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System Dynamics Modeling for Policy Analysis of Occupational Injuries

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Abstract

Purpose. Because traditional statistics approach had limitations in learning future forecasting and major factors causing occupational injuries in each industry, this paper develops a model forecasting and evaluating occupational injury rate by using a system dynamics model through the analysis of the industry injury statistics and the project for industry injury prevention.
Method. The model of this paper consists of 12 total models such as a model of employees, of industrial disaster victims, of injury rate, etc.; In the analysis of firm size, it is classified and developed according to 12 groups on the basis of the number of employees, and in the analysis of industrial classification, it is done according to 10 total business fields such as manufacturing business, construction one, etc.
Results. This paper suggests the methodology which forecasts industry injury rate by business field and size on the basis of developed model, and evaluates an industry injury prevention project from various angles.
Conclusions. This paper deduced problem through the analysis of an industry injury by business fields and a comparative analysis of foreign cases, and analyzed to affect industry injury prevention by industry. And it also analyzed actual condition of industry injury, and did a difference in the level of safety consciousness according to the general characteristics of workers and occupational safety and health education related characteristics. In result, this paper suggests that analyzing occupational injury related factors, a safety budgetary allocation, and industry injury related factors can reduce illness costs such as employees' injury and medical care, and also assist cost for a disability.

Key Words: Forecasting, Occupational(industry) injury rate, Safety facilities, System dynamics model

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1. Introduction

Occupational injury is an inter-disciplinary domain related to protecting health and safety as well as workers' welfare in employment. The purpose of occupational injury prevention programs includes fostering a safe and healthy environment.[1)]

It may also protect co-workers, family members, employers, customers, and many others who might be affected by the workplace environment. Occupational injury can be important for legal and moral as well as monetary regards. Most of institutions have a duty of care to ensure that employees and any other workers affected by the organizations experiencing an occupational injury remain safe.[2)] Moral obligations grip the defense of human lives and physical condition. Related law practices relate to the preventative, punitive and compensatory effects of laws that protect worker's injury. Analyzing factors related to occupational injury can also reduce employee injury and costs related to disease including medical care, and quit disability assistant costs. Analyzing factors related to occupational injury may involve interactions among many detailed subject areas including occupational medicine, occupational injury, sanitation, healthiness, security, industrial structures, and ergonomics matters. Korean Government calculates annual injury rate using following formular to describe the occupational injuries[2~5)].

where, IR = Measure for occupational injury rate[1)]

Injuries = Number of injuries reported during the year, and

Employee = Average number of employees working on the factories or companies.

$$IR = \frac{Injuries}{Employee}$$

According to the above definition, the historical data shows following trend(Figure 1).

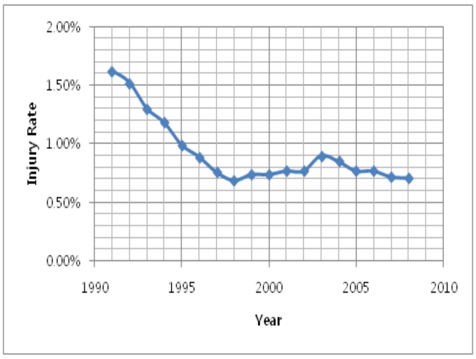

Figure 1. Historical Data for Occupational Injury Rate

As shown in Figure 1, the injury rate was dropped dramatically in the early 1990s, but has been remained at relatively stable level since 1999. Now, Korean government is doubtful that the current level of occupational injury rate is the minimum level.

Noticing that traditional statistical analysis has limitations in learning, the Korean government initiated a system dynamics project.

The system dynamics project had dual purposes; one was to explain why the current steady state is maintained; the other was to analyze the phenomena from the industrial world viewpoint. The first system dynamics project was carried out in 2009, and after the review the second project was started in 2011[6)]. This paper is based on the first system dynamics project.

2. Model Description

The model structure is designed on the basis of the following conceptual framework(Figure 2).

