National Defense
University

Developing R&D and Mass Production Cost Estimating Methodologies for Korean Maneuver Weapon System

Doohyun Lee

Suhwan Kim

Sung-Jin Kang

Contents

Background and Objective

- **Cost analysis method in R.O.K**
  - → **PRICE model developed in the U.S.**

- **Key variables in PRICE model (Ex)**
  - WE : Weight of a Electronic,
  - WS : Weight of a System
  - MCPLXE : Manufacturing Complexity of a Electronic
  - MCPLXS : Manufacturing Complexity of a System

→ **Not domestic data**

↓ Lack of reliability

Need to develop cost estimating model suitable for R.O.K

$$DftAU = f(WE, MCPLXE) + f(WS, MCPLXS)$$

Literature Review

Research	Contents
A study on developing a parametric R&D cost estimating model for missile System(Lee Yong bok, 2011)	Formula development based on actual domestic originals.
	R&D cost estimation using ROC cost drivers
A study on developing a life cycle cost estimation model for military aircraft(Kim Dong gyu, 2012)	Developing models for R&D, mass production, and O&S costs (Partially including foreign data)

- Regression methods are used in both papers to derive CER(Cost Estimating Relationship)
- Not considered to resolve the problems caused by Multicollinearity and Outliers

Range and Methodology

Domestic maneuver weapon systems (Tank(4) and armored vehicle(5))

- Developing WBS for the maneuver weapon systems
- Defining cost derivers based on the ROC
- Developing CER of R&D cost and mass production cost

