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시스템다이내믹스를 이용한 산업재해율 분석

정희태*

요 약

산업의 고도화 및 새로운 기계의 도입, 화학물질 사용 등 산업재해의 다양한 양상과 더불어 생산설비들의 자동화, 대형화로 인해 산업재해 발생의 양상이 점차 다양해지고 있다.국내 산업재해는 OECD(Organization for Economic Cooperation and Development) 경제협력개발기구대비, 상대적 하위수준에 있어 기업 발생 산업재해는 근로자들의 심리적 및 치료와 보상 손실에도 타격이 되어 기업 총생산과 이윤 추구에도 중요문제가 야기되고 있다. 더불어, 장애자와 사망유족들의 증가로 생활 안정문제 등 사회적 문제도 제기된다. 이러한 동기에서 본 논문은 산업재해 통계와 산재예방사업을 분석하고, 시스템다이내믹스 법론을 이용하여 산업재해율을 예측하고 평가하는 모델을 개발하였다. 모델은 근로자수 모델, 재해자수 모델, 재해율 모델 등 총 12개의 모델로 구성되었고, 규모별 분석에서는 근로자수를 기준으로 12개 그룹으로, 업종별 분석에서는 제조업, 건설업 등 총 10개의 업종으로 구분하여 개발하였다. 개발된 모델을 토대로 업종별 규모별 산업재해율을 예측하고 산재예방사업을 다각도로 평가하는 방법론을 제시하였다.

키워드 : 산업재해율, 시스템 다이내믹스 모델, 예측, 안전시설

System Dynamics Modeling for Policy Analysis of Occupational Injuries

Hee Tae Chung

Abstract

The research of occupational injury for safety and health is a comparatively recent occurrence. As labor activities took place regarding to employee concerns in industrial uprising, human resources health was tried to enhanced as a labor safety subject.

Noticing that traditional statistics approach has limitations in learning future forecasting and major factors causing occupational injuries in each industry, Korean Government initiated a quantitative systematic simulation model project to analyze how the annual injury rate has been dropped and stays in a level for recent years. From this motivation and the project, system dynamics models have been developed to explain the mechanisms for reducing annual injury rate, and the mechanisms quantitatively.

The main cause effects for the reduction of annual injury rate were due to the government driven investment on safety facilities. In overall viewpoint the gain achievable from these efforts has been reached a saturated level. However, it could reduce the annual injury rate if you chose the industry and size carefully. The model for forecasting, major injury factors, safety budget and allocation are introduced and analyzed, and Analyzing occupational injury related factors can also reduce employee injury and disease related costs, including medical care, quit, and disability assistance costs.

Key words : occupational injury, system dynamics models, forecasting, safety facilities

※ Corresponding Author : Chung, Hee Tae
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* Dept.of Health Management, Namseoul University
Tel: +82-41-580-2338, Fax:+82-41-580-2926

1. Introduction

Occupational injury is a inter-disciplinary domain related with protecting the health, safety, as well as workers' welfare in employment. The purposes of occupational injury prevention programs include to foster 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, 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 remain safe.[2] Moral obligations would grip the defense of human resources lives and physical condition. Related law practices relate to the preventative, punitive and compensatory effects of laws that protect worker's injury. Analyzing occupational injury related factors can also reduce employee injury and disease related costs, including medical care, quit, and disability assistance costs. Analyzing occupational injury related factors may involve interactions among many 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.

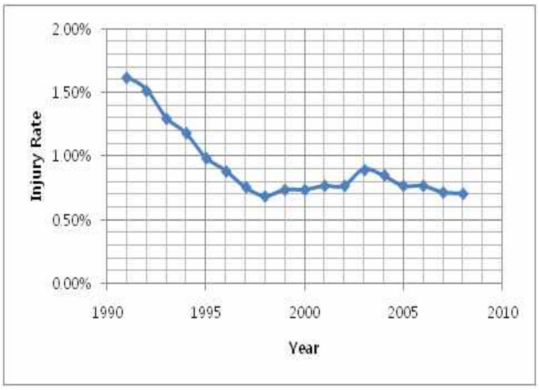
where IR = Measure for occupational injury rate

Injuries = Number of injuries reported during theyear, and

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

According to the above definition, the historical data show following trend[1].

