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Analysis of Economic Lifespan for Replacement Policy of Container Ship using Fuzzy Interval Numbers

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Abstract : *This study determined the ship replacement life expectancy from an economic perspective. There are many ambiguities in the cost for calculation of economic lifespan, and these were expressed as fuzzy numbers. Also, a fuzzy cost model using fuzzy numbers was developed and suggested as a more practical analysis method than the existing cost model. And the suggested fuzzy model was used to determine the economic lifespan for various types of container ships. As the result, Without fuzziness, the economic lifespan of 5000 TEU Ships was found to be 19 years. it was found that the greater the container ship, the greater the economic lifespan was.*

Key words : *Economical replacement policy, Fuzzy number, Existing cost model, Fuzzy cost model, Economic lifespan*

1. Introduction

The recent global economic crisis has caused the shipping economy to shrink, and the shipping companies are putting in many efforts to cut costs such as selling ships and introducing cheaper ships.

Accordingly, the businesses and military units are actively conducting the study to find the replacement point of deteriorated equipment, and there are even departments dedicated to replacement(Kim & Kim, 1999).

Due to concerns about high costs and loss of profit due to service halt during equipment replacement, however, the awareness of loss factors such as increased maintenance and repair costs due to the deterioration of equipment is relatively poor.

Also in the issue of choosing to replace ships, there are various logical consideration factors as discussed above, but the considerations for the economic efficiency would be the most important. Surely, it would be rational for the economic efficiency to consider the freight charges due to transportation of the freight and the costs for ships, but if the ships can be ordered according to a plan and the operation of alternate ships is made available, the matter boils down to the economic efficiency of the freight charges of the ship. In this case, if the economic lifespan periods for ships are analyzed and a rational replacement plan is promoted, the waste arising from unnecessary costs could be stopped on the forwarder's part.

As a method to determine the economic lifespan of equipment, the annual average cost method is widely known(Bae et al, 2010; Kang & Lee, 2002). This method, however, assumes that the equipment price does not change and there is no used price. Actual equipment, however, fluctuates depending on the interest rate, so the changing price must be considered, and in the calculation of actual replacement cost, the used value needs to be considered. As a method complementing such shortages of annual average cost method, the annual equivalent cost method is suggested and used. Meanwhile, the interest rate in the annual equivalent cost method differs in the cost depending on the market price of the equipment and the inflation, so such price fluctuations needs to be considered together. Also, quite a bit of ambiguity is included in the actual data and thus there are limitations to definitive analysis. Therefore, the annual equivalent cost model using fuzzy numbers is suggested and applied to the container ship to analyze the economic lifespan of container ship in this study. Also, for simplicity of application, it is necessary to establish an expandable model from the beginning so that it can be applied to container ships of any capacity. For this, this study uses fuzzy regression model to suggest a flexible model to easily draw the results with simple change in parameters.

2. Equipment Lifespan Method and Fuzzy Number

2.1 Annual Equivalent Cost Method Considering Price Fluctuations

The annual equivalent cost method makes use of the fact

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that the current value of all costs for n years multiplied with capital recovery factor yields annual average equivalent cost(Terborgh, 1949; Terborgh, 1958). The annual equivalent cost represents the annual average cost for certain equipment and the one with the lowest cost can be said to be the economic lifespan. Meanwhile, the interest rate fluctuates in real life according to market price of the equipment or inflation. Therefore, such price fluctuations need to be reflected to the model. In this study, the annual equivalent cost model incorporates price fluctuations. Generally, the consideration factors for the economic lifespan of the container ships are the building costs for a new ship, the value of an used ship, and the maintenance costs. Thus

· Cost of Container Ship = Building Cost for a New Ship − Used Ship Price + Maintenance Cost

All equipment has interest rates, so the capital regression coefficient which is the cost that brings this to the present is:

$$\{\frac{i(1+i)^n}{((1+i)^n-1}\}$$

Thus, the method to calculate the annual equivalent cost of building cost for a new ship, used ship price, and maintenance cost using capital regression coefficient.