Regression Analysis

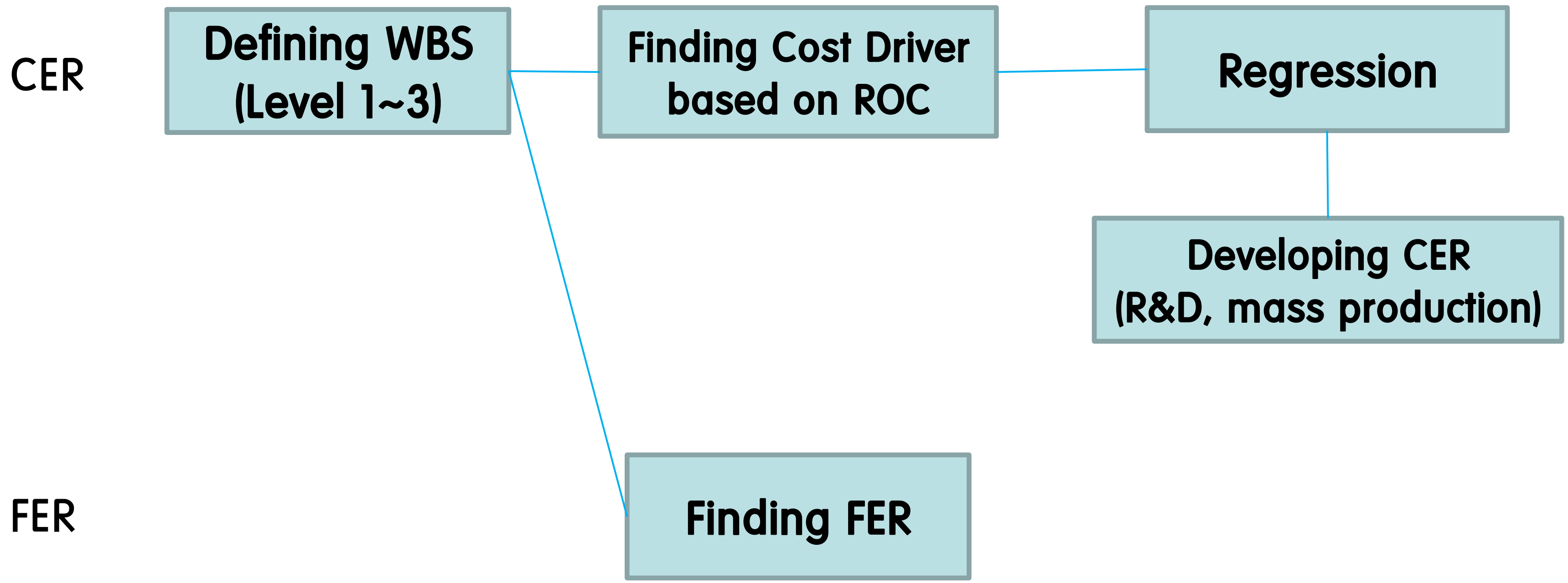
Transformation of Dependent Variable

Contributions

Improving suitability of regression models	Box-Cox transformation (Box & Cox, 1964) - Improve suitability for regression models without eliminating variables
Improvement in the criteria of multicollinearity	Considered two different VIFs (ex, VIF(max)>10, VIF(mean)>1)
Domestic actual cost Data	Developed WBS and CER concerning R.O.K army maneuver weapon systems, for the first time Collected cost data about R&D and deployed weapon systems

