Innovative Ship and Offshore Plant Design

Part II. Offshore Plant Design

Ch. 3 Weight Estimation of Topside Systems

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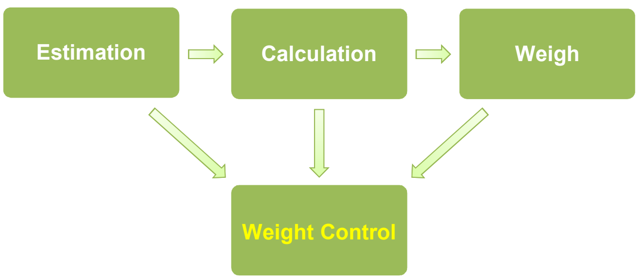
Ch. 3 Weight Estimation of Topside Systems

1. Generation of Weight Estimation Model by Using Statistical Method
2. Generation of Weight Estimation Model by Using Optimization Method

Necessity of the Weight Estimation of Offshore Topsides

☑ The weight estimation of offshore topsides is necessary,
- To provide the information required for
- To estimate the to be built and the amount of to be procured
- To estimate of the project

☑ If the topsides weight can be accurately estimate at FEED state, it is possible to control efficiently the weight and to produce stably material cost.



Weight engineering process of high level

Classification of Weight Estimation Methods (1/3)

☑ Volumetric Density Method
- A method of estimating the detailed weight group by the multiplication of space volume and bulk factor (density)
- e.g., detailed weight = space volume * bulk factor

☑ Parametrics
- A method of representing the weight with several parameters, and an essential prerequisite of the following ratiocination
- e.g., hull structural weight = $L^{1.6}(B + D)$

☑ Ratiocination
- A method of estimating the weight with a ratio from past records and a parametric equation
- e.g., hull structural weight = $C_S \cdot L^{1.6}(B + D))$

☑ Baseline Method
- A method of estimating the weight by using the result of the first one for a series of ships and offshore plants

Classification of Weight Estimation Methods (2/3)

☑ Midship Extrapolation Method
- A method of estimating the weight by the multiplication of the length and the midship weight per unit length
- e.g., fore body weight = midship weight per unit * fore body length * coeff.

☑ Deck Area Fraction Method
- A method of estimating the weight by the multiplication of the deck area and the deck weight per unit area
- e.g., detailed weight = deck weight per area * deck area * coeff.

☑ Synthesis Method
- A method of estimating by using a delicate synthesis program which was made from the integration all engineering fields (e.g., performance) based on requirements
- Most ideal method but it needs much time and efforts.

Classification of Weight Estimation Methods (3/3)

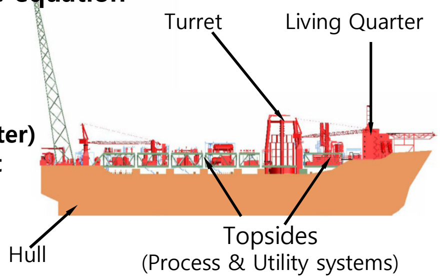
☑ **Statistical Method** ➡ To be presented here
- A method of developing a weight equation from statistical analysis of various past records, and of estimating the weight by using the equation

☑ **Optimization Method** ➡ To be presented here
- A method of developing a weight equation by optimization method such as genetic programming

1. Generation of Weight Estimation Model by Using Statistical Method

Generation of Weight Estimation Model by Statistical Method (1/11)

☑ A method of developing **a weight equation (weight estimation model) from** of various past records, and of estimating the weight by using the equation



☑ 1. Classification of FPSO weight

- FPSO weight =
  Hull weight (Including Living Quarter)
  + Topsides weight + Turret weight

☑ 2. Initial determination of individual variables

Items	Independent Parameters
Principal dimensions	L, B, D, T, H_LWT, DWT
Capacity	S_C, O_P, G_P, W_P
Miscellaneous	Crew

* H_LWT: Hull light weight[ton], DWT: Deadweight[ton], S_C: Storage capacity[MMbbl], O_P: Oil production[MMbopd], G_P = Gas production[MMscf/d]
W_P: Water processing[MMbwpd], T_LWT: Topsides weight[ton], Crew: Crew number