P The annual equivalent cost of building cost for a new ship is:

$$P\times\{\frac{i(1+i)^n}{((1+i)^n-1}\}$$

T_nHere, for the residue value, let the residue value after n years be

Current value of residue value: $\frac{T_n}{(1+i)^n}$

Annual equivalent cost: $\frac{T_n}{(1+i)^n}\times\{\frac{i(1+i)^n}{((1+i)^n-1}\}$

The maintenance cost is the present value of the maintenance cost for j years:

$$\frac{M_j}{(1+i)^j}$$

The present value of maintenance cost for n years:

$$\sum_{j=1}^{n}\{\frac{M_j}{(1+i)^j}\},\ (j=1,...,n)$$

Thus, annual equivalent cost of these maintenance costs:

$$[\sum_{j=1}^{n}\{\frac{M_j}{(1+i)^j}\},\ (j=1,...,n)]\times\{\frac{i(1+i)^n}{((1+i)^n-1)}\}$$

And here, the price fluctuation k for inflation h:

$$k=\frac{1+i}{1+h}-1$$

Thus, the total annual equivalent cost is:

$$E_n=P+\sum_{j=1}^{n}\frac{M_j}{(1+k)^j}-\frac{T_n}{(1+k)^n}\times\frac{k(1+k)^n}{(1+k)^n-1} \quad (1)$$

Therefore, the economic lifespan is the minimum value of the total annual equivalent cost

Economic lifespan: $n^*=min\{E_n, i=1,2,...n\}$

But there are numerous ambiguities in the real-life data. Thus, these ambiguities need to be expressed as fuzzy numbers in a fuzzy model.

2.2 Definition of Fuzzy Number and Calculation Method

Before bringing the fuzzy annual average cost model to the present, the fuzzy numbers and related arithmetic operations shall be explained first(Chang, 2005).

Definition 1. $0\leqq a\leqq 1$, $\widetilde{a_\alpha}$ The fuzzy number in the fuzzy space $R=(-\infty,\infty)$ is called α - level fuzzy point, and $\widetilde{a_\alpha}$ the membership function is as in the formula.

$$\mu_{\widetilde{\alpha_x}}(x)=\begin{cases}\alpha, & x=a,\\ 0, & x\neq a,\end{cases}$$

Definition 2. $\widetilde{N}=(m_1,m_2,\lambda,\beta)_{LR}$ The fuzzy set defined on fuzzy space R is called LR-fuzzy number and $\widetilde{N}$ the membership function is

$$\mu_{\widetilde{N}}(x)=\begin{cases}L((m_1-x)/\lambda), & m_1-\lambda\leq x\leq m_1,\\ 1, & m_1\leq x\leq m_2\\ R((x-m_2)/\beta), & m_2\leq x\leq m_2+\beta\\ 0, & otherwise,\end{cases} \quad (2)$$

But, $c\leq a\leq b\leq d$

Here, $\mu_{\widetilde{N}}(x)\in[0,1]$ means the degree of membership of factor x and $\widetilde{N}$. $[m_1,m_2]$ is the peak of $\widetilde{N}$, and $\lambda>0$ and $\beta>0$ means the left and right width. L and R are the left and right reference functions: $[0,1]\rightarrow[0,1]$

L(0)=R(0)=1, L(1)=R(1)=0 which is monotone increasing. Meanwhile, expressing $\widetilde{N}=(m_1,m_2,\lambda,\beta)_{LR}$ in another format results in $\widetilde{N}=(l,m_1,m_2,u)_{LR}$. Here is $l(\equiv m_1-\lambda)$ and $\beta(\equiv m_2+\beta)$, which shows the boundary between the top layer and the bottom layer. For each of $\widetilde{N}$ and $(l,u)\widetilde{N}$, here the membership function of $\widetilde{N}$, $\mu_{\widetilde{N}}(x)>0,\ \forall x\in(l,u)$ and $\widetilde{N}$ the α-level of certain interval fuzzy is the degree of special membership, and α-level set is the normal consecutive closed interval. It is defined with $N^a=[l^a,u^a]$, $\widetilde{N}$ of $x \mid \mu_{\widetilde{N}}(x)\gg\alpha, x\in\mathbb{R}\}$.