Contents

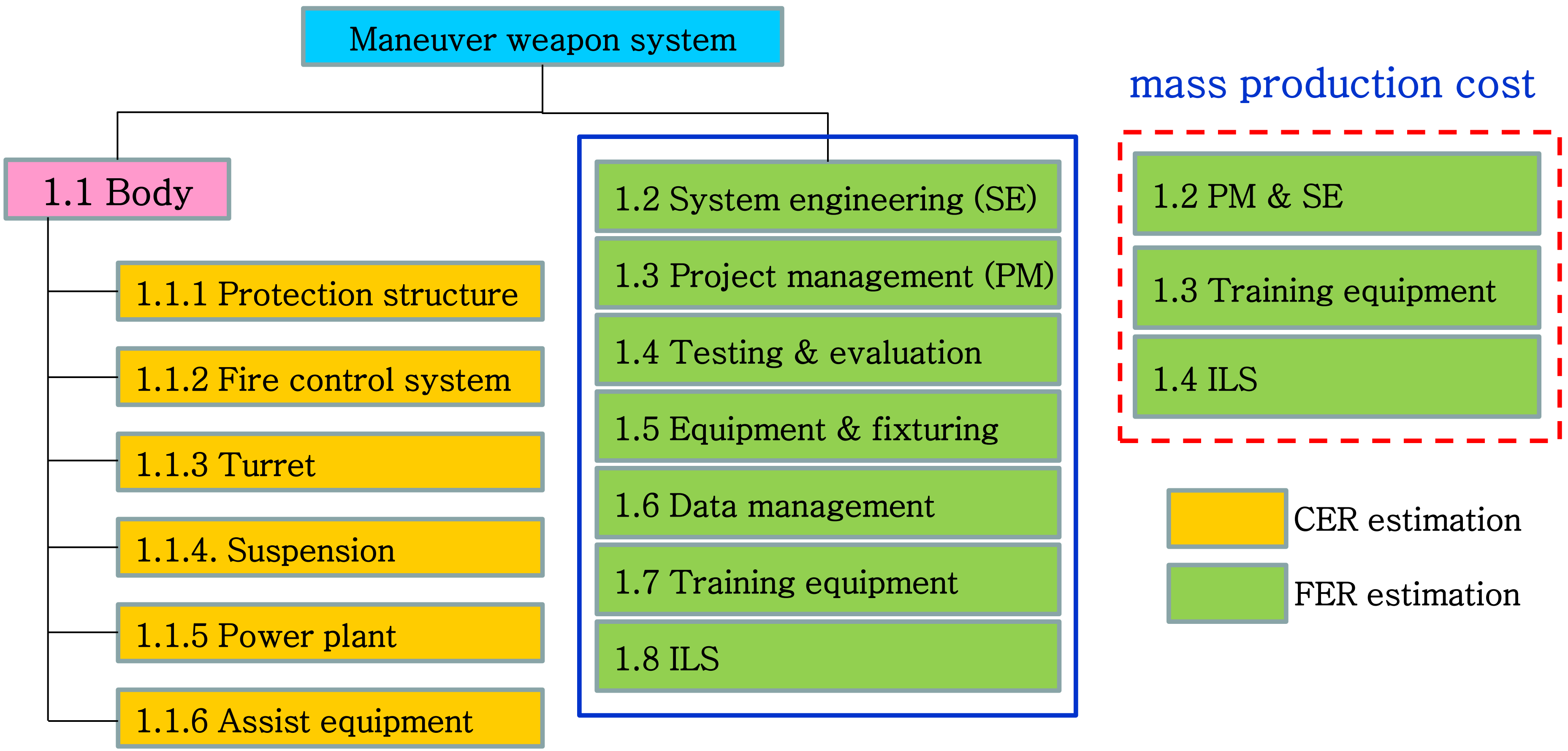
Process of Cost Estimation



*FER(Factor Estimation Relationship) : Unexpressed factors by CERs
(ex, costs of project management, testing and evaluation, ILS, etc)

Defining WBS for Maneuver Weapon Systems

Reference: manual MIL-HDBK-88 from DoD



Deriving Cost Drivers

Cost Drivers: Factors as independent variables for each factor in level 3.

Select cost drivers based on ROC and technical manual.

Characteristic variables(17)	Dummy variables(10)
Length, total weight, caliber/gun barrel, effective range, engine weight, engine output, maximum speed, maximum torque, cruising range, fuel tank capacity, road wheel, engine shape, hole pass ability, obstacle pass, telescope sight detectable range, fire control computer weight, laser ranger range	Suspension shape, automatic detection and tracking equipment, automatic navigator, reactive armor, loading ammunition shape, laser ranger, ballistic computer efficiency, CBR equipment, C4I system interworking, Active protection driver * Dummy variables are represented by 0 or 1.

Process of Developing R&D CER

Ex. R&D CER for protection structure:

Step 1. Selecting variables: stepwise selection

Result	total weight, maximum speed, engine output, maximum torque, presence of reactive armor

R^2 selection(determinate an optimal combination of variables)

Model	Variables	R^2	R^2_{adj}
Model 1	maximum speed, engine output, maximum torque, presence of reactive armor	0.9889	0.9779
Model 2	total weight, maximum speed, maximum torque, presence of reactive armor	0.9567	0.9134
Model 3	total weight, maximum speed, engine output, presence of reactive armor	0.9565	0.9130
Model 4	total weight, maximum speed, maximum torque, presence of reactive armor	0.9507	0.9014

※ mean VIF >1, max VIF >10 → Principal Component Regression(PCR)

Developing R&D CER

Step 2. Establishing CER

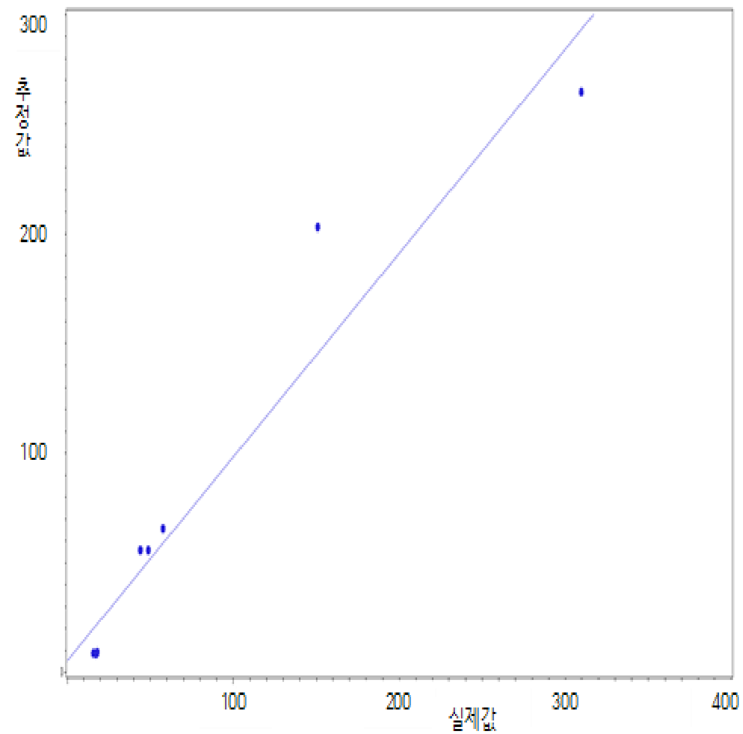
Model	Variable	R^2	R^2_{adj}
Model 1	Y = - 505.8566 + 5.6519(maximum speed) - 0.1296(engine output) + 1.0135(maximum torque) + 108.627(presence of reactive armor)	0.9292	0.9056
Model 2	Y = - 261.194 – 0.4475(Total weight) + 2.8817(maximum speed) + 0.4548(maximum torque) + 139.661(presence of reactive armor)	0.9227	0.8970
Model 3	Y = - 279.4858 + 2.8558(Total weight) + 3.4547(maximum speed) - 0.0149(engine output) + 164.936(presence of reactive armor)	0.9297	0.9063
Model 4	Y = 221.027 – 21.672(Total weight) + 0.3159(engine output) - 4.330(maximum torque) + 510.697(164.936(presence of reactive armor)	0.9019	0.8692