(Figure 1) Historical Data for Occupational Injury Rate



As shown in the graph, the injury rate had been dropped dramatically in early 1990's, but has been remained at relatively stable level since then. Now Korean government is curious if the current level is the minimum level they could achieve.

Noticing that traditional statistical analysis has limitations in learning, the Korean government initiated a system dynamics project[2].

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 in industry wise viewpoints. The first system dynamics project carried out in Year 2009, and after thorough review the second project has started in Year 2011[3]. This paper is based on the first system dynamics project.

2. Model Description

The model structure is designed based upon following conceptual framework[1]

Occupational injury rate changes because of 3 increasing factors and 4 decreasing factors

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e-mail: ceochung@nsu.ac.kr

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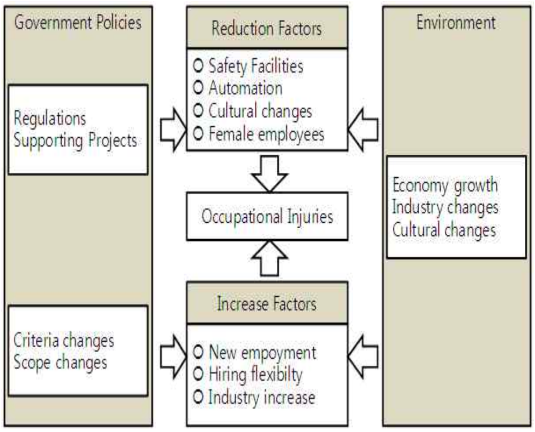
as described above. Government may intervene the system in both sides. Direct efforts such as subsidies for safety facility reduce the injuries, while any efforts to support the industry result in more injuries because of new employment. Economy and cultural changes may alter the occupational injury rate.

(Figure 2) Conceptual Framework of the Model



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

<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

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 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 future economy growth rate will be included as a component of scenarios. It is calculated based on the number of companies for 12 sizes, which is described in the following stock flow diagram.

<Table 1> Subscript Variable for Industry

Subscripts	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 3> Basic Time Variables

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

(Figure 3) Stock Flow Diagram for Number of Companies

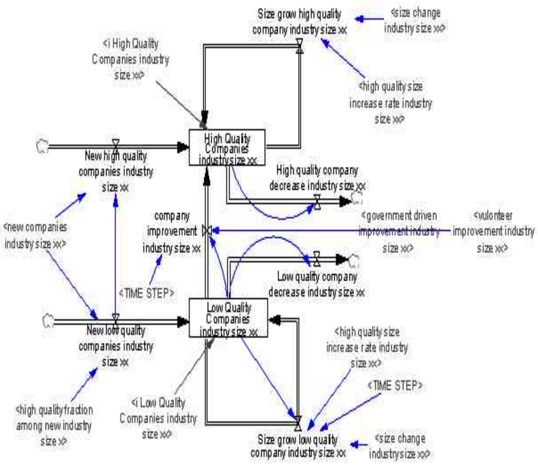
The model assumes following three kinds of factors for occupational injuries;

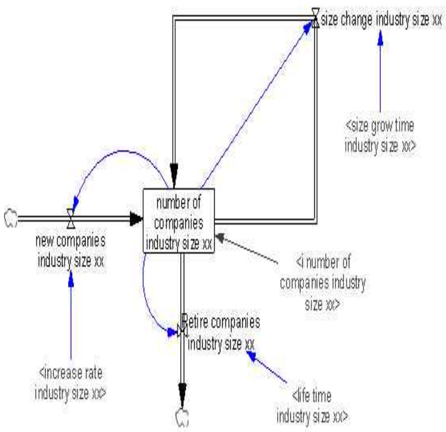
1) skill factor,

2) facility factor, and

3) cultural factor.