$$N^a=\begin{cases}[L^{-1}(\alpha),\ R^{-1}(\alpha),\ \text{if}\ \ \alpha\in(0,1),\\ [m_1,m_2]\ \ \text{if}\ \alpha=1,\end{cases} \tag{3}$$

$\forall\alpha\in(0,1]$ Here, $L^{-1}$and $R^{-1}$are the inverse functions of L and R respectively . After all, the interval fuzzy becomes α-level set$\widetilde{N}$:=$[N^a=[l^a,u^a],\ \forall\alpha(0,1]\}$. If $m_1=m_2=m$ is applied to formula (2) and formula (3), it becomes $\widetilde{N}=(l,m,u)_{LR}$, and applying it to triangle fuzzy number results in $(l,m,u)_T$

$$\mu_{\widetilde{N}}(x)=\begin{cases}1-((m-x)/(m-l), & il\le x\le m,\\ 1-((x-m)/(u-m), & im\le x\le u\\ 0, & otherwise,\end{cases}$$

Expressing this as a set of α-level set is

$\widetilde{N}$:=$[N^a=[l^a,u^a]=[(m-l)\alpha+l,u-(u-m)\alpha],\ \forall\alpha(0,1]\}$

The fuzzy numbers $\widetilde{N_1}$, $\widetilde{N_2}$ fuzzy calculation using expansion principle of Zadeh are $N_1^a=[l_1^a,u_1^a]$, $N_2^a=[l_2^a,u_2^a]$

$$\widetilde{N_1}\otimes\widetilde{N_2}:=\{[min(l_1^al_2^a,l_1^au_2^a,u_1^ql_2^a,u_1^al_2^a),$$
$$max(u_1^au_2^a,u_1^al_2^a,l_1^au_2^a,l_1^al_2^a)],\ \forall\alpha\in(0,1]\},$$
$$\widetilde{N_1}\oslash\widetilde{N_2}:=\{[min(l_1^a/u_2^a,l_1^a/l_2^a,u_1^q/u_2^a,u_1^a/l_2^a),$$
$$max(u_1^a/l_2^a,u_1^a/u_2^a,l_1^a/l_2^a,l_1^a/u_2^a)],\ \forall\alpha\in(0,1]\},$$
$$\widetilde{N_1}\oplus\widetilde{N_2}:=\{[l_1^a+l_2^a,u_1^a+u_2^a],\ \forall\alpha\in(0,1]\},$$
$$\widetilde{N_1}\ominus\widetilde{N_2}:=\{[l_1^a-u_2^a,u_1^a-l_2^a],\ \forall\alpha\in(0,1]\}$$

Here, except for addition and subtraction, the initial value of fuzzy numbers cannot be conserved.

3. Development of Fuzzy Annual Equivalent Cost Model

3.1 Cost Model Application of Fuzzy Regression

In this study, for the cost regarding various container ship capacities, the fuzzy regression model shall be used for expansion(Chang, 2005). There are many known fuzzy regression models, but a general case is as follows:

$$\widetilde{Y}=f(x,\widetilde{A})=\widetilde{A}_0\oplus\widetilde{A}_1\otimes x_1\oplus\cdots\oplus\widetilde{A}_w\otimes x_w=\widetilde{A}^t\otimes x,$$