Developing R&D CER

Step 3. Verifying CER (model 3)

Unit: Hundred million won

Weapon System	Real cost	Estimated cost
K-1	44.10	55.85
K-1 Rescue tank	57.87	65.56
K1A1	48.97	55.85
K-2	309.84	264.85
K-200	15.93	8.83
K-200A1	18.26	9.21
K-242	17.35	8.64
K-281	17.67	8.64
K-21	150.79	203.23



MMRE = 0.333 PRED(0.25) = 0.333 RMSE = 0.306

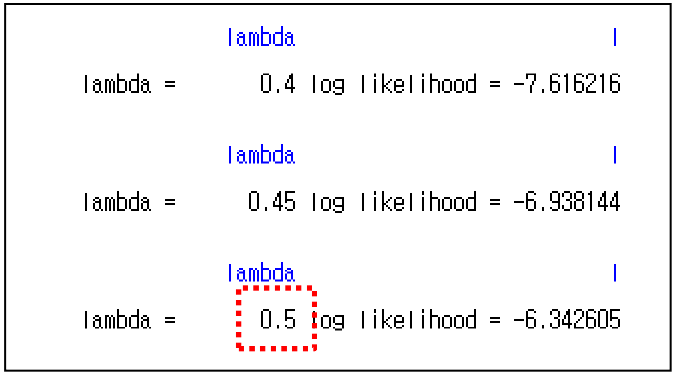
Developing R&D CER

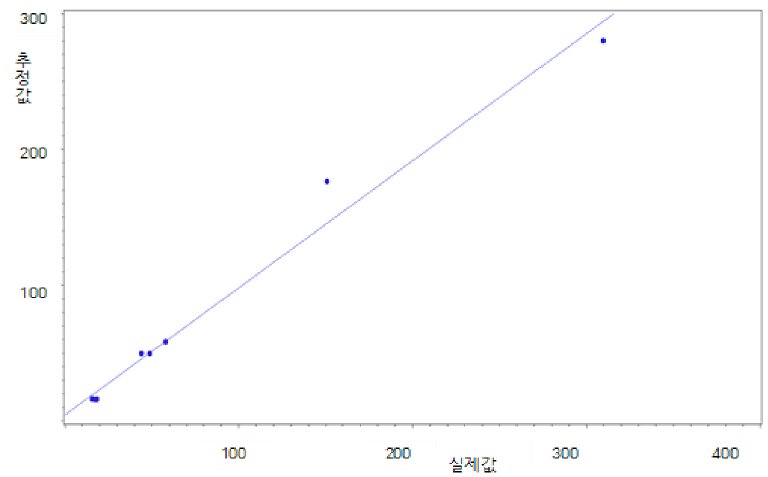
Step 4. Transforming the dependent variable(if necessary)

$Y^{1/2}$ = - 8.891 + 0.1716(total weight) + 0.1505(maximum speed)
- 0.00154(engine output) + 7.7950(presence of reactive armor)

Unit: Hundred million won

Weapon System	Real cost	Estimated cost
K-1	44.10	49.84
K1 rescue tank	57.87	58.42
K1A1	48.97	49.84
K-2	309.84	280.18
K-200	15.93	16.23
K-200A1	18.26	16.05
K-242	17.35	15.78
K-281	17.67	15.78
K-21	150.79	176.65





