Master of Science in Engineering

Analysis of Korean Construction R&D Policies Using System Dynamics

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Abstract

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Due to the acceleration of international competition, the importance of secured source technology and increased technical level by Research and Developmet(R&D) is increasing these days. In the construction division, securing the R&D budget and project management is performed by KAIA (Korea Agency for Infrastructure Technology Advancement) which was established in 2002. However, as the budget increases, the government and the administrators from KAIA pursued for fast and visible outcome, and that caused adverse effect to R&D, which needs ceaseless time and effort to reach fine quality.

The purpose of this study is to analyze both short and long-term effects of the currently applied construction R&D management policies. Based on the peculiarity of the construction R&D and various policies, and 4 main doubtful policies are deducted. System Dynamics modeling method is applied to develop models for each policy. Based on the analysis model, strategic policy for both policy makers and administrators were proposed.

This study provides better understanding and a logical basis for the R&D process and the relationship between researchers and administrators. Also, it may support to draw efficient management plan for the construction R&D.

Keywords: Construction R&D Policies, R&D Outcome, R&D Efficiency, System Dynamics

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Contents

List of Tables

List of Figures

Chapter 1. Introduction

This chapter presents the background of the research and identifies the problems in present situation of the construction R&D in Korea. The necessity of proper policy management in construction R&D process is described with the objectives, scope, and method through this chapter.

1.1 Research Background and Objectives

According to OECD (The Organisation for Economic Co-operation and Development), Research & Development is a creative systematic activity undertaken in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this knowledge to devise new applications. As the international competition accelerates, the demand for a secure source of knowledge and technology through research and development is increasingly spreading. In addition, R & D is essential for the country's growth potential and international competitiveness which increases the productivity and technology. In a long-term perspective, R&D investment is an important factor in determining the growth and development of the country. (Hwang, 2013).

Construction department also recognized the importance of R & D projects, and have expanded the scale of investment from a budget of 12 billion won in 1994, to 430 billion won in 2011. (Ministry of Land, Infrastructure and Transport, 2011).

As with other industries, the construction field expects not only research results, as well as the creation of achievements, but also improvement of improve the level of skills and knowledge that will help in the development of the country from R&D projects. However, because of R&D investment’s outcome take a long time for its expression and the effects are instable, so it is difficult to maintain a policy continuously. (Seo, 2010). As a result, constant policy changes have been progressed, and a study on how the policy change affects the performance and efficiency of R&D research needs to be done.

Numerous studies have been done due to the instability of R&D investment and its impact, and policy. Industrial association analysis, time series analysis, production function, cost function, such as regression analysis, DEA methodology was used to analyze the effect of R&D investment. However, these studies pursued for the numerical prediction accuracy by building a quantitative forecasting model of the value of investment amount, indicators and so on. R&D policy-related analysis also was a regression analysis and correlation between using data from the cross-sectional area analysis and there were a small number of complementary research.

Since the R&D investment is long-term effected by sustainable cyclical causality, there are limitations when disconnected and fragmentary empirical analysis (the cross-sectional analysis, and time series analysis) is used to discuss the circular relationships which comes from the inherent relevant variables and performance leads to continuous investment.

Therefore, the objective of this study is to analyze the process of construction R&D and the effectiveness of current policy. System Dynamics

modeling methodology was applied to verify the causal relationships among the variables. In addition, strategic policy recommendations to stramline the construction R&D efficiency are proposed.

1.2 Research Scope and Methods

This study limits its scope to construction R&D projects of public institutions which are funded by the government. As private companies' pursue only for their own interest and the influence of policy changes are low, R&D of private companies are excluded.

During the whole process of Research & Development, not only political factors but also various elements interact inside the system. Since this study focuses on the interaction between researchers and administrators, policy makers and the users are considered as an external factor. Furthermore, as the whole procedure of a R&D project needs a considerable time for visible outcome, System Dynamics methodology was used to understand the causal relationship in both short and long term. The causal loop diagrams are based on characteristics of construction R&D, feedback relationship and external variables' effects on the entire system are considered thoroughly.

This research is developed in the following procedures:

(1) Definition and characteristics of R&D are analyzed through reviewing official reports.

(2) The peculiarity of construction R&D is defined through reviewing literatures.

(3) Background and status of Korea's policy in construction R&D is explained.

(4) Participant Factors of R&D process is determined.

(5) System Dynamics causal loop diagrams are constructed for each of the

relationship between Participant Factors that have been chosen.

(6) Situational analysis in accordance with each of the policy application is performed.

(7) Finally, strategic policy recommendations for streamlining the R&D efficiency of Korea’s construction R&D are derived.

The entire research process of this research is summarized in Figure 1-1.