Here $\widetilde{A}=(\widetilde{A}_0,...,\widetilde{A}_1,...,\widetilde{A}_w)^t$ is the vector of the fuzzy regression number and $x=(1,x_1,...,x_w)^t$ $\widetilde{A}_j=(l_j,m_j,u_j)_T$ is the non-fuzzy independent variable. Fuzzy coefficient is $(m_j-l_j\equiv u_j-m_j)$ using triangle. For convenience, $c_j\equiv m_j-l_j=u_j-m_j$ and $\widetilde{A}_j$can be expressed in short as $\widetilde{A}_j=(m_j,c_j)$ using the spread format. The arithmetic expression for the fuzzy output of a general fuzzy regression model is:

$$\widetilde{Y}=(l_0,m_0,u_0)_T\oplus(l_1,m_1,u_1)\otimes x_1\oplus\cdots\oplus(l_w,m_w,u_w)_T\otimes x_w$$
$$=(l_0+\sum_{j=1}^{w}l_jx_j,m_0+\sum_{j=1}^{w}m_jx_j,u_0+\sum_{j=1}^{w}u_jx_j)_T$$
$$=(m_0+\sum_{j=1}^{w}m_jx_j,c_0+\sum_{j=1}^{w}c_j\mid x_j\mid)=(m^tx,c^t\mid x\mid),$$

Here, $m=(m_0,m_1,...,m_w)^t$, $c=(c_0,c_1,...,c_w)^t$, $\mid x\mid=(1,\mid x_1\mid,...,\mid x_w\mid)^t$and the membership function is

$$\mu_{\widetilde{N}}(x)=\begin{cases}1-\mid y-m^tx\mid/c^tx, & if\mid y-m^tx\mid\le c^tx,\\ 0, & otherwise,\end{cases}$$

The w set of observed crisp data (y_i,x_i), $i=1,2,...,W$, W set can be said to be $x_i=(1,x_{i1},...,x_{iw})^t$. The fuzzy regression number $\widetilde{A}=(m_j,c_j)$ can be obtained as follows.

$$\min\ J=\sum_{i=1}^{w}(c_0+c_1\mid x_{i1}\mid+\cdots+c_w\mid x_{iw}\mid,$$
$$\text{subject to}\ c^t\mid x_i\mid\geqq 0,$$
$$m^tx_i+(1-\alpha)c^t\mid x_i\mid\geqq y_i,$$
$$-m^tx_i+(1-\alpha)c^t\mid x_i\mid\geqq -y_i,\ \forall i,$$

Here, $\forall\alpha\in(0,1]$ is determined by the decision maker. Therefore, the fuzzy regression model can be used to calculate the cost due to TEU. That is, the operation cost for n years for O TEU of container ship is

$$\widetilde{M}_n^o=\{[M_{n,l}^{o,a},M_{n,u}^{o,a}],\ \forall\alpha\in(0,1]\} \tag{4}$$

The ship building cost for container ship O TEU can be expressed as

$$\widetilde{P}^{o} = \{[P_l^{o,a}, P_u^{o,a}],\ \forall\alpha \in (0,1]\} \quad (5)$$

3.2 Fuzzy Model Development of Annual Equivalent Cost

Thus, the annual equivalent cost model can be modeled to a fuzzy model using interval fuzzy numbers based on the above definition as follows.

The fuzzy capital regression coefficient for capital regression coefficient is

$$(\frac{\widetilde{A}}{\widetilde{P}}\tilde{I},n) = \frac{\tilde{i}\,(1+\tilde{i}\,)^n}{(1+\tilde{i}\,)^n-1} = \{\frac{[i_l^a, i_u^a][\times](1+[i_l^a, i_u^a])^n}{(1+[i_l^a, i_u^a])^n-1}2,$$
$$\forall\alpha \in (0,1]\}$$
$$= \{[\frac{i_l^a(1+i_l^a)^n}{(1+i_l^a)^n-1}, \frac{i_u^a(1+i_u^a)^n}{(1+i_u^a)^n-1}],\ \forall\alpha\in(0,1]\}$$