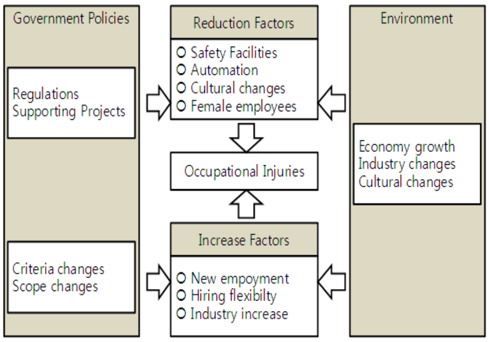

Figure 2. Conceptual Framework of Research Model

Occupational injury rate changes because of 3 increasing factors and 4 decreasing factors as described above. Government may intervene in the systems of both sides. Direct efforts such as subsidies for safety facility reduce the injuries, while any efforts to support the industry result in more injuries because of new employment. Economy and culture changes may alter the occupational injury rate[7~8].

The research model separates the industry into 10 categories and size of companies into 12 categories as described in the following tables.

Table 1. Subscript Variable for Industry

Key Word	Definitions	Examples
IN1	Mining industry	Metal, non-metal, natural resources
IN2	Manufacture industry	Automobile, shipbuilding, aircraft
IN3	Utility industry	Electric, water, gas
IN4	Construction industry	Civil engineering, public works
IN5	Logistic industry	Distribution, warehouse, supply chiains
IN6	Forestry industry	Livestock, ecology-natural resource management
IN7	Fishery industry	Coastal & inshore piscatorial sectors
IN8	Agricultural industry	Farming, hardy plants, cash crop
IN9	Financing industry	Monetary, banking, relief loan, finalcial
IN10	Other industries	Internet, building management, education

Table 2. Subscript Variable for Industry

Subscripts	Number of Employees
EN1	Less than 5
EN2	5 ~ 9
EN3	10~29
EN4	30~49
EN5	50~99
EN6	100~299
EN7	300~499
EN8	500~999
EN9	1000~1999
EN10	2000~2999
EN11	3000~4999
EN12	More or equal to 5000

Table 3. Basic Time Variables

Variables	Values	Units
Time	Year	Year
Initial Time	1991	Year
Final Time	2015	Year
Time Step	0.125	Year

The basic time unit is “Year” with time step of 0.125, which is slightly greater than 1 month. The model is designed to simulate data of past 10 years and future 5 years, so that 2/3 of simulations can be compared to historic data.

The number of employees is treated as an endogenous variable since the future economy growth rate will be included as a component of scenarios. It is calculated on the basis of the number of companies for 12 sizes, which is described in the following stock flow diagram.

The model assumes the following three kinds of factors for occupational injuries;

1) Skill factor
2) Facility factor
3) Cultural factor

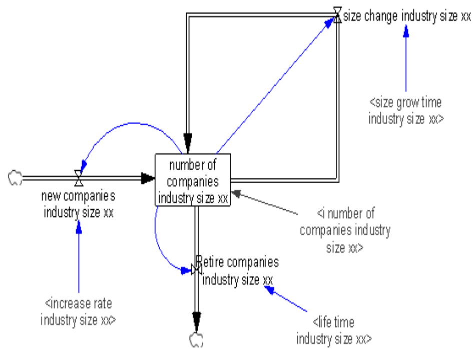

Figure 3. Stock Flow Diagram for Number of Companies

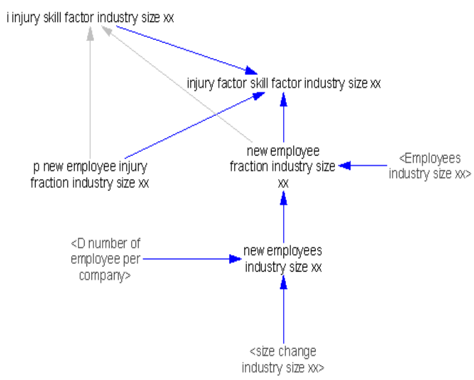

Figure 4. Stock Flow Diagram for Skill Factor

The skill factor is calculated via “size change”, as shown in the following stock flow diagram, because a company has to hire new employees due to its growth.

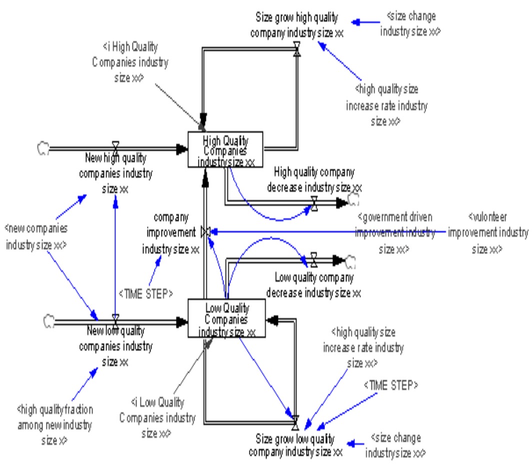

Figure 5. Stock Flow Diagram for Facility Factor

As for the facility factors, the model introduces two kinds of companies; high quality- and low quality-companies. The transition between them is rather complicated as described in the following stock flow diagram.