Generation of Weight Estimation Model by Statistical Method (2/11)

☑ 3. Past records of FPSOs through literature survey (Total 10 FPSOs)

	L [m]	B [m]	D [m]	T [m]	Storage capacity [MMbbl]	Oil production [MMbopd]	Gas production [MMscf/d]	Water processing [MMbwpd]	Crew	DWT [ton]	Topside [ton]	Hull [ton]	L/Q [ton]	Total weight [ton]
Akpo	310	61	31	23	2.00	0.185	530.00	0.420	220	303,669	37,000	70,500	2,860	110,360
USAN	310	61	32	24	2.00	0.160	500.00	0.420	180	353,200	27,700	75,750	3,072*	106,522
Kizomba A	285	63	32.3	24	2.20	0.250	400.00	0.420	100	340,660	24,400	56,300	1,170	81,870
Kizomba B	285	63	32.3	25	2.20	0.250	400.00	0.420	100	340,660	24,400	56,300	1,170	81,870
Greater Plutonio	310	58	32	23	1.77	0.220	380.00	0.400	120	360,000	24,000	56,000	2,200*	82,200
Pazflor	325	61	32	25	1.90	0.200	150.00	0.380	240	346,089	37,000	82,000	3,227	122,227
CLOV	305	61	32	24	1.80	0.160	650.00	0.380	240	350,000	36,300	63,490	2,900	102,690
Agbami	320	58.4	32	24	2.15	0.250	450.00	0.450	130	337,859	34,000	68,410	2,590	105,000
Dalia	300	60	32	23	2.00	0.240	440.00	0.405	160	416,000	30,000	52,500	2,500	85,000
Skarv-Idun	269	50.6	29	19	0.88	0.085	670.00	0.020	100	129,193	16,100	40,600	1,930*	56,700

* Not defined clearly and thus estimated from the ratio of hull and L/Q weights of other FPSOs

Generation of Weight Estimation Model by Statistical Method (3/11)

☑ 4. Determination of dependent variables through

- Correlation: Any of a broad class of involving dependence between variables
- Correlation analysis: One of statistical methods to analyze statistical relationships between variables
- Correlation coefficient: Degree of correlation between variables.
- The coefficient can be calculated by using Pearson method.
- According to correlation analysis, independent variables having a close connection to a dependent variable (topsides weight) can be determined.
- In this study, L, B, T, DWT, and H_LWT were selected as the revised independent variables to generate a weight equation.

Generation of Weight Estimation Model by Statistical Method (4/11)