The fuzzy annual equivalent cost for the annual equivalent cost of P of new ship building costs for container ship O TEU is

$$\widetilde{P}^{o}\otimes(\frac{\widetilde{A}}{\widetilde{P}}\tilde{I},n) = \{[P_l^{o,a}, P_u^{o,a}][\times]$$
$$[\frac{i_l^a(1+i_l^a)^n}{(1+i_l^a)^n-1}, \frac{i_u^a(1+i_u^a)^n}{(1+i_u^a)^n-1}\cdot\ \forall\alpha\in(0,1]\}$$

The fuzzy residue present value for the present value of the residue value for container ship O TEU is

$$\frac{\widetilde{T}_n^o}{(1+\tilde{i}\,)^n} = \{\frac{[T_{n,l}^{o,a}, T_{n,u}^{o,a}]}{(1+[i_l^a+i_u^a])^n},\ \forall\alpha\in(0,1]\}$$

The fuzzy residue annual equivalent cost for the residue value annual equivalent cost of container ship O TEU is

$$\frac{\widetilde{T}^o{}_n}{(1+\tilde{i})^n}\otimes(\frac{\widetilde{A}}{\widetilde{P}}\tilde{I},n) = \{\frac{[T_{n,l}^{o,a}, T_{n,u}^{o,a}]}{(1+[i_l^a, i_u^a])^n}[\times]$$
$$[\frac{i_l^a(1+i_l^a)^n}{(1+i_l^a)^n-1}, \frac{i_u^a(1+i_u^a)^n}{(1+i_u^a)^n-1}],\ \forall\alpha\in(0,1]\}$$

For the maintenance cost for container ship O TEU, the fuzzy present value of maintenance cost for j years is

$$\frac{\widetilde{M}_j^o}{(1+\tilde{i}\,)^j} = \{\frac{[M_{j,l}^{o,a}, M_{j,u}^{o,a}]}{(1+[i_l^a+i_u^a])^j},\ \forall\alpha\in(0,1]\}$$

The fuzzy annual equivalent cost of maintenance cost for n years regarding containership O TEU is

$$[\sum_{j=1}^{n}\{\frac{\widetilde{M}_j^o}{(1+\tilde{i}\,)^j}\},\ (j=1,\dots,n)]\otimes(\frac{\widetilde{A}}{\widetilde{P}}\tilde{I},n)$$
$$= \{\frac{[M_{j,l}^{o,a}, M_{j,u}^{o,a}])}{(1+[i_l^a, i_u^a])^j}[\times][\frac{i_l^a(1+i_l^a)^n}{(1+i_l^a)^n-1}, \frac{i_u^a(1+i_u^a)^n}{(1+i_u^a)^n-1}],$$
$$\forall\alpha\in(0,1]\}$$

The fuzzy $\tilde{k}$ for price fluctuation k for inflation h is

$$\tilde{k} = [(1\oplus\tilde{i}\,)\oslash(1\oplus\tilde{h}\,)]-1$$
$$= \{[(1+i_l^a, 1+i_u^a)\oslash(1+h_l^a, 1+h_u^a)]-1,\ \forall\alpha\in(0,1]\}$$
$$= \{[\frac{(1+i_l^a)}{(1+h_u^a)}, \frac{(1+i_u^a)}{(1+h_u^a)}]-1,\ \forall\alpha\in(0,1]\}$$

Thus, the fuzzy annual equivalent cost model for container ship O TEU changes from the model of formula (1) to the model considering fuzziness.

$$\widetilde{E}_n^o = \widetilde{P}^o\oplus\sum_{j=1}^{n}\frac{\widetilde{M}_j^o}{(1+\tilde{k}\,)^j}\ominus\frac{\widetilde{T}_n^o}{(1+\tilde{k}\,)^n}\otimes\frac{\tilde{k}\,(1+\tilde{k}\,)^n}{(1+\tilde{k}\,)^n-1} \quad (6)$$

