
| SAFETY UTILITIES | SU | 1 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 1 | 2 | 2 | - | | | |
| ELEC. POWER GEN. | EL | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 3 | - | | |
| TRANSMISSION SYSTEMS | TS | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 3 | 3 | - | |
| WATER INJECTION | WI | 0 | 3 | 3 | 2 | 2 | 3 | 3 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | - |

**Each number (1~3)** represents a quantitative value of the risk when two modules are located in adjacent zones close. **The higher number, the more risk layout.**

* References
- PETRONAS, "Layout Considerations for Offshore Topsides Facilities", 1990
- Quantitative Risk Assessment, SIPM Report EP 55000-18, May 1990
- Guidelines for Risk Analysis Data, Doc. Ref F-RADS, SIPM, June 1990

# Relationship between Topside Modules
# - Affinities

☑ Characteristics for defining affinities

- Engineering affinities: The need to locate certain modules close together, the most fundamental being the requirements of the process logic
- Manning affinities: Ways to minimize the movement of staff around the platform

Manning Affinities Matrix

| FUNCTION GROUP | | | W | D | SS | GP | GC | R | F | LQ | C | WS | MH | U | SU | EL | TS | WI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | LUND | 3 | 3 | 3 | 3 | 1 | 2 | 0 | 3 | 3 | 3 | 3 | 2 | 1 | 2 | 0 | 3 |
| WELL HEAD | W | 3 | - | 3 | 3 | 3 | | | | 3 | 3 | 3 | 3 | | | | | 3 |
| DRILLING | D | 3 | | - | 3 | 3 | | | | 3 | 3 | 3 | 3 | | | | | 3 |
| SEP./STABILIZATION | SS | 3 | | | - | 3 | | | | 3 | 3 | 3 | 3 | | | | | 3 |
| GAS PROCESSING | GP | 3 | | | | - | | | | 3 | 3 | 3 | 3 | | | | | 3 |
| GAS COMPRESSION | GC | 1 | | | | | - | | | | | | | | | | | |
| RISERS | R | 2 | | | | | | - | | | | | | | | | | |
| FLARE SYSTEM | F | 0 | | | | | | | - | | | | | | | | | |
| LIVING QUARTER | LQ | 3 | | | | | | | | - | 3 | 3 | 3 | | | | | 3 |
| CONTROL | C | 3 | | | | | | | | | - | 3 | 3 | | | | | 3 |
| WORKSHOP/STORES | WS | 3 | | | | | | | | | | - | 3 | | | | | 3 |
| MATERIAL HANDLING | MH | 3 | | | | | | | | | | | - | | | | | 3 |
| UTILITIES | U | 2 | | | | | | | | | | | | | | | | |
| SAFETY UTILITIES | SU | 1 | | | | | | | | | | | | | | | | |
| ELEC. POWER GEN. | EL | 2 | | | | | | | | | | | | | | | | |
| TRANSMISSION SYSTEMS | TS | 0 | | | | | | | | | | | | | | | | |
| WATER INJECTION | WI | 3 | | | | | | | | | | | | | | | | |

Each number (1~3) represents a quantitative value of the advantage when two modules have frequent movement of staff each other in the aspect of manning affinities.

* Reference: PETRONAS, "Layout Considerations for Offshore Topsides Facilities", 1990



# Relationship between Topside Modules
# - Definition of Adjacency Factor between Modules

**Adjacency Factor between Modules** $Q = \begin{bmatrix} q_{11} & & \\ & \ddots & \\ & & q_{NN} \end{bmatrix}$

(= Affinities - Antagonisms)

