Resilience modeling of nuclear industry for nuclear power phase-out in South Korea: Spirit from the Center for Technology and Systems Management at the University of Maryland

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1. Introduction

The resilience modeling is performed for the nuclear industry in South Korea for the nuclear power phase-out. There are many different kinds of situations for the public acceptance and favorability in nuclear energy. Recently, the nuclear industry in South Korea has suffered from the turmoil produced by the newly announced nuclear free policy. However, the situations have progressed in two significant directions as the scheduled power generation halting in a domestic side and the expanding in an export side. Following the declaration of nuclear free era in South Korea, it has been a hot issue in the global nuclear power plants (NPPs) markets (Song, 2017). The phase-out of the nuclear power had been planned in 2017 by the South Korean government until 2083. So, the recovery of the nuclear power reactivation strategy could be interesting to the Korean nuclear industry. It was done in 2017 that the suspension of constructing the Shin-Kori unit 5 & 6 had started the public discussions to reactivate the constructions (Herh, 2017) and the decision was to resume the construction (Kim, 2017; SKPDC, 2017). These reactors are the Advanced Power Reactor 1400 (APR 1400) type. During this period, the Korea Electric Power Corporation (KEPCO) has been selected as the priority constructor of new NPPs in Moorside, United Kingdom (UK) (BBC, 2017).

This kind of double standing situation as domestic ceasing and exporting favoring is based on the mismatch between political view and economical status. That is, the politicians have worried about the potential possibility of dangerous nuclear accident. Especially, the Fukushima nuclear disaster has impacted on the South Korean politicians extremely and seriously. In real situation, currently, all fishery imported goods from the Fukushima and adjacent areas have been investigated for the radioactive contaminations. However, there is an example of the industrial change in the United States. After terminating the nuclear power construction at 1979 from Three Mile Island (TMI) NPP accident, the re-buildings of the NPP have been done in Georgia and South Carolina. It is possible to imagine the military defense strengthening was done after 9/11 terror when the nuclear force had been rearranged and the nuclear industry also has been focused as the partner in the war against the terrorism. So, it is imaginable to make the cause to reactivate using the export to UK which is similar to the case of the defense booming in nuclear industry as well as nuclear force. By the way, considering the cost of terror attack produced disaster, it is not expensive in cost to reactivate the nuclear industry as the exporting to UK in South Korea. It is shown in Fig. 1 for the comparisons of considerable progresses in nuclear industry between United States and South Korea.

2. Methods and Results

It is proposed as the social matter based investigations on the resilience of the nuclear industry (Ayyab, 2013; 2014a; 2014b). So, three factors as society, human, and environment could be regarded as a certain industrial failure which are reflected in the modeling.

2.1 Analysis of resilience

The theoretical meaning of the resilience is in the material science and technology where industrial features are described such as the stress-strain curve in Fig. 2 (Beer et al., 2015). The lower one curve is utilized for the application in this study for the analogy of the event resilience. There is the equation for the stress and strain in which the following equation is described in the material sciences,

$$\begin{aligned} &Modulus\ of\ resilience \\ &= \frac{1}{2} \times (Yiled\ point\ stress) \\ &\times (Elastic\ strain) \\ &= \frac{(Yiled\ point\ stress)^2}{2 \times Young's\ Modulus} \end{aligned} \tag{1}$$

Unit is varied as follows,

$$Modulus\ of\ resilience \propto (Force)^2 \propto \frac{Energy}{Volume} \tag{2}$$

So, the force could be proportional to the energy regarded as the entropy which is considered as a chaotic feature in the social problem as well as the thermodynamic matter. The procedure of resilience based nuclear industrial consequences is in Fig. 3. There are several stages as Normal, Failure, Aftershock, Recovery, Stable, and Developing in which the period from Failure to Recovery is the important interval. Aftershock means the extremely significant event that could change the event flow. It is seen for the recovery period and stable period. For the South Korea, the