But, $\tilde{k} = \{(1\oplus\tilde{i}\,)\oslash(1\oplus\tilde{h}\,)\}-1$

Thus, fuzzy economic lifespan is the value that minimizes

$$\tilde{n}^{o*} = min\{\widetilde{E}_n^o, i=1,2,\dots n\}$$

4. Application of Fuzzy Annual Equivalent Cost Model

4.1 Fuzzy Cost Analysis for Container Ship

There are various forms for classification of raw costs related to ships, but it is general practice to divide it into ship cost and transport cost. Ship cost includes labor cost, repair/maintenance cost, insurance, ship article cost, and general management costs, and the transport cost can be divided into fuel cost and port charge.

This study employed the resources(Park et al, 2006) that analyzed the economic efficiency of container ships for analysis of economic lifespan of container ships.

Based on the pacific course, the annual ship operation costs for container ships can be shown as in Table 1.

Table 1. Shipping service tariff Unit: $

TEU(min)	TEU(mean)	TEU(max)	Maintenance Cost
3,800	4,000	4,200	2,314
5,900	6,000	6,100	1,962
9,900	10,000	10,100	1,449

As in Table 1, it can be seen that from 2,314 dollars for

3,800~4,000 TEU, as TEU increased to 9,900~10,100 TEU, it was reduced to 1,449. Based on the data of Table 2, the fuzzy regression formula for operation cost M against TEU fluctuation of X is as in formula (7).

$$\widetilde{M} = 2,074.7 - (0.063 \pm 0.002)X \quad (7)$$

Meanwhile, the new ship building cost for a container ship is as in Table 2.

Table 2. Container Ship's First hand article price

Unit: Million $

TEU(min)	TEU(mean)	TEU(max)	Building Cost for a New Ship
900	1,000	1,100	21
2,350	2,500	2,650	41
3,900	4,000	4,100	50
6,800	7,000	7,200	88

As seen in Table 2, the new ship building cost varies depending on the capacity of the container ship as in 21 million dollars for 900 ~ 1,100 TEU and 88 million dollars for 6,800 ~ 7,200 TEU, and the price increased as TEU increased. Thus, based on Table 3, the new ship building cost P for the TEU fluctuation X is as in formula (8).

$$\widetilde{P} = 11,217,544 + (10,825 \pm 1,158)X \quad (8)$$

4.2 Determination of Economic Lifespan by Fuzzy Annual Equivalent Cost Model

When $\alpha = 0$ for 1,000TEU, the fuzzy data for the ship operation cost and used value is as in Fig 1.

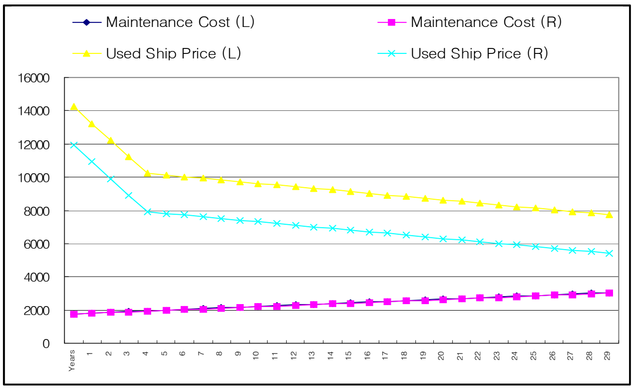

Fig. 1 Shipping Operation Cost

As seen in Table 2, The maintenance costs increased every year, and the used ship price appeared every year by decreasing. especially, the used ship price suddenly decreased until four years a period of service.

Using Fig. 1, the economic lifespan is calculated for 1,000 TEU ships, and Fig. 2 is the result.