MMRE : 0.042 PRED(0.25) : 1.00 RMSE : 0.048

Developing R&D CER

Step 5. Integrating R&D CER

Dep. Var.	Result of CER development
Protection structure	WC_1 : $Y^{1/2}$ = - 8.891 + 0.1716(total weight) + 0.1505(maximum speed) - 0.00154(engine output) + 7.795(presence of reactive armor)
Power equipment	WC_2 : $Y^{1/2}$ = - 23.6445 + 0.2905(total weight) + 0.00282(fuel tank capacity) + 3.3968(kind of engine) - 0.0378(maximum torque)
Suspension equipment	WC_3 : Y = 583.947 + 4.0898(total weight) + 0.07518(cruising range) - 132.666(Number of road wheel) + 165.947(kind of suspension)
Assistant equipment	WC_4 : $Y^{1/2}$ = 4.5426 - 0.9634(length) + 0.1346(total weight) + 0.9641(obstacle pass) + 5.762(C4Isystem interworking)
Turret	WC_5 : Y = - 641.428 + 14.429(total weight) + 564.197(active protection driver)
Fire control system	WC_6 : $Y^{1/2}$ = - 96.70713 + 0.00117(telescope sight detectable range) + 4.78319(fire control computer weight)

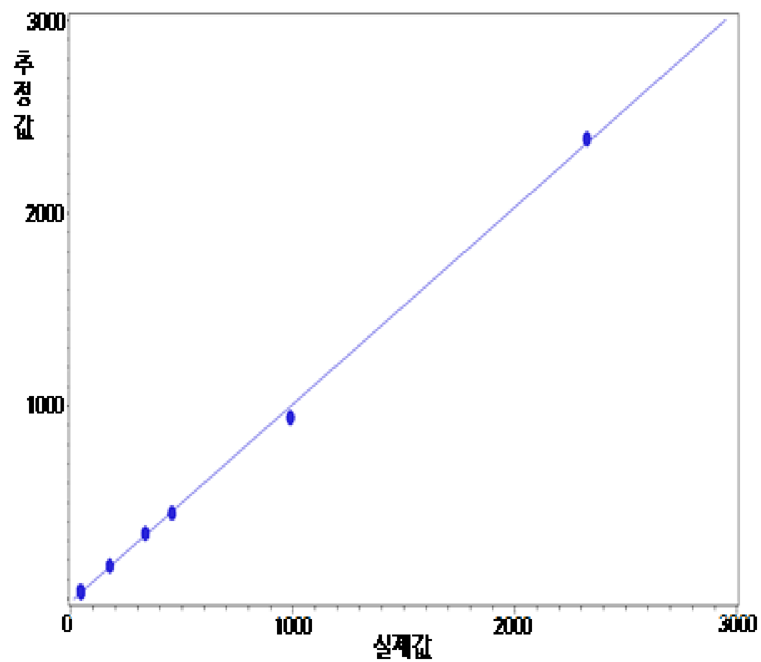
Estimated R&D Cost: $WC_T = WC_1 + WC_2 + WC_3 + WC_4 + WC_5 + WC_6$

Developing R&D CER

Step 6. Verifying the integrated R&D CER

Unit: Hundred million won

Weapon System	Real cost	Estimated cost
K-1	339.57	336.1
K-1 resque tank	445.58	448.15
K1A1	171.77	187.53
K-2	2385.73	2329.64
K-200	42.85	42.72
K-200A1	49.11	45.9
K-242	46.66	44.27
K-281	47.51	44.27
K-21	940.35	986.13



MMRE : 0.041

Average deviation between real and estimated costs : about 4%

Developing Mass Production Cost CER

Similar to developing R&D CER, but learning effect needs to be considered.