Adjacency Factor Matrix

| FUNCTION GROUP | | W | D | SS | GP | GC | R | F | LQ | C | WS | MH | U | SU | EL | TS | WI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WELL HEAD | W | - | 6 | 6 | 3 | 2 | 0 | 0 | 3 | 3 | 3 | 3 | 0 | 0 | 6 | 6 | 2 |
| DRILLING | D | | - | 3 | 3 | 2 | 0 | 0 | 3 | 3 | 3 | 3 | 0 | 1 | 1 | 3 | 2 |
| SEP./STABILIZATION | SS | | | - | 3 | 3 | 0 | 0 | 3 | 3 | 3 | 3 | 0 | 5 | 5 | 6 | 2 |
| GAS PROCESSING | GP | | | | - | 3 | 5 | 5 | 5 | 5 | 6 | 6 | 0 | 0 | 1 | 1 | 0 |
| GAS COMPRESSION | GC | | | | | - | 1 | 1 | 1 | 1 | 5 | 5 | 4 | 4 | 3 | 3 | 0 |
| RISERS | R | | | | | | - | 2 | 2 | 2 | 2 | 6 | 6 | 3 | 3 | 0 | 0 |
| FLARE SYSTEM | F | | | | | | | - | 5 | 5 | 4 | 4 | 4 | 4 | 3 | 3 | 3 |
| LIVING QUARTER | LQ | | | | | | | | - | 3 | 3 | 0 | 0 | 3 | 3 | 3 | 3 |
| CONTROL | C | | | | | | | | | - | 5 | 5 | 5 | 3 | 3 | 3 | 3 |
| WORKSHOP/STORES | WS | | | | | | | | | | - | 3 | 3 | 6 | 6 | 6 | 6 |
| MATERIAL HANDLING | MH | | | | | | | | | | | - | 5 | 5 | 5 | 6 | 6 |
| UTILITIES | U | | | | | | | | | | | | - | 0 | 0 | 5 | 5 |
| SAFETY UTILITIES | SU | | | | | | | | | | | | | - | 5 | 5 | 5 |
| ELEC. POWER GEN. | EL | | | | | | | | | | | | | | - | 3 | 3 |
| TRANSMISSION SYSTEMS | TS | | | | | | | | | | | | | | | - | 3 |
| WATER INJECTION | WI | | | | | | | | | | | | | | | | - |

## Proposal of an Algorithm for Optimal Module Layout - Formulation of an Optimization Problem

### Definition of a problem

Determination of module layout which minimizes total material flow ($F_1$) considering the magnitude of accident risk and the distance ($F_2$) between total COG of modules in transverse direction and centerline

### Formulation of the problem

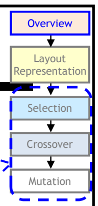
$$Minimize \quad F_1 = \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} (q_{i,j} \cdot d_{i,j}) \qquad \text{; Total material flow}$$

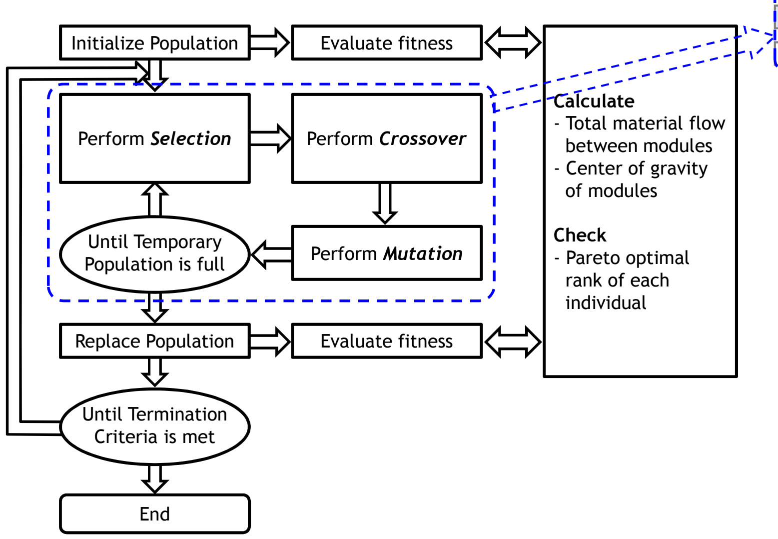
$$and \quad F_2 = \left| \sum_{i=1}^{N} (w_i \cdot y_i) \Big/ \sum_{i=1}^{N} w_i \right| \qquad \text{; Weight distribution}$$