Result of Correlation Analysis

		LBP	B	D	T	S_C	O_P	G_P	W_P	CREW	DWT	T_LWT	H_LWT
LBP	Pearson Correlation	1	.365	.513	.676*	.464	.298	-.490	.643*	.649*	.586	.810**	.848**
	Sig. (2-tailed)		.300	.129	.032	.177	.403	.150	.045	.042	.075	.004	.002
	N	10	10	10	10	10	10	10	10	10	10	10	10
B	Pearson Correlation	.365	1	.865**	.887**	.908**	.669*	-.456	.858**	.305	.783**	.520	.538
	Sig. (2-tailed)	.300		.001	.001	.000	.034	.186	.001	.392	.007	.123	.109
	N	10	10	10	10	10	10	10	10	10	10	10	10
D	Pearson Correlation	.513	.865**	1	.924**	.894**	.803**	-.560	.918**	.155	.927**	.447	.479
	Sig. (2-tailed)	.129	.001		.000	.000	.005	.092	.000	.670	.000	.195	.162
	N	10	10	10	10	10	10	10	10	10	10	10	10
T	Pearson Correlation	.676*	.887**	.924**	1	.873**	.668*	-.620	.889**	.415	.826**	.669*	.749*
	Sig. (2-tailed)	.032	.001	.000		.001	.035	.056	.001	.234	.003	.034	.013
	N	10	10	10	10	10	10	10	10	10	10	10	10
S_C	Pearson Correlation	.464	.908**	.894**	.873**	1	.854**	-.492	.946**	.114	.825**	.507	.515
	Sig. (2-tailed)	.177	.000	.000	.001		.002	.149	.000	.755	.003	.135	.127
	N	10	10	10	10	10	10	10	10	10	10	10	10
O_P	Pearson Correlation	.298	.669*	.803**	.668*	.854**	1	-.604	.794**	-.225	.747*	.251	.164
	Sig. (2-tailed)	.403	.034	.005	.035	.002		.065	.006	.533	.013	.484	.651
	N	10	10	10	10	10	10	10	10	10	10	10	10
G_P	Pearson Correlation	-.490	-.456	-.560	-.620	-.492	-.604	1	-.481	-.085	-.498	-.258	-.488
	Sig. (2-tailed)	.150	.186	.092	.056	.149	.065		.159	.816	.143	.471	.152
	N	10	10	10	10	10	10	10	10	10	10	10	10
W_P	Pearson Correlation	.643*	.858**	.918**	.889**	.946**	.794**	-.481	1	.248	.901**	.595	.584
	Sig. (2-tailed)	.045	.001	.000	.001	.000	.006	.159		.490	.000	.070	.076
	N	10	10	10	10	10	10	10	10	10	10	10	10
CREW	Pearson Correlation	.649*	.305	.155	.415	.114	-.225	-.085	.248	1	.284	.837**	.709*
	Sig. (2-tailed)	.042	.392	.670	.234	.755	.533	.816	.490		.426	.003	.022
	N	10	10	10	10	10	10	10	10	10	10	10	10
DWT	Pearson Correlation	.586	.783**	.927**	.826**	.825**	.747*	-.498	.901**	.284	1	.529	.444
	Sig. (2-tailed)	.075	.007	.000	.003	.003	.013	.143	.000	.426		.116	.199
	N	10	10	10	10	10	10	10	10	10	10	10	10
T_LWT	Pearson Correlation	.810**	.520	.447	.669*	.507	.251	-.258	.595	.837**	.529	1	.778**
	Sig. (2-tailed)	.004	.123	.195	.034	.135	.484	.471	.070	.003	.116		.008
	N	10	10	10	10	10	10	10	10	10	10	10	10
H_LWT	Pearson Correlation	.848**	.538	.479	.749*	.515	.164	-.488	.584	.709*	.444	.778**	1
	Sig. (2-tailed)	.002	.109	.162	.013	.127	.651	.152	.076	.022	.199	.008	
	N	10	10	10	10	10	10	10	10	10	10	10	10

Generation of Weight Estimation Model by Statistical Method (5/11)

Result of Correlation Analysis

		L	B	T	W_P	DWT	H_LWT	T_LWT
L	Cor. coeff.[1]	1.00	0.37	0.68	0.64	0.59	0.85	**0.81**
	p-value[2]	-	0.30	0.03	0.05	0.08	0.00	0.00
	N[3]	10.00	10.00	10.00	10.00	10.00	10.00	10.00
B	Cor. coeff.	0.37	1.00	0.89	0.86	0.78	0.54	**0.52**
	p-value	0.30	-	0.00	0.00	0.01	0.11	0.12
	N	10.00	10.00	10.00	10.00	10.00	10.00	10.00
T	Cor. coeff.	0.68	0.89	1.00	0.89	0.83	0.75	**0.67**
	p-value	0.03	0.00	-	0.00	0.00	0.01	0.03
	N	10.00	10.00	10.00	10.00	10.00	10.00	10.00
DWT	Cor. coeff.	0.59	0.78	0.83	0.90	1.00	0.44	**0.53**
	p-value	0.08	0.01	0.00	0.00	-	0.20	0.12
	N	10.00	10.00	10.00	10.00	10.00	10.00	10.00
H_LWT	Cor. coeff.	0.85	0.54	0.75	0.58	0.44	1.00	**0.78**
	p-value	0.00	0.11	0.01	0.08	0.20	-	0.01
	N	10.00	10.00	10.00	10.00	10.00	10.00	10.00

➡ Independent variables (L, B, T, DWT, H_LWT) which have high correlation coefficients with T_LWT (to be estimated) were selected as the revised independent variables to generate a weight equation.