It also has to maintain the sizes which may change as time goes on, while the industry is fixed. Transition from a low quality company to a high quality is classified into two categories; voluntary- and government-driven. Policy variables are connected to government-driven transition so that scenario approaches may be possible regarding this factor.

The model is composed of 312 symbols, which represents more than 10,000 variables.

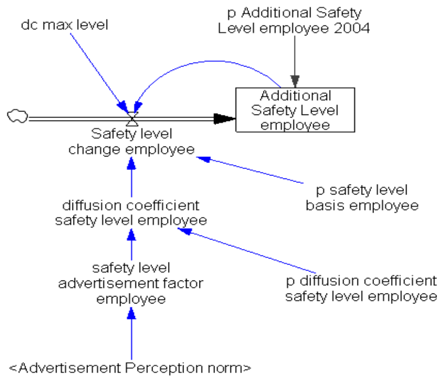

Figure 6. Stock Flow Diagram for Cultural Factor

3. Model Validation

As for validation processes, the following tasks were carried out.

1) Unit Check
2) Time Step Checking
3) Sensitivity Study for Assumed Constants
4) Comparison with historic data
5) Review of future trend

Unit check was carried out by using the tool provided by Vensim DSS, and it was confirmed that there was no conflict among the variables of units.

The model uses 92 symbols which represent 1,159 constant variables. They are classified into following 5 categories;

1) System variables (Time Step, Initial Time, Final Time, and SavePer),
2) Defined constants,
3) Constants for scenario(decision and environmental variables for future scenarios)
4) Initial values, and
5) Assumed variables

Among the above categories, sensitivity studies were carried out for initial values and assumed variables by using the tool provided by Vensim DSS. The standard deviation was 1.2%, which is small enough as shown in the following figure.

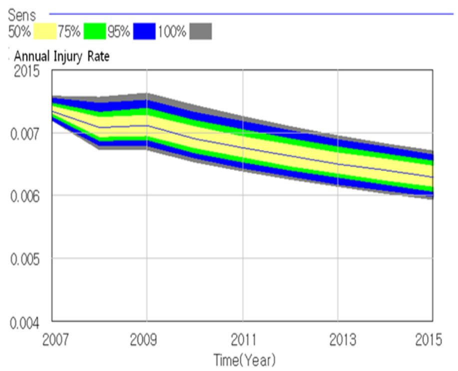

Figure 7. Result of Sensitivity study

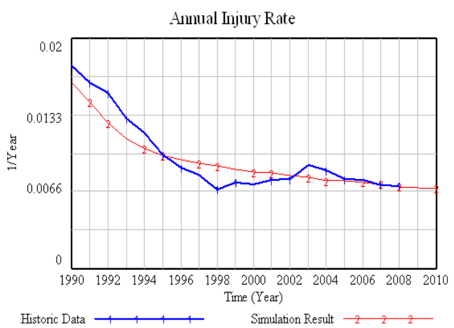

Figure 8. Annual Injury Rate Simulation

In Figure 8, it compares the simulation results with the historic data. As shown in the figure, the model can predict the general trend very well (R^2=0.9098), especially the recent ones.

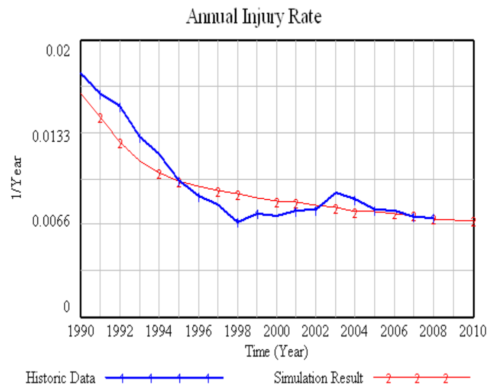

Figure 9. Comparison between Simulation Results and Historic Data(Overall Injury Rate)

Government agencies reviewed the simulation results for next 5 years. They concluded that the future trend qualitatively matches well with their mental model, and forecasted that the results of the model are within the reasonable ranges quantitatively.