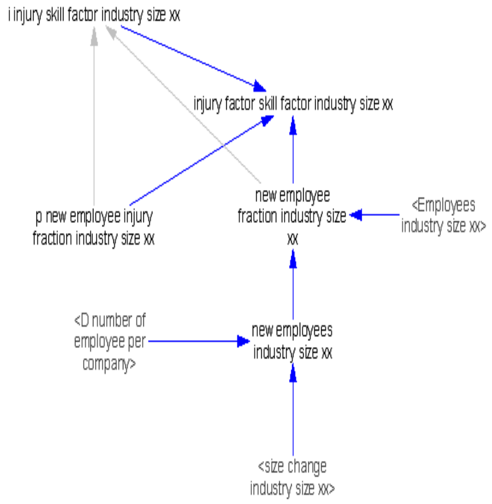
(Figure 4) Stock Flow Diagram for Skill Factor





The skill factor is calculated via “size change” as shown in the following stock flow diagram on the ground that as a company grows it has to hire new employees.

(Figure 5) Stock Flow Diagram for Facility Factor

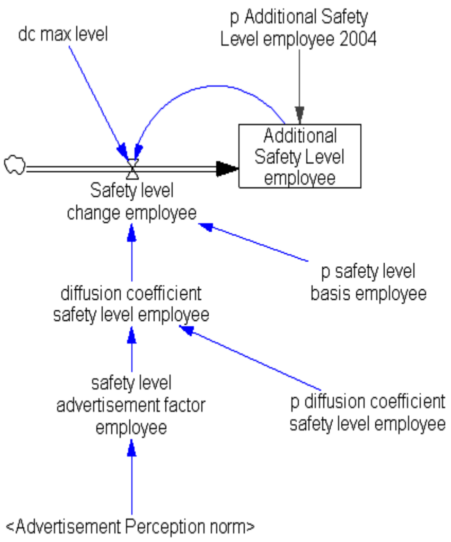


As for the facility factors, model introduces two kinds of companies; high quality and low quality. The transition between them is rather complicated as described in the following stock flow diagram.

It also has to maintain the sizes, which may change as time goes on, while the industry is fixed. Transition from low quality to high quality is classified into two categories; voluntary and government driven. Policy variables are connected to government driven transition so that scenario approaches may 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 validation processes 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 using the tool provided by Vensim DSS, and it was confirmed that there was no conflict in units among variables.

Model uses 92 symbols which represent 1159 constant variables. They are classified into following 5 categories;

1) System variables (Time Step, Initial Time, Final Time, and SavePer),

2) Defined constants,

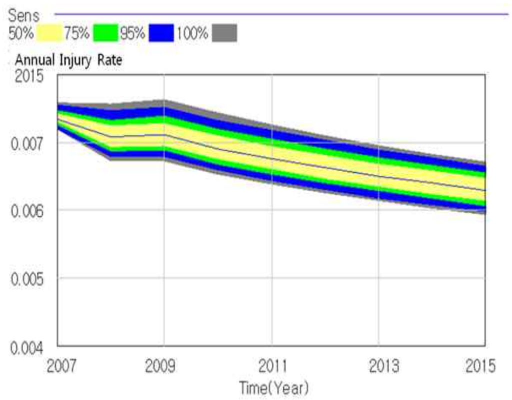
3) Constants for scenario (decision and environmental variables for future scenarios)

4) Initial values, and

5) Assumed variables

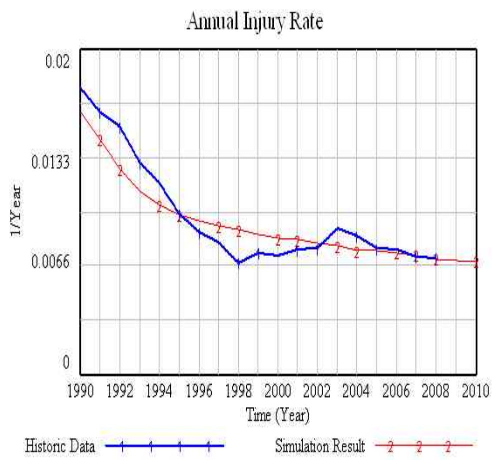
Among the above categories, sensitivity studies were carried out for initial values and assumed variables using the tool provided by Vensim DSS. Standard Deviation was 1.2%, which is small enough as shown in the following figure.