$N$: Number of zones and modules
$q_{i,j}$: Adjacency factor between module $i$ and module $j$
$d_{i,j}$: Distance between module $i$ and module $j$
$w_i$: Weight of module $i$
$y_i$: y-coordinate (transverse position) of module $i$



## Proposal of an Algorithm for Optimal Module Layout - Algorithm for Optimal Module Layout

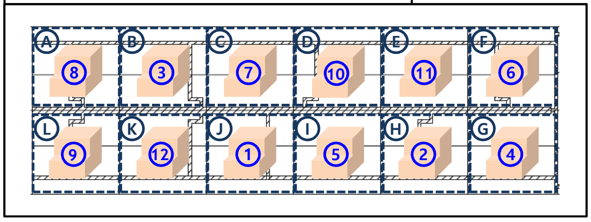


## Proposal of an Algorithm for Optimal Module Layout - Representation of the Module Layout

Overview → **Layout Representation** → Selection → Crossover → Mutation

Deck zones filled with modules




**"Representation of the positions of modules with a chromosome"**

Encoding | Decoding

Optimization

| 1 | 3 | 5 | 8 | 11 | 2 | 4 | 6 | 7 | 9 | 12 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| A | B | C | D | E | F | G | H | I | J | K | L |

→ 8 3 7 10 11 6 4 2 5 1 12 9



## Proposal of an Algorithm for Optimal Module Layout - Selection (Roulette Wheel Selection)

Overview → Layout Representation → **Selection** → Crossover → Mutation

| Individual | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $C_5$ | $C_6$ | $C_7$ |
|---|---|---|---|---|---|---|---|
| F | 460,136 | 323,287 | 406,656 | 317,550 | 587,101 | 350,094 | 496,949 |
| Ft | $2.17\times 10^{-6}$ | $3.09\times 10^{-6}$ | $2.46\times 10^{-6}$ | $3.15\times 10^{-6}$ | $1.70\times 10^{-6}$ | $2.86\times 10^{-6}$ | $2.01\times 10^{-6}$ |
| $P_{selection}$ | 12.5% | 17.7% | 14.1% | 18.0% | 9.8% | 16.4% | 11.5% |

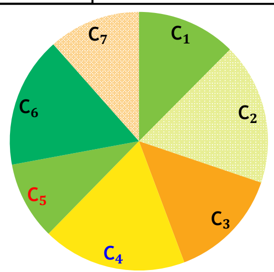
**Fitness (Ft) Calculation**

$$Ft = -F \quad or \quad Ft = \frac{1}{F} \quad (if\ F > 0)$$

**Probability of Selection**

$$P_{selection}(i) = \frac{Ft(i)}{\sum_i Ft(i)}$$

**Roulette Wheel**




* **Fitness**: Quantitative value for measuring the quality of each individual. The higher fitness, the better individual. The fitness is usually the value of the objective function in the optimization problem being solved.

## Proposal of an Algorithm for Optimal Module Layout - Crossover (PMX: Partially Mapped Crossover*)

Overview → Layout Representation → Selection → **Crossover** → Mutation

1st Parent($P_1$)

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 8 | 7 | 1 | 0 | 6 | 3 | 4 | 9 | 5 | 2 |

2nd Parent($P_2$)

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 2 | 4 | 3 | 1 | 5 | 6 | 7 | 8 | 9 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | 3 | 1 | 5 | | | | |
| 8 | 7 | ~~1~~ | | | | 4 | 9 | ~~5~~ | 2 |
| 8 | 7 | 6 | | | | 4 | 9 | ~~3~~ | 2 |

1st Child($C_1$)

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 8 | 7 | 6 | 3 | 1 | 5 | 4 | 9 | 0 | 2 |

* Reference: Goldberg, D.E. and Lingle, R., 1985. Alleles, Loci and the Traveling Salesman Problem. Proceedings of the First International Conference on Genetic Algorithms, San Francisco, CA, USA. pp.154-159



## Proposal of an Algorithm for Optimal Module Layout - Mutation

Overview → Layout Representation → Selection → Crossover → **Mutation**

1st Child($C_1$) – Before mutation

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 8 | *7* | 6 | *3* | 1 | *5* | 4 | 9 | 0 | *2* |