international trading would be the factor of the Aftershock. That is, the export to UK could be a trigger of the industrial reactivation. In this work, the chance to export to UK could be described as the critical point. Then, the Recovery is positioned on the upper side comparing to the Failure, because the unstable environments could be still exited. It is thinkable of the analogy for the degree of industrial stagnations in which the stress could be the quantity of the industrial depression to be changed to the energy which can be understood as the entropy for the degree of chaos or the randomness. Entropy has the unit as follows,

$$Entropy \propto \frac{Energy}{Temperature} \tag{3}$$

The operation and production are included in the normal condition. If not, the failure is related to the resistance and corruption. The recovery can be regarded as the integrity and restore. Fig. 4 is the meaning for the procedure of resilience where 3 major important points could give the meaning of the events. Although the Failure has resistance and corruption, in the Recovery the curable situations could be shown as integrity and restore.

For the application to the topic in this study, Fig. 5 is the analogy for the recovery curve in the procedure of resilience. In Fig. 5 (a), there are 3 kinds of material deformation graphs where the upper one has the biggest modulus of resilience. So, the highest cost is needed to be recovered. Similarity, the event flow graphs are described where the gap between Failure and Recovery is shown in Fig. 5 (b) which is simplified one from Fig. 3. So, in this graph, the area and gap are characteristics of the analogy the recovery curve.

2.2 System dynamics (SD)

The system dynamics (SD) is applied to the description in which several variables are quantified by the designed algorithm that was created by Dr. J. Forrester in MIT around 1960s (SDS, 2017). In the representative characteristics, the Level and Rate are used which can be described. Using eq. (3),

$$Modulus\ of\ resilience \propto Entropy \propto \int_0^t Energy(t)dt \tag{4}$$

In addition,

$$\frac{dt}{d}(Modulus\ of\ resilience) \propto Energy(t) \tag{5}$$

The accumulation of the event flow can be described by eq. (4) and the rate of event flow can be shown. In addition, Fig. 6 shows the modeling of SD where the Industrial Failure and Recovery are major variables incorporated with the Export to UK using Vensim code system (Ventana, 2015). The variables in the modeling are in Table I where the numeric values are described. In the Society case, the randomly sampled value is lower than 0.3, it is 0. Otherwise, it is 1. The Boolean values are generated. In the case of the Recovery, the values are accumulated from 5, which is the meaning of the eq. (4). Hence, it can be described as,

$$Recovery \propto \int_0^t Export\ to\ UK(t)dt \tag{6}$$

For the discrete values,

$$Recovery \propto Export\ to\ UK(1990) + Export\ to\ UK(1990) + \cdots + Export\ to\ UK(2050) = \sum_{t=1990}^{t=2050} Export\ to\ UK(t) \tag{7}$$

Furthermore, there are the multiplication by asterisk and the division by slash mark. It is simple to consider the event quantifications by the arithmetic operations. In Fig. 7, the Causes tree for modeling shows the event flows with the logical connections. The Export to UK is a major factor in the modeling which could make the event flow be opposite in the other result.

In Fig. 8, the simulation results are described modeling as Export to UK. The dynamic simulation is in Fig. 9 in which the favorability of the nuclear industry in South Korea is shown around the zero point. Positive value is more favorable than the negative one. There are some significant events as the Fukushima nuclear accident is in 2011, the declaration of nuclear free era and export to UK in 2017, and the completion of NPPs in UK in 2025. As it is shown in Fig. 9, the graph decreases slightly after shock in 2017 and then the increases a little bit. The decreased one is proposed by government and the increased one is requested by the industry. Finally, the graph decreases abruptly after 2020 that could be done by the acceleration period of the nuclear free policy. After 2022, it increases through 2025 which is the expected completion of the NPPs in UK. The line trend shows the gradual increasing. In Table II, the case for exportation to UK is seen. The analysis of sensitivity is shown as the 30% and 70% to the mean value which is quantified in the simulations. In Table III, there are four major years as 2011, 2017, 2025, and 2050.