* 1: Correlation coefficient: Measuring the degree of correlation between two variables
* 2: p Value: Probability of obtaining a test statistic at least as extreme as the one that was actually observed, assuming that the null hypothesis is true.
It has a value between 0~1. The smaller, the better.
* 3: Number of data (number of past records)

Generation of Weight Estimation Model by Statistical Method (6/11)

☑ **5. Generation of weight equation through**

- **Regression analysis: One of statistical methods**
- **The case of one independent variable is called simple linear regression. For more than one independent variable, it is called multiple linear regression.**
- **In this study, the backward elimination method was used to generate the final regression equation.**
  - **Starting with all candidate variables, testing the deletion of each variable using a chosen model comparison criterion, deleting the variable (if any) that improves the model the most by being deleted, and repeating this process until no further improvement is possible**
  - **Through the backward elimination method, L, B, T, and DWT were selected as the final independent variables to generate a weight equation.**

Generation of Weight Estimation Model by Statistical Method (7/11)

Result of regression analysis

➡ "Model 2" was selected as the final regression model by considering p value (less than 0.1).

Model		Beta[1]	Std. Error[2]	VIF[3]	t[4]	PV[5]	R^2 [6]	PV of F[7]
1	(Const.)	-192,557.8	138,275.4		-1.39	0.24	0.78	0.165
	L	573.6	372.8	1.42	1.54	0.20		
	B	2,213.4	1,763.9	1.13	1.26	0.28		
	T	-2,222.3	3,874.6	-0.52	-0.57	0.60		
	DWT	-55.3	71.9	-0.59	-0.77	0.49		
	H_LWT	-0.2	0.5	-0.39	-0.44	0.68		
2	(Const.)	-137,044.7	5,4129.1		-2.53	0.05	0.77	0.074
	L	429.7	168.9	1.07	2.54	0.05		
	B	1766.5	1,327.3	0.90	1.33	0.24		
	T	-2554.6	3,483.1	-0.60	-0.73	0.50		
	DWT	-29.1	37.7	-0.31	-0.77	0.48		
3	(Const.)	-117,509.5	45,270.8		-2.60	0.04	0.75	0.032
	L	334.8	104.2	0.83	3.21	0.02		
	B	932.6	657.9	0.48	1.42	0.21		
	DWT	-31.0	36.1	-0.33	-0.86	0.42		
4	(Const.)	-88,217.0	29,166.8		-3.03	0.02	0.72	0.012
	LBP	288.4	87.4	0.72	3.30	0.01		
	B	506.7	423.6	0.26	1.20	0.27		

* 1: Regression coefficients, 2: Standard or mean error, 3: Variance Inflation Factor (Representing multicolinearity of variables. Less than 10 is good.), 4: t value, 5: p-value of each variable, 6: Adjusted R^2 (Representing the expectation accuracy of the regression model. To close to 1 is good.), 7: p-value of the regression model

Generation of Weight Estimation Model by Statistical Method (8/11)

☑ **6. Generation of weight equation model for offshore plant topside**

- **The topside weight can be estimated from the following model which is comprised of L, B, T, and DWT.**

$$T_{LWT} = \beta_0 + (L)\beta_1 + (B)\beta_2 + (T)\beta_3 + (DWT)\beta_4$$

where,

$$\beta_0 = -137044.7$$

$$\beta_1 = 429.7$$

$$\beta_2 = 1766.5$$

$$\beta_3 = -2554.6$$

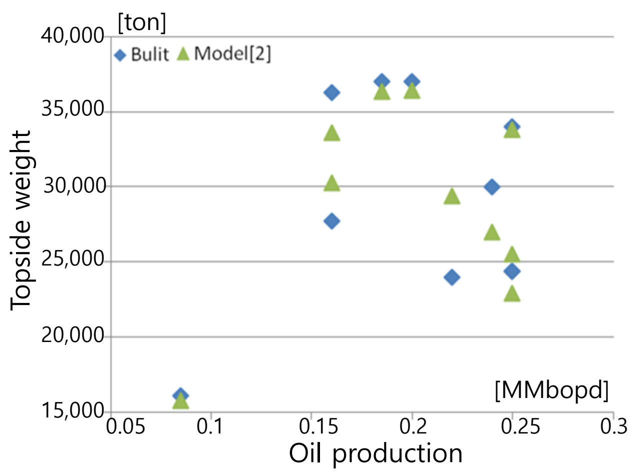
$$\beta_4 = -29.1$$

Generation of Weight Estimation Model by Statistical Method (9/11)