4. Policy Analysis

4.1. Explanation of Phenomena

For the discussion, a construction industry is selected. As shown in the following figure, both actual data and simulation results show a steady state in last 5 years or so.

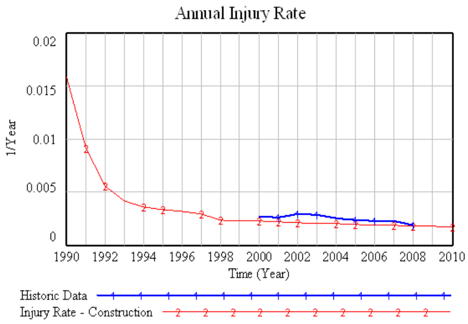

Figure 10. Comparison between Simulation Results and Historic Data (Injury Rate for Construction Industry)

The model assumes three factors (skill, facility and cultural factors). Among them, the skill factor is more or less a steady state (the sharp increase in the first year results from the initial transient). Facility factor played important role in the early 1990s, while cultural factor was affecting the system slowly but steadily. It is concluded that the current quasi steady state comes from the saturated effect of facility factor.

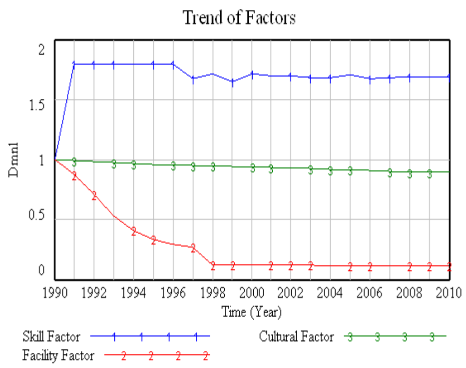

Figure 11. Simulated Past Trend of Factors for Injury Rate

According to the above figure, cultural factor may affect the future system, but it turns out that this effect also makes almost saturation as shown in the following figure.

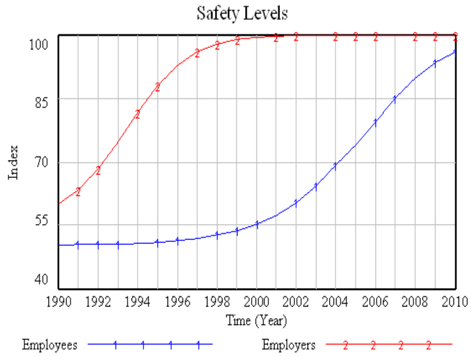

Figure 12. Simulated Past Trend of Safety Level

4.2. Explanation of Phenomena

The situation, however, may be interpreted in different ways if you look into the industry in detail. The following is one example of such microscopic view. The sizes of companies to be improved are different from each other; For example, EN8(500~999 employees) is important for construction companies while EN1(less than 5 employees) is important for mining companies.

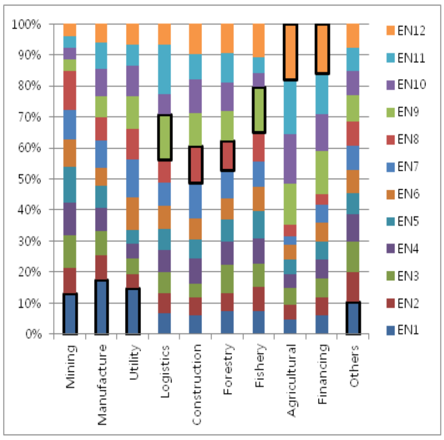

Figure 13. Facility Factors for each Industry and Size(2009).

In short, the current level is the minimum level of injury rate in general approaches, but there are a room for change of the level in industry-wide and size-wide.

Simple scenario analysis is performed for economic growth rate.

5. Conclusions

A system dynamics model is developed to explain how the injury rate has been reduced and approached to the current level. The main reason for the reduction of injury in the early 1990s was the government-driven investment on the safety facilities. Some other reason were that the safety levels for both employees and employers had been improved, and then contributed steadily to the reduction of injury rate[9].

The level of reduction via such efforts, however, has reached a saturated level, and it is time to focus on a specific area in industry and size of the companies. The model is to show which area Korean Government should focus.

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