Formulation for applying learning rate

$$Y_N = AN^b$$

Y_N : the number of labor hours required to produce Nth unit

A : the number of labor hours required to produce the first unit

N : accumulated product quantity

b : exponent for learning curve (2^b = learning rate)

Ex.) Mass production cost 125million won, learning rate 90%,
mass production quantity 1000EA

b = log(0.9) / log(2) = - 0.152

A = 1.25 / (1000^-0.152) = 3.57(cost for the first production)

Developing Mass Production Cost CER

Results of Mass Production Cost CERs

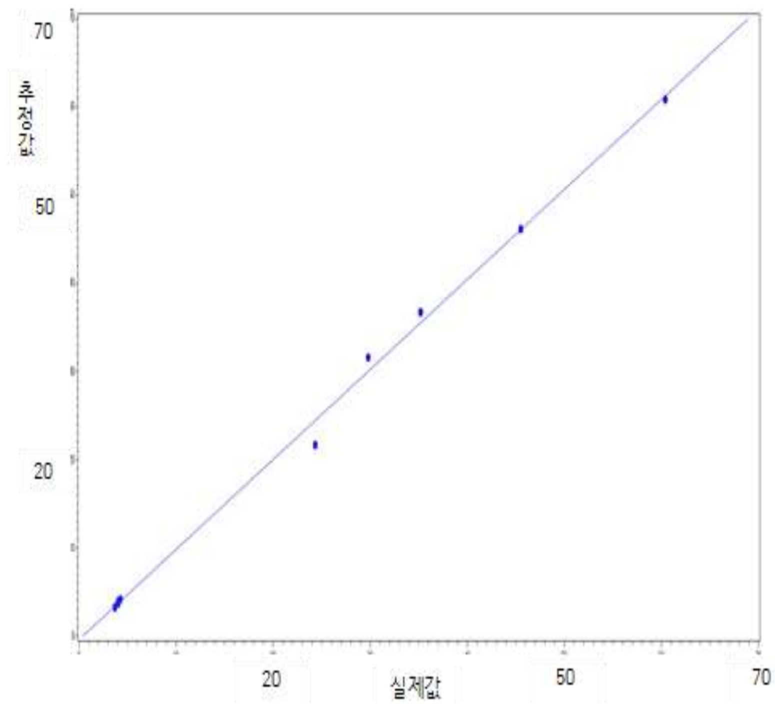
Level 3	CER
Protection structure	Y = {7.4939 + 0.10722(total weight) - 0.0132(cruising range) - 0.0058(maximum torque) + 3.9546(reactive armor)} × (mass production quantity)[b]
Power equipment	Y = {- 23.6445 + 0.2905(total weight) + 0.00282(fuel tank capacity) + 3.3968(engine shape) - 0.0378(maximum torque)} × (mass production quantity)[b]
Suspension equipment	Y = {583.947 + 4.0898(total weight) + 0.07518(cruising range) - 132.666(road wheel) + 165.947(suspension shape)} × (mass production quantity)[b]
Assistant equipment	$Y^{1/4}$ = {4.5426 – 0.9634(length) + 0.1346(total weight) + 0.9641(hole pass ability) + 5.762(C4I system interworking)} × (mass production quantity)[b]
Turret	Y^{-2} = {- 641.428 + 14.429(total weight) + 564.197(active protection driver)} × (mass production quantity)[b]
Fire control system	Y = {- 96.70713 + 0.00117(telescope sight detectable range) + 4.78319(fire control computer weight)} × (mass production quantity)[b]

Developing Mass Production Cost CER

Total Mass Production CER Verification

Unit : million won

Weapon system	Real value	Estimated value
K-1	46.16	45.52
K-1 rescue tank	31.61	29.8
K1A1	21.68	24.35
K-2	60.85	60.4
K-200	3.27	3.72
K-200A1	4.19	4.28
K-242	3.73	4.05
K-281	3.95	4.05
K-21	36.75	35.2



MMRE : 0.058

Average deviation between real and Estimated costs : about 6%

Contents

Conclusion

1. Introducing Box-Cox transformation
2. Strengthening criteria for multicollinearity
3. First CER developed by domestic data