☑ 7. Validation of weight estimation model

Past records	Actual weight [A]	Estimated weight [B]	Ratio[A/B]
Akpo	37,000	36,347	1.020
USAN	27,700	33,614	0.820
Kizomba A	24,400	25,505	0.960
Kizomba B	24,400	22,951	1.060
Greater Plutonio	24,000	29,388	0.820
Pazflor	37,000	36,431	1.020
CLOV	36,300	30,275	1.200
Agbami	34,000	33,784	1.010
Dalia	30,000	26,993	1.110
Skarv-Idun	16,100	15,770	1.020
Mean	-	-	**1.003**
COV (Coefficient of Variation)	-	-	**0.116**

Generation of Weight Estimation Model by Statistical Method (10/11)



Generation of Weight Estimation Model by Statistical Method (11/11)

☑ **Discussion**

- **It is very important**
  . Based on experts' experience, the variables which are less impact on the weight estimation should be excluded.

- **To estimate more accurate weight, it is needed**
  and to discuss the standard of weight control (e.g., the inclusion of L/Q in hull or topsides weight).

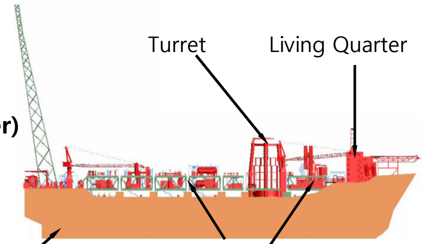
- **If the detailed weight information on each module from past records is available, it is possible to generate a weight estimation model for topside modules.**

2. Generation of Weight Estimation Model by Using Optimization Method

Generation of Weight Estimation Model by Optimization Method (1/7)

☑ A method of developing **a weight equation by** such as genetic programming

☑ 1. Classification of FPSO weight
- FPSO weight = Hull weight (Including Living Quarter) + Topsides weight + Turret weight



☑ 2. Initial determination of individual variables

Items	Independent Parameters
Principal dimensions	L, B, D, T, H_LWT, DWT
Capacity	S_C, O_P, G_P, W_P
Miscellaneous	Crew

* H_LWT: Hull light weight[ton], DWT: Deadweight[ton], S_C: Storage capacity[MMbbl], O_P: Oil production[MMbopd], G_P = Gas production[MMscf/d] W_P: Water processing[MMbwpd], T_LWT: Topsides weight[ton], Crew: Crew number

Generation of Weight Estimation Model by Optimization Method (2/7)

☑ 3. Past records of FPSOs through literature survey (Total 10 FPSOs)

	L [m]	B [m]	D [m]	T [m]	Storage capacity [MMbbl]	Oil production [MMbopd]	Gas production [MMscf/d]	Water processing [MMbwpd]	Crew	DWT [ton]	Topside [ton]	Hull [ton]	L/Q [ton]	Total weight [ton]
Akpo	310	61	31	23	2.00	0.185	530.00	0.420	220	303,669	37,000	70,500	2,860	110,360
USAN	310	61	32	24	2.00	0.160	500.00	0.420	180	353,200	27,700	75,750	3,072*	106,522
Kizomba A	285	63	32.3	24	2.20	0.250	400.00	0.420	100	340,660	24,400	56,300	1,170	81,870
Kizomba B	285	63	32.3	25	2.20	0.250	400.00	0.420	100	340,660	24,400	56,300	1,170	81,870
Greater Plutonio	310	58	32	23	1.77	0.220	380.00	0.400	120	360,000	24,000	56,000	2,200*	82,200
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CLOV	305	61	32	24	1.80	0.160	650.00	0.380	240	350,000	36,300	63,490	2,900	102,690
Agbami	320	58.4	32	24	2.15	0.250	450.00	0.450	130	337,859	34,000	68,410	2,590	105,000
Dalia	300	60	32	23	2.00	0.240	440.00	0.405	160	416,000	30,000	52,500	2,500	85,000
Skarv-Idun	269	50.6	29	19	0.88	0.085	670.00	0.020	100	129,193	16,100	40,600	1,930*	56,700