1st Child($C_1$) – After mutation

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 8 | *3* | 6 | *7* | 1 | *2* | 4 | 9 | 0 | *5* |

# Example of Optimal Module Layout of FPSO - Input Data

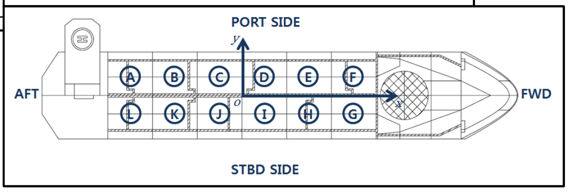
## Modules to be optimized

| Module ID | Module name | Module weight [ton] |
|---|---|---|
| 1 | Electrical BLD'G | 910 |
| 2 | Power generation | 2,270 |
| 3 | Water injection | 2,240 |
| 4 | Utilities area | 1,700 |
| 5 | Separation Train1 | 1,810 |
| 6 | Separation Train2 | 2,050 |
| 7 | Injection comp. | 2,800 |
| 8 | I/M metering | 960 |
| 9 | SDV platform | 780 |
| 10 | Recompressor | 1,590 |
| 11 | M/F dep. tower | 1,710 |
| 12 | Laydown area | 105 |

## Adjacency factor between modules

| Module ID | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | - | 6 | 6 | 3 | 2 | 0 | 0 | 3 | 3 | 3 | 3 | 0 |
| 2 | | - | 3 | 3 | 2 | 0 | 0 | 3 | 3 | 3 | 3 | 0 |
| 3 | | | - | 3 | 1 | 0 | 0 | 3 | 3 | 3 | 3 | 0 |
| 4 | | | | - | 1 | 0 | 0 | 3 | 3 | 3 | 3 | 0 |
| 5 | | | | | - | 0 | 0 | 2 | 2 | 2 | 2 | 0 |
| 6 | | | | | | - | 3 | 3 | 1 | 1 | 3 | 3 |
| 7 | | | | | | | - | 3 | 1 | 1 | 3 | 2 |
| 8 | | | | | | | | - | 3 | 3 | 6 | 2 |
| 9 | | | | | | | | | - | 6 | 3 | 4 |
| 10 | | | | | | | | | | - | 3 | 4 |
| 11 | | | | | | | | | | | - | 3 |
| 12 | | | | | | | | | | | | - |

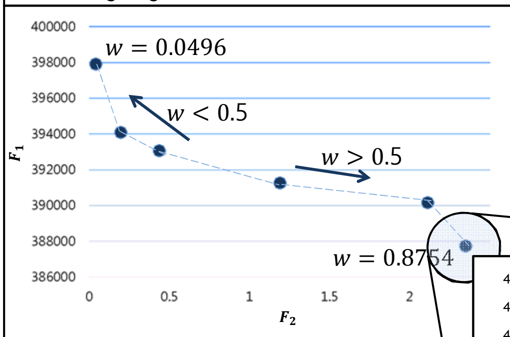
## Zone ID of FPSO topsides in this example(plan view)






# Example of Optimal Module Layout of FPSO - Pareto Optimal Set[1] by Using Weight Method[2]

Pareto optimal set[2] obtained from the parametric study for the weighting factor



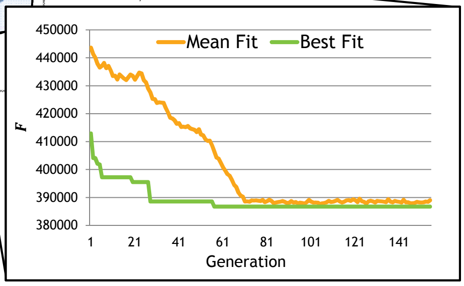

Number of population : 100
Number of generations : 300
Probability of crossover : 100%
Probability of mutation : 20%
Elitism : applied

Single objective function using weighting method[1]

$$F = wF_1 + (1-w)F_2\ , \quad 0 \le w \le 1$$

**[1]Pareto optimal set: Solutions that cannot be improved in any of the objectives without degrading at least one of the other objectives. The set of Pareto optimal outcomes is often called the Pareto front or Pareto boundary.**