(Figure 7) Result of Sensitivity Study



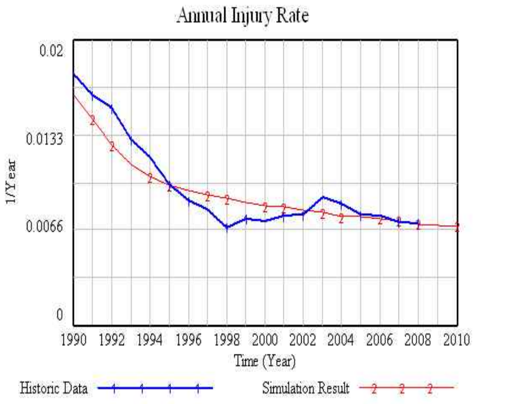
(Figure 8) Annual Injury Rate Simulation

Following figure compares the simulation



results with the historic data. As shown in the figure, the model could 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)

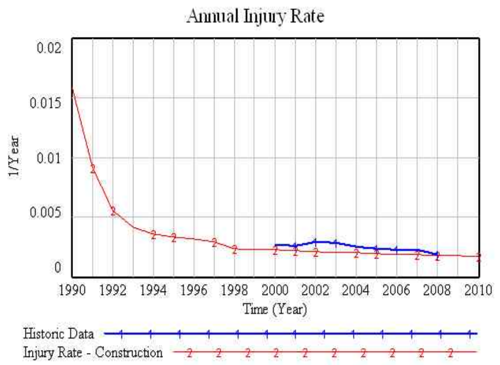


Government agencies reviewed the simulation results for next 5 years. They concluded that the future trend matches well with their mental model qualitatively and forecasted ones are within the reasonable ranges quantitatively.

4. Policy Analysis

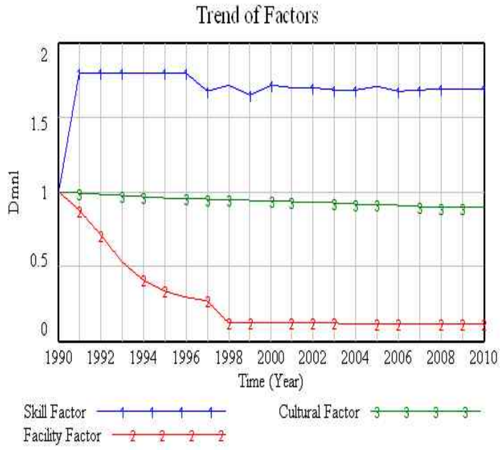
4.1 Explanation of Phenomena

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



For the discussion, 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 11) Simulated Past Trend of Factors for Injury Rate



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

(Figure 12) Simulated Past Trend of Safety Level

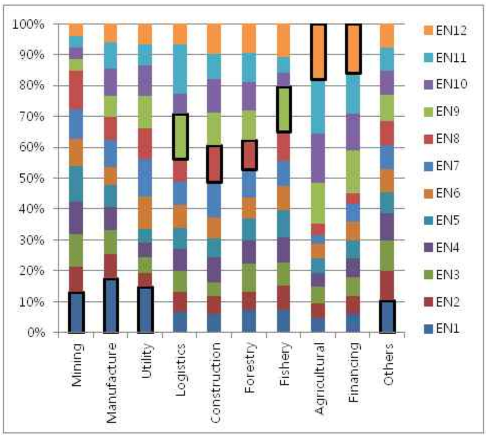
According to the above figure, cultural

factor may affect the future system, but it turns out that this effect is also almost saturated as shown in the following figure.

4.2 Explanation of Phenomena

However, the situation may be interpreted in different ways if you look into industry in detail. 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 (Year 2009)



In short, the current level is the minimum level of injury rate in general approaches, but there are some rooms to be approved in industry wise and size wise.

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 early 1990s' was the government driven investment on the safety facilities, which and some other reason the safety levels of both employees and employers have been improved, and contributed steadily to the reduction of injury rate.

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

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Hee Tae Chung

2008 Hanyang University Graduate School of Health Dr.
2015 Nam Seoul National University and Assistant Professor of Health Administration

2013- 현재 남서울대학교 보건행정학과 조교수
관심분야: 병원경영, 의료마케팅,보건의료정보
E-Mail : ceochung@nsu.ac.kr