* Not defined clearly and thus estimated from the ratio of hull and L/Q weights of other FPSOs

Generation of Weight Estimation Model by Optimization Method (3/7)

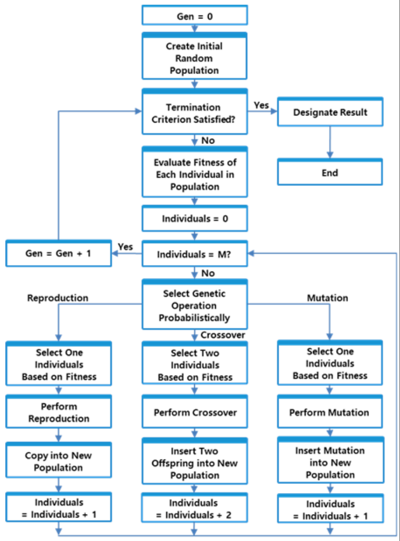
☑ 4. Generation of weight equation by

■ Genetic Programming
- One of evolutionary algorithms which evolve original solutions to better solutions
- Overall procedures
  - Step 1: Make a population with individuals which represent solutions.
  - Step 2: Generate the next population by applying genetic operators (selection, crossover, mutation, reproduction, etc.) considering fitness to the population.
  - Step 3: Repeat Step 2 until stopping criteria are satisfied.

■ Selection of terminal and function sets

set:
included in the weight equation

set: to
represent the weight equation



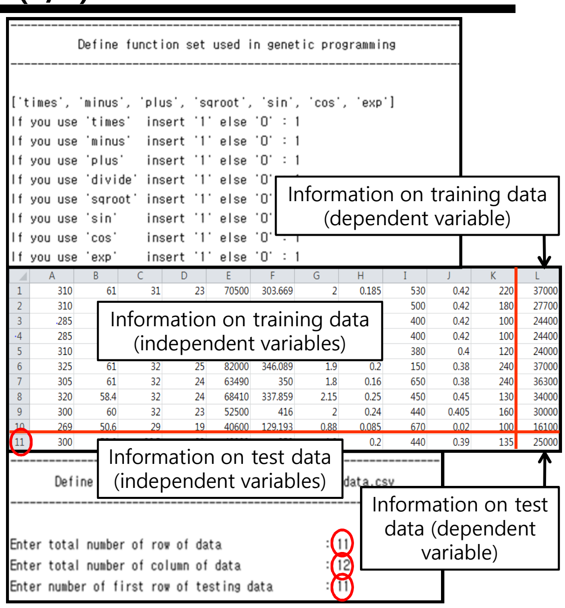
Generation of Weight Estimation Model by Optimization Method (4/7)

Parameters for terminal set to generate an estimation model

Terminal Set
L, B, D, T, H_LWT, DWT, S_C, O_P, G_P, W_P, Crew

Parameters for function set to generate an estimation model

Function Set
+, -, ×, ÷, sin, cos, exp, √



```
Define function set used in genetic programming

['times', 'minus', 'plus', 'sqroot', 'sin', 'cos', 'exp']
If you use 'times'  insert '1' else '0' : 1
If you use 'minus'  insert '1' else '0' : 1
If you use 'plus'   insert '1' else '0' : 1
If you use 'divide' insert '1' else '0'
If you use 'sqroot' insert '1' else '0'
If you use 'sin'    insert '1' else '0'
If you use 'cos'    insert '1' else '0'
If you use 'exp'    insert '1' else '0' : 1
```