[2]Reference: Cohon, J. L., 1978, Multiobjective Programming and Planning, Academic Press, New York



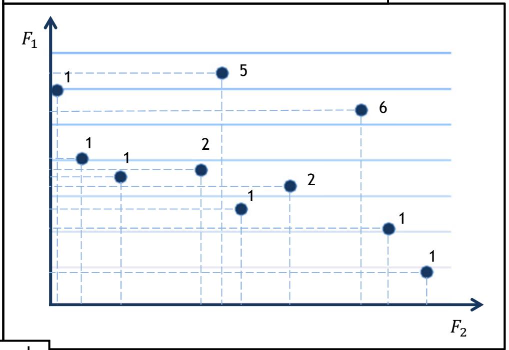
# Example of Optimal Module Layout of FPSO
# - Pareto Optimal Set by Using Rank-based Method* (1/2)

* **Rank-based fitness assignment method:** A method that determines the rank for each individual according to domination relation and calculates the fitness by using the rank.

Determination of the rank for each individual

$$r^{(t)} = 1 + p^{(t)}$$

Multiobjective ranking for the individuals



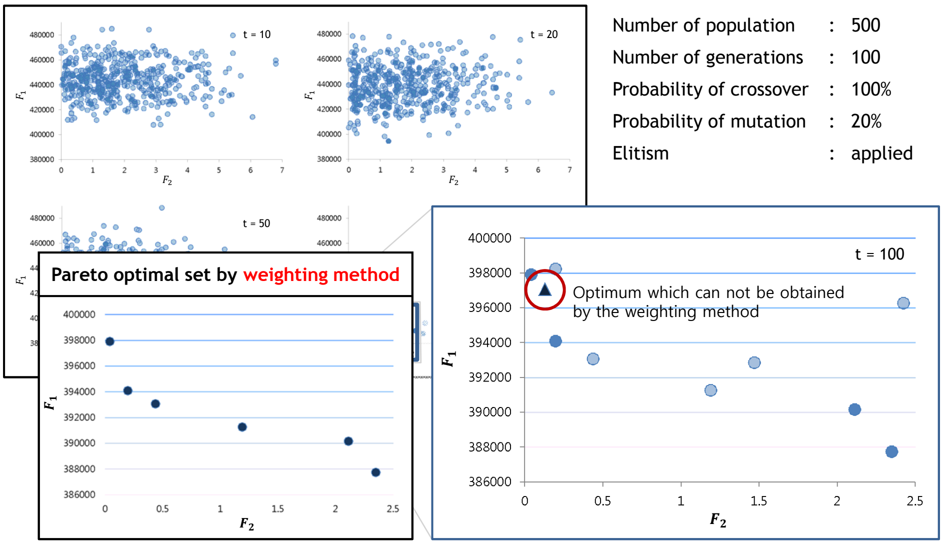

Calculation of the fitness by using the rank

$$Ft = \begin{cases} 1/r & \text{in case of a minimization} \\ r & \text{in case of a maximization} \end{cases}$$

* Reference: Fonesca, C. H. and Fleming P. J., July 1993. Genetic Algorithms for Multiobjective Optimization: Formulation, Discussion and Generalization, Proceedings of the 5th International Conference on Genetic Algorithms



# Example of Optimal Module Layout of FPSO
# - Pareto Optimal Set by Using Rank-based Method* (2/2)




| | | |
|---|---|---|
| Number of population | : | 500 |
| Number of generations | : | 100 |
| Probability of crossover | : | 100% |
| Probability of mutation | : | 20% |
| Elitism | : | applied |

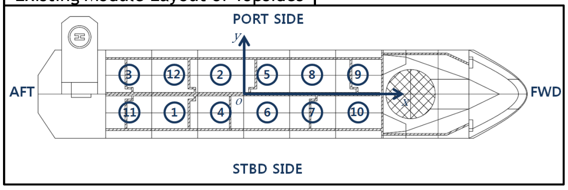
* Reference: Fonesca, C. H. and Fleming P. J., July 1993. Genetic Algorithms for Multiobjective Optimization: Formulation, Discussion and Generalization, Proceedings of the 5th International Conference on Genetic Algorithms