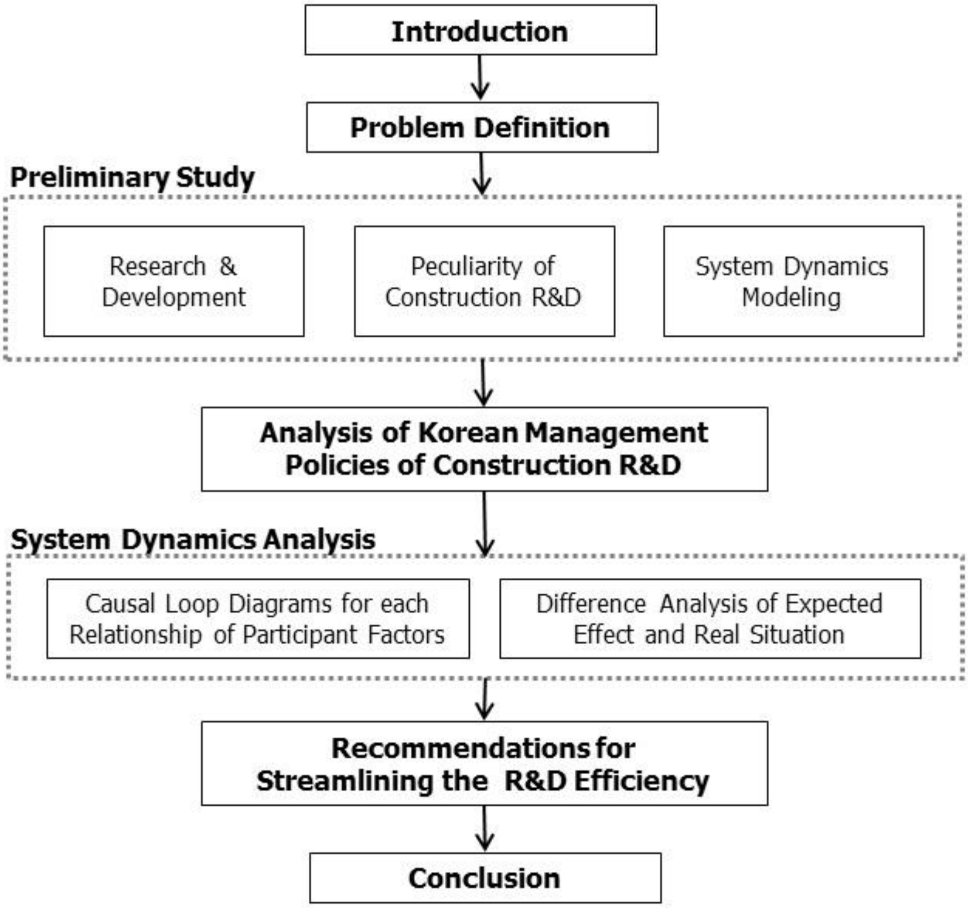


Figure 1-1 Research Process

Chapter 2. Preliminary Study

Even though there are numerous amounts of researches on the topic of research & development and system dynamics methodology, not many researches were done with R&D of construction field and the Research Capability. This chapter presents the definitions of important terms, relevant literature, and academic limitations of existing studies.

2.1 Definition

2.1.1 Research & Development

OECD (The Organisation for Economic Co-operation and Development) defines Research and Development as a "Any creative systematic activity undertaken in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this knowledge to devise new applications. It includes fundamental research, applied research in such fields as agriculture, medicine, industrial chemistry, and experimental development work leading to new devices, products or processes."

Also, they divided the Research and development in to three activities: basic research, applied research, and experimental development. Applied research is the investigation of phenomena to discover whether their properties are appropriate to a particular need or want, usually a human need or want. In contrast, basic research investigates phenomena without reference to particular needs and wants. Applied research is more closely associated with technology, engineering, invention, and development. Basic research is sometimes described as "pure research”.

Experimental Development means the acquiring, combining, shaping and using of existing scientific, technological, business and other relevant knowledge and skills for the purpose of producing plans and arrangements or designs for new, altered or improved products, processes or services. These definitions are summarized in Table 2-1.

Table 2-1 Different Types of R&D (Seo, 2010; OECD, 2012)

Types	**Definition**
Basic Research	Investigates phenomena without reference to particular needs and wants
Applied Research	Investigation of phenomena to discover whether their properties are appropriate to a particular need or want
Experimental Development	Using of existing scientific, technological, business and other relevant knowledge and skills for the purpose of producing plans

In this paper, the definition of the word R&D (Research & Development) is in accordance with OECD.

2.1.2 Research Capability

Research Capacity is a general term for a process of individual and institutional development which leads to higher levels of skills and greater ability to perform useful research. It is well used in the field of pharmaceuticals.