3. Conclusions

Using the resilience based area called as the modulus of resilience which is quantified by SD method (Woo, 2018), the dynamic summations are performed. So, it is concluded the depression of the nuclear industry in South Korea is unavoidable, but the gradual effective status as the favorability could be increasing, although it is lower status than that of the pre-nuclear free declaration. Fig. 10 shows the progress in the nuclear industry after significant situation changes where political declaration of the nuclear-free era and successful export to UK are done in South Korea. This is another kind of the nuclear

industry resilience after the nuclear comeback in the United States in which the 9/11 terror attack had provoked the national defense ability incorporated with the nuclear industry booming. So, the historic events could change the direction of the industry. An industry could be affected by the finances which is governed by the supply and demand rule. But, the big industry like the nuclear sector should consider the political aspect, because the finance is very expensive comparing to the stuff of private companies. Hence, it is thinkable that the national presidential election is very important to the groups that take charges in developing the industry like the nuclear energy.

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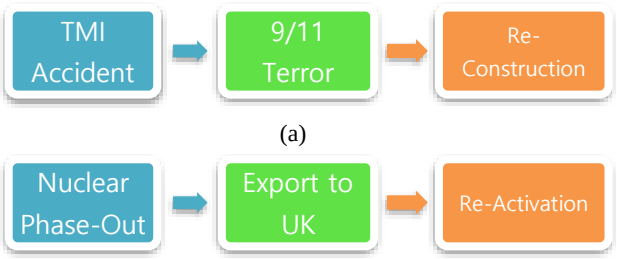


Fig. 1. Comparisons of progress between United States and South Korea.

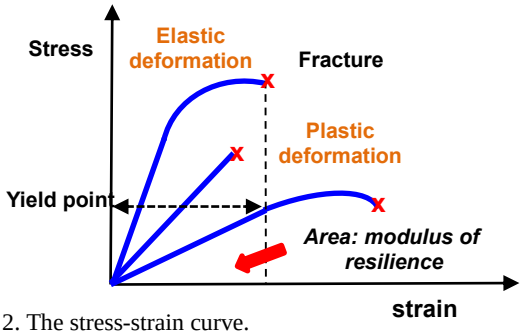


Fig. 2. The stress-strain curve.

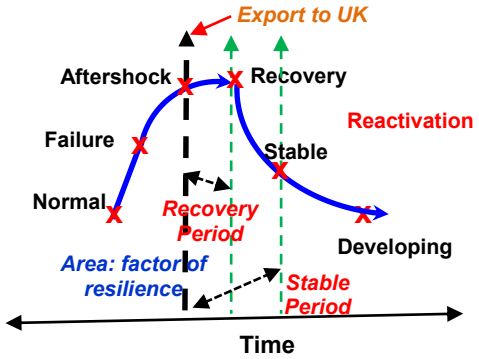
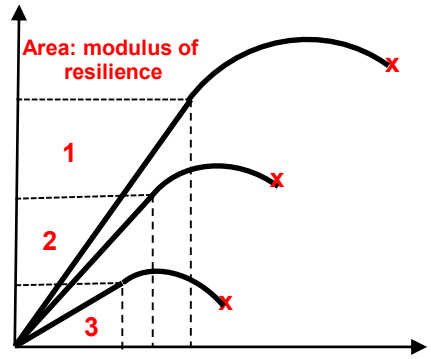
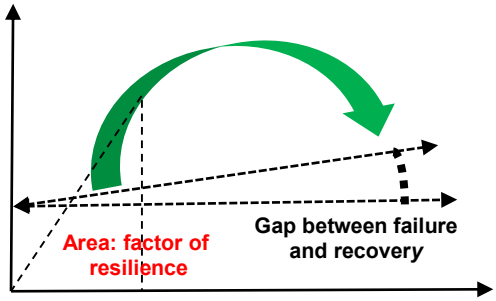


Fig. 3. The modeling of procedure of resilience based nuclear industrial consequences.

Fig. 4. Meaning for the procedure of resilience.



(a)



(b)

Fig. 5. Analogy graph for the recovery curve in the procedure of resilience.

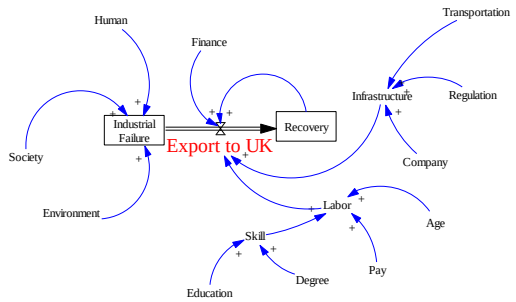


Fig. 6. Modeling of system dynamics (SD) for Export to UK.