→ Improving accuracy of cost estimation for ROK weapon system

Future Research

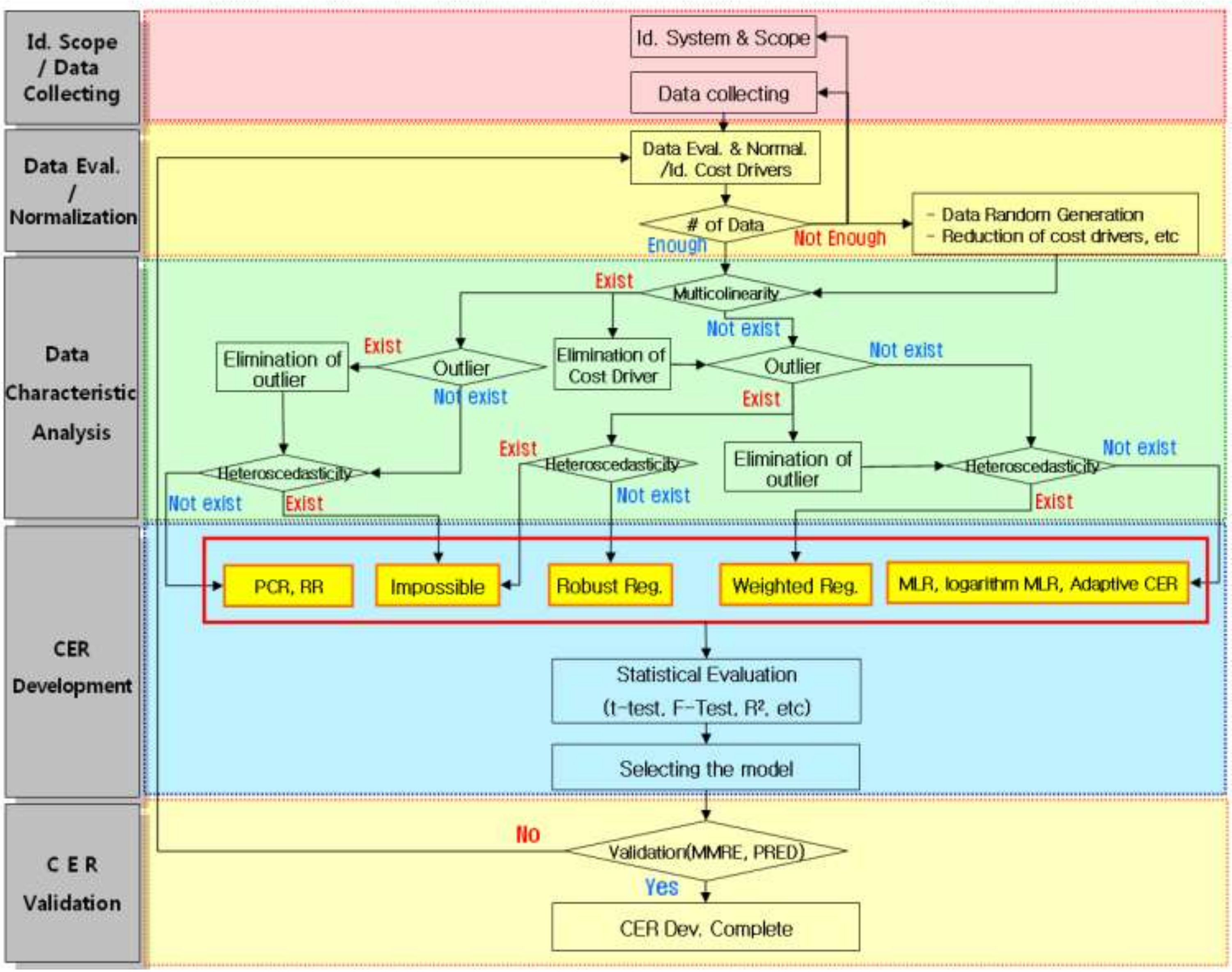
- **Identifying more cost drivers**
  - Cost is influenced by not only the physical specifications of the materials like weight and range, but also the quality of those materials, so we need to add variables in connection with them.

- **Need to develop a system to collect accurate data**
  - It is difficult to collect accurate data because there is no system to collect data
  - So we need to make the framework for gathering cost data of WBS.

Thank You!