## Example of Optimal Module Layout of FPSO - Optimization Result

Modules to be optimized

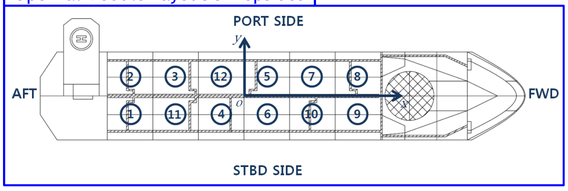
| Module ID | Module name |
|---|---|
| 1 | Electrical BLD'G |
| 2 | Power generation |
| 3 | Water injection |
| 4 | Utilities area |
| 5 | Separation Train1 |
| 6 | Separation Train2 |
| 7 | Injection comp. |
| 8 | I/M metering |
| 9 | SDV platform |
| 10 | Recompressor |
| 11 | M/F dep. tower |
| 12 | Laydown area |

Existing Module Layout of Topsides




| | Existing | Optimization |
|---|---|---|
| Adjacency between Modules [$F_1$] | 463,010 | 393,050 (-15.1%) |
| Transverse position of COG [$F_2$] | 2.7814 $m$ | 0.4395 $m$ (-84.2%) |

Optimal Module Layout of Topsides






## Optimal Equipment Layout in the Topsides Module of Offshore Plant (for Liquefaction Module)

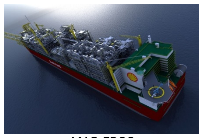
## Considerations on Optimal Equipment Layout in the Liquefaction Module for Offshore Plant

<Liquefaction process system>

+

<Exploration and Production of the Natural Gas>

=



<LNG FPSO>

### ☑ Safety

- Safety studies: HAZard and Operability (HAZOP), HAZard Identification (HAZID), Failure Modes and Effects Analysis (FMEA), Fault Tree Analysis (FTA), Event Tree Analysis (ETA)
- Optimal layout: Maintenance, Working space area, Emergency area

### ☑ Compactness

- Available area for the liquefaction cycle of offshore application is smaller than that of onshore plant.
- By determining the optimal operating conditions and doing the optimal synthesis of the liquefaction cycle, the required power for the compressors can be reduced which will result in the reduction of the compressor size and the flow rate of the refrigerant. Thus, the overall sizes of the liquefaction cycle including the pipe diameter, equipment and instrument can be reduced.
- Therefore, the compactness can be achieved by optimization studies such as determination of the optimal operating condition or optimal synthesis of the liquefaction cycle.

⇨ For the optimization of the process layout, 'Compactness' & 'Safety' are the most important consideration.



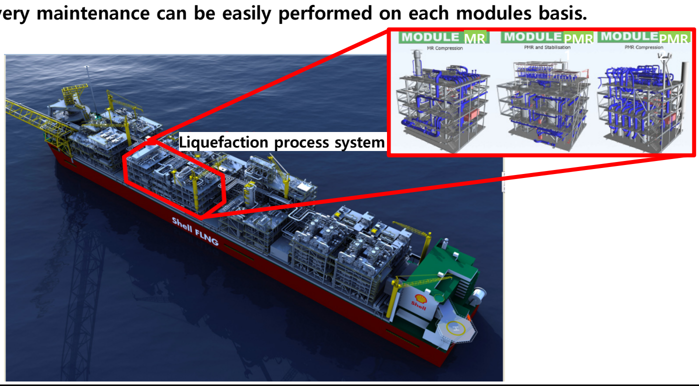
## Characteristics of Equipment Layout in Topsides Modules of Offshore Plant

### ☑ Limited Installation Area

- Considering the limited Hull area, equipment shall be placed on the multi-floors module.
- Same functional systems shall be installed in the same module in order to reduce the piping installation space.