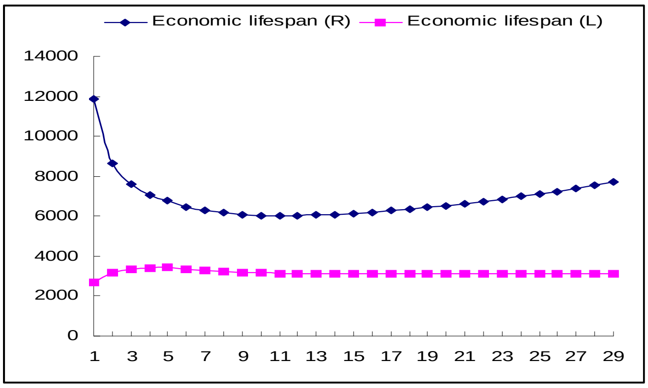

Fig. 2 Economic lifespan for 1,000 TEU ships by α-level=0

As seen in Fig. 2. when $\alpha = 0$, the minimum value was found to be [16, 11]years.

The analysis of economic lifespan depending on the capacity of various container ships is as in Table 3.

Table 3. α-level set of ship's economical life

α	1,000TEU	5,000TEU	10,000TEU
1.0	[17]	[19]	[22]
0.9	[17,15]	[19,17]	[22,18]
0.8	[17,14]	[19,16]	[22,17]
0.7	[17,14]	[18,15]	[22,16]
0.6	[16,13]	[18,14]	[21,15]
0.5	[16,13]	[18,13]	[21,14]
0.4	[16,12]	[18,13]	[21,13]
0.3	[16,12]	[18,12]	[21,13]
0.2	[16,11]	[18,12]	[21,12]
0.1	[16,11]	[17,12]	[20,12]
0.0	[16,11]	[17,11]	[20,11]

As seen in Table 3, the economic lifespan was found to be increasing as the capacity of container ship increased. The model of this study is annual equivalent cost method, which, as shown in formula (7) and (8), as the container ship capacity increases, the increase in used value appears greater than the increase in operation costs.

Meanwhile, examining the economic lifespan according to change in a, the container ship of 5,000 TEU has some fluctuations of about 6 years with [17, 11] for $\alpha = 0$, and [18, 13] for $\alpha = 0.5$ with 1 additional year in the lifespan with about 5 years in fluctuations. $\alpha = 1$ Without fuzziness, the economic lifespan was found to be [19] years.

Also, for 10,000 TEU ships, the fluctuation was about 9 years with [20, 11] for $\alpha = 0$, and [21, 14] for $\alpha = 0.5$ with 1 additional year in the economic lifespan with 7 years of fluctuation, and for $\alpha = 1$, the economic lifespan was increased by a year to be [22] years.

From such results, the fluctuation was found to be increasing along with the increase in the capacity of the container ship. Thus, it can be seen that it is a more flexible model to analyze the economic lifespan by the decision-maker determining an appropriate α.

5. Conclusion

Regarding the choice to replace the ships, there are numerous logical consideration factors as discussed earlier, but the consideration for economic efficiency would be more important than anything. Meanwhile, the annual equivalent cost method is used to complement the shortfalls of annual average cost method, but the price fluctuations need to be considered for cost calculations, and for a practical analysis, this can be said to be more practical by analyzing with treatment of fuzzy numbers rather than definitive data. Thus, in this study, the fuzzy regression model that can reflect fuzzy numbers and capacity of model ships was used to establish a simple and flexible fuzzy annual equivalent cost model, which was applied to the container ships to analyze their economic lifespan.

As the result, it was found that the greater the container ship, the greater the economic lifespan was. Such results is caused by the fact that the increase in used ship price is greater than the increase in operation cost. Practically, equipment is bound to have an used value, so for an issue of equipment replacement by a long-term plan such as the container ship replacement plan, it would be more rational to use the annual equivalent cost method than the annual average cost method. This study analyzed the ship replacement period which still lacks research works domestically from the perspective of economic efficiency, and can be utilized as an elementary material when making decisions on the ship replacement period.

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