Appendix

CER Development Methodology



Verification Criteria for CER

$$R^2_{adj} = 1-(1-R^2)\frac{n-1}{n-p-1} \geq 0.8$$

(n : No. of data, p : No. of independent variable)

$$MMRE = \frac{1}{n}\sum_{i=1}^{n}\frac{|y_i - \hat{y_i}|}{y_i} \leq 0.25$$

(y_i : real value, $\hat{y_i}$: estimating value)

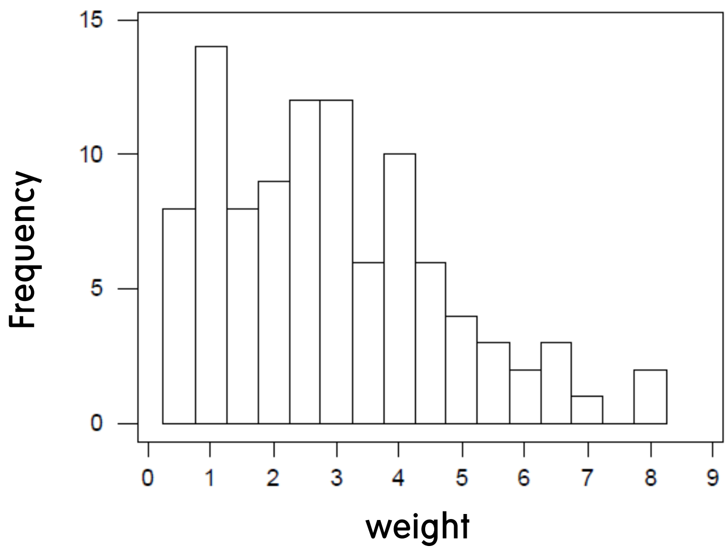
$$PRED(0.25) = L / n \geq 0.75$$

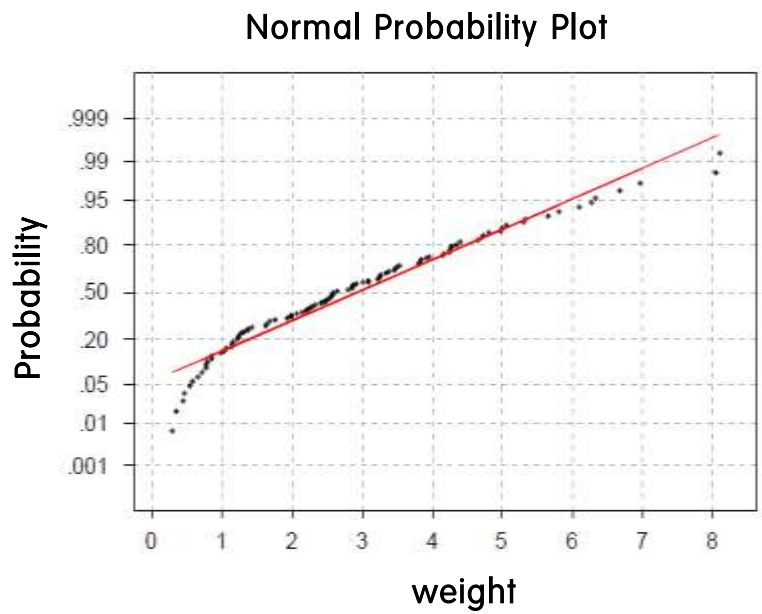
(n : No. of data, L : No. of data corresponding MRE $\leq$ 0.25)

Transformation of Dependent Variable(1/2)

Box-Cox Transformation procedure

- Select power λ of dependent variable to meet normality of data
- Apply maximum likelihood method to find best λ





This graph did not meet normality.

Transformation of Dependent Variable(2/2)

Application to CER for R&D cost of protection structure

1. CER before Box-Cox:

Y = - 279.4858 + 2.8558(total weight) + 3.4547(maximum speed)

- 0.0149(engine output) + 164.936(existence of reactive armor)

MMRE : 0.333 ($\leq$0.25) PRED(0.25) : 0.333 (<0.75)

$\lambda = 0.5$

2. CER after Box-Cox:

$Y^{1/2}$ = - 8.891 + 0.1716(total weight) + 0.1505(maximum speed)

- 0.00154(engine output) + 7.7950(existence of reactive armor)

MMRE : 0.086 ($\leq$0.25) PRED(0.25) : 1.00 ($\geq$0.75)