	A	B	C	D	E	F	G	H	I	J	K	L
1	310	61	31	23	70500	303.669	2	0.185	530	0.42	220	37000
2	310								500	0.42	180	27700
3	285								400	0.42	100	24400
4	285								400	0.42	100	24400
5	310								380	0.4	120	24000
6	325	61	32	25	82000	346.089	1.9	0.2	150	0.38	240	37000
7	305	61	32	24	63490	350	1.8	0.16	650	0.38	240	36300
8	320	58.4	32	24	68410	337.859	2.15	0.25	450	0.45	130	34000
9	300	60	32	23	52500	416	2	0.24	440	0.405	160	30000
10	269	50.6	29	19	40600	129.193	0.88	0.085	670	0.02	100	16100
11	300							0.2	440	0.39	135	25000

```
Define                                      data.csv

Enter total number of row of data          : 11
Enter total number of column of data       : 12
Enter number of first row of testing data  : 11
```

Generation of Weight Estimation Model by Optimization Method (5/7)

☑ **5. Generation of weight equation model for offshore plant topside**

- **The topside weight can be estimated from the following model which is comprised of L, B, D, T, H_LWT, DWT, S_C, O_P, G_P, W_P, and Crew.**

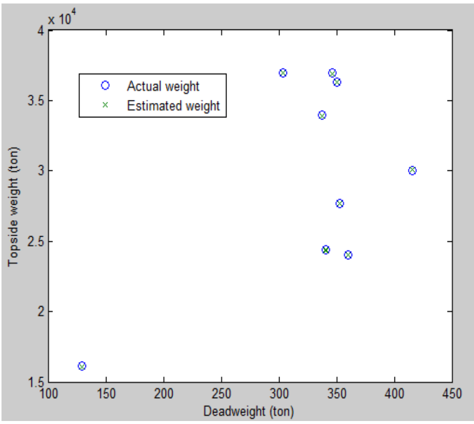
$$
\begin{aligned}
T\_LWT = {} & 67.38 \cdot Crew + 67.38 \cdot B + 67.38 \cdot S\_C - \\
& 3059 \cdot \cos(L \cdot WP \cdot (H\_LWT - 3.838)) + \\
& 12533 \cdot \cos(\exp(\sin(S\_C))) + 0.5007 \cdot B \cdot T + \\
& 67.38 \cdot O\_P \cdot G\_P + 0.5007 \cdot D \cdot \sin(H\_LWT) \cdot L^2 - 30033
\end{aligned}
$$

Generation of Weight Estimation Model by Optimization Method (6/7)

☑ **6. Validation of weight estimation model**

$$
\begin{aligned}
T\_LWT = {} & 67.38 \cdot Crew + 67.38 \cdot B + 67.38 \cdot S\_C - \\
& 3059 \cdot \cos(L \cdot WP \cdot (H\_LWT - 3.838)) + 12533 \cdot \cos(\exp(\sin(S\_C))) + 0.5007 \cdot B \cdot T + \\
& 67.38 \cdot O\_P \cdot G\_P + 0.5007 \cdot D \cdot \sin(H\_LWT) \cdot L^2 - 30033
\end{aligned}
$$

Past records	Actual weight [A]	Estimated weight [B]	Ratio [A/B]
Akpo	37,000	36,951	0.9987
USAN	27,700	27,672	0.9990
Kizomba A	24,400	24,352	0.9980
Kizomba B	24,400	24,383	0.9993
Greater Plutonio	24,000	24,063	1.0226
Pazflor	37,000	36,918	0.9978
CLOV	36,300	36,318	1.0005
Agbami	34,000	33,906	0.9972
Dalia	30,000	30,059	1.0020
Skarv-Idun	16,100	16,093	0.9996
Test	25,000	24,928	0.9971
Mean			1.0011



Generation of Weight Estimation Model by Optimization Method (7/7)

☑ Discussion

- As compared to the ,
  .

  which are included in the
  weight equation and thus
  .

  ➡ The selection process of variables which will be included in the final weight equation is needed such as correlation analysis.

- It takes much time to generate the weight equation due to the nature of evolutionary algorithms such as genetic programming.
  ➡ The time can be reduced when the number of variables (terminal set) becomes small.