Fig. 7. Causes tree for modeling.

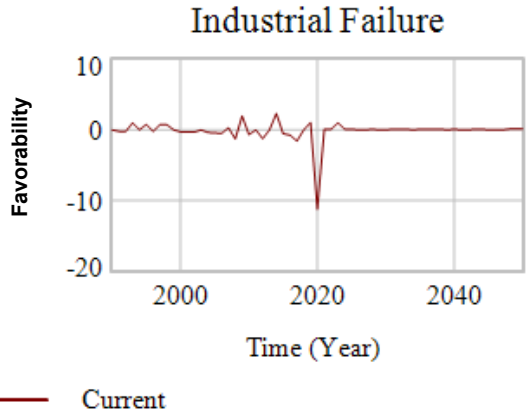


Fig. 8. The results for modeling.

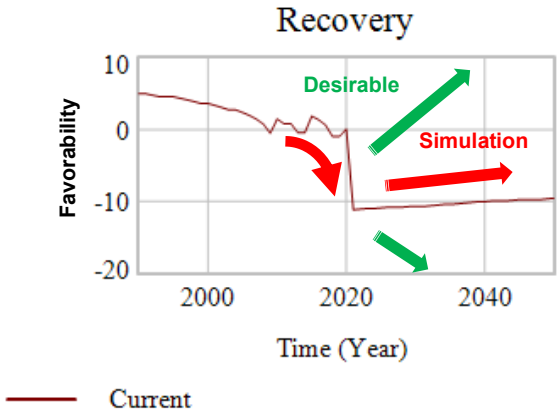


Fig. 9. The result of Recovery.

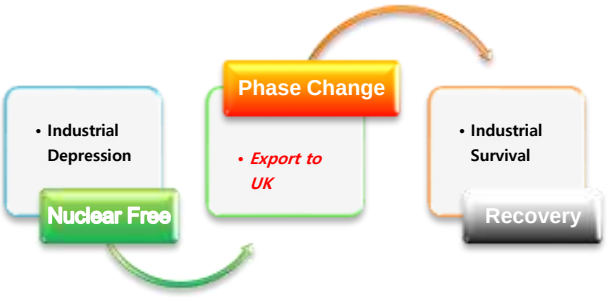


Fig. 10. The progress of nuclear industry by resilience.

Table I: List of variables

Name	Value
Society	if then else(random 0 1 () < 0.3, 0, 1)
Human	if then else(random 0 1 () < 0.7, 0, 1)
Environment	if then else(random 0 1 () < 0.6, 0, 1)
Finance	if then else(random 0 1 () < 0.3, 0, 1)
Education	if then else(random 0 1 () < 0.3, 0, 1)
Degree	if then else(random 0 1 () < 0.7, 0, 1)
Skill	Degree*Education
Age	if then else(random 0 1 () < 0.3, 0, 1)
Pay	if then else(random 0 1 () < 0.5, 0, 1)
Labor	Age*Pay*Skill
Company	if then else(random 0 1 () < 0.4, 0, 1)
Regulation	if then else(random 0 1 () < 0.6, 0, 1)
Transportation	if then else(random 0 1 () < 0.7, 0, 1)
Infrastructure	Company*Regulation*Transportation
Industrial Failure	Environment * Human * Society + Export to UK
Recovery	Export to UK, Initial Value : 5
Export to UK	Finance*Infrastructure*Labor*Recovery - if then else(random 0 1 () < 0.3, 0, 1)/Recovery

Table II: Case for exportation to United Kingdom

Year	Export to UK
2011	0.807636
2017	0.630206
2025	-10.899000
2030	-10.714700
2040	-10.043400
2050	-9.535260

Table III: Analysis of sensitivity

Year	Value	30%	70%
2011	0.807636	0.484582	1.130690
2017	0.630206	0.378124	0.882288
2025	-10.899000	-6.539400	-15.258600
2050	-9.535260	-5.721160	-13.349400