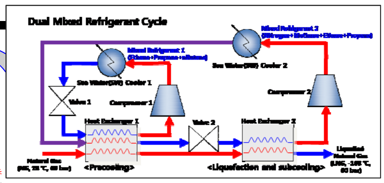
### ☑ Easy Installation and Maintenance

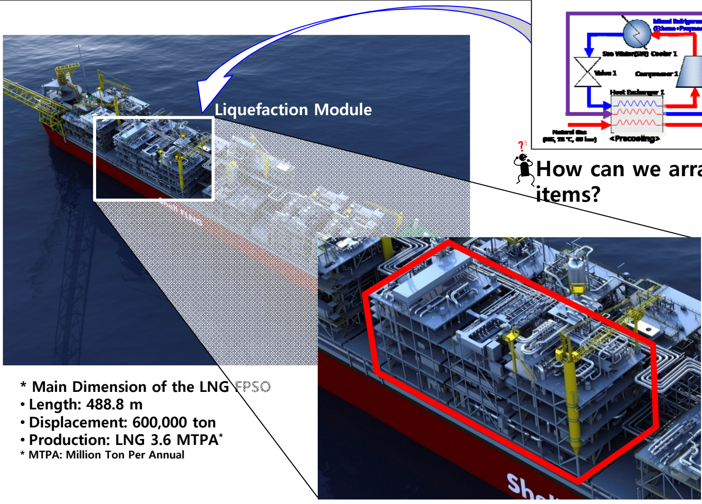
- Offshore installation shall be performed on the module basis to easily install each modules on the hull area.
- Every maintenance can be easily performed on each modules basis.




* MR: Mixed Refrigerant, PMR: Pre-Mixed Refrigerant

## Necessity of Multi-Deck Layout in the Liquefaction Module of LNG FPSO




How can we arrange the equipment items?

* Main Dimension of the LNG FPSO
- Length: 488.8 m
- Displacement: 600,000 ton
- Production: LNG 3.6 MTPA*

* MTPA: Million Ton Per Annual

**For the compactness**, the plant layout for the liquefaction process system of the LNG FPSO is **multi-deck equipment layout!**

* Reference: (Website) http://www.shell.com/home/content/innovation/feature_stories/2010/flng



## Procedures of Process FEED of Liquefaction System of LNG FPSO and Importance of Optimal Equipment Layout in Module

### Procedure of Construction of LNG FPSO

Exploration & Feasibility Study → Pre-FEED → **FEED** → EPCI → Commissioning

Engineering (Detail Design) → Procurement → Construction → Installation

① **Design Criteria**

➲ Well Components, Well Scale, Required Daily Production, Environment & Geographical Factor, etc.

② Process Configuration and Simulation Utility Consideration ⟵ - Determining optimal operating conditions of the liquefaction cycle of LNG FPSO

➲ Configuration of the process system and **operating conditions of each stream of the refrigerant and natural gas such as** temperature, pressure, specific volume, flow rate and mole fraction[1].

1) Mole fraction: Components of the mixed refrigerant and natural gas

③ **Process & Utility Hydraulic Calculations**

➲ Diameter of the pipe for each stream

④ **PFD** (Process Flow Diagram), **UFD** (Utility Flow Diagram)

➲ Diagram to show the safety & control logic of the topside systems and heat & material balance tables2)

⑤ **PED** (Process Equipment Datasheet), **UED** (Utility Equipment Datasheet)
**PID** (Process Instrument Datasheet), **UID** (Utility Instrument Datasheet)

➲ **Datasheets to show the operating conditions** and diameter of the inlet and outlet of each equipment for **performing procurement, construction, and operation of the topside process systems**

⑥ **P&ID** (Pipe & Instrument Diagram), SAC(Safety Analysis Checklist)

➲ Diagram that shows all data about the operating conditions, process control logic, safety and maintenance for the equipment and instruments, and vendor data about the equipment.

⑦ **Plant Layout for Liquefaction Process** ⟸ **- Determining optimal plant layout by using the optimization technique**

➲ For the compactness, the plant layout for the liquefaction process system of the LNG FPSO is multi-floor plant layout!

# Initial Equipment Layout in Topsides Modules of Offshore Plant