However, the definition of Research Capability differs from Research Capacity. In this paper, two kinds of Research Capability are defined, which is Research Capability of Institute and Research Capability of Researcher. Definition of the word research capability of institute is in accordance with the word Research Capacity. But for the Research Capability of researcher, it is divided in to two parts: Researcher's concentrativeness and Project's concentrativeness. An ability to do study or work well is an attributes of humans, but during the process of a R&D project, there are other factors that sways the outcome of the project.

In this study, the elements of each research capacity will be shown through the System Dynamics model structure.

2.2 Literature Review

2.2.1 Characteristic or R&D

As stated before, R&D is a creative systematic activity undertaken in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this knowledge to devise new applications. It includes fundamental research, applied research in such fields as agriculture, medicine, industrial chemistry, and experimental development work leading to new devices, products or processes.

To understand the spillover process of R&D investment, and to analyze the effect of long-term, direct or indirect investments, there are five characteristic of R&D. (Seo,2010; Hwang, 2013).

(1) Diffusivility: The achievements of R&D investment occurs sequentially by going through 1)Primary developed technology 2) Company (1st stage) 3) Industry (2nd stage) and 4) Country (3rd stage).

(2) Feedback Process: The impact originated from each step affects the occurrence of the impact of the following step, as well as the impact of the previous steps. In other words, when the riffle effect of R&D investment have affected Industry(2nd stage) , by going through Primary outcome and Company application (1st stage), the changed characteristic of the industry can feedback to the primary stage and affect both primary outcome and company application (1st stage).

Figure 2-1 is an example of showing the feedback process of R&D

investment. The solid line shows the flow of R&D investment and how it is spread. The dotted line shows the feedback process that can be found in this model structure.

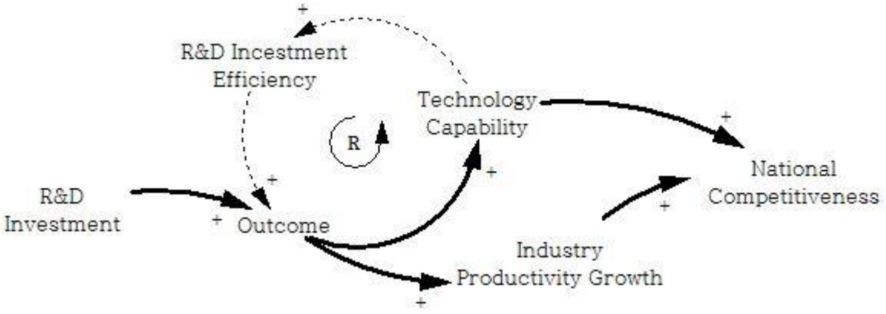


Figure 2-1 Feedback Process of R&D Investment

(3) Non-Specificity: The results of R & D investment are not limited to a specific field or objectives. It can be shared throughout the whole system, including scientific technology, economics, and social sciences.

(4) Time-Lag: It is a characteristic of R&D that certain amount of time should be consumed for the results of the investments to be reflected to the next stage of the diffusion process, and other areas. The time-lag is determined by the influence of the various parameters of the system.

For example, when a new construction management system for the improvement of productivity in the construction industry was developed, due to the rigidity of the construction industry, the spread of the operating system may need considerable amount of time, even though its effect is verified.

(5) Uncertainty: By its effects on a variety of causes, including the failure of research process or commercialization stage, the ripple effect of the R&D

investment may be less or none. These uncertainties may have caused from unexpected external variables, but sometimes it may occur by measuring the ripple effect incorrectly when the characteristics described above were misunderstood.

To sum up, in order to correctly measure and analyze the impact of R&D investment, the ability to identify the interaction between the socio-economic system's configuration variable is necessary.

Table 2-2 Characteristics of R&D (Seo, 2010; Hwang, 2013)

Characteristic	**Details**
Diffusivility	The achievements of R&D investment occur sequentially by going through four stages.
Feedback Process	The impact originated from each step affects the occurrence of the impact of the following step, as well as the impact of the previous steps.
Non-Specificity	The results of R & D investment are not limited to a specific field or objectives.
Time-Lag	Time is needed for the results of the investments to be reflected to the next stage of the diffusion process, and other areas.
Uncertainty	By its effects on a variety of causes, including the failure of research process or commercialization stage, the ripple effect of the R&D investment may be less or none.

2.2.2 Peculiarity of Construction R&D

Korean construction R&D funded by the government is under control of KAIA (Korea Agency for Infrastructure Technology Advancement), which is a government (Ministry of Land, Infrastructure and Transport) affiliated organization.

There are 7 fields of construction R&D as shown in Table 2-3. They are construction technology innovation field, plant technology advancement field, advanced urban development field, R&D policy and infrastructure field, regional technology innovation field, policy research & development field, construction & transportation research planning field. Each field has different characteristics and aiming goals. Also, their projects and project scale differs from each other. Therefore, defining the representative characteristic of construction R&D is impossible.

Construction department also recognized the importance of R & D projects, and have expanded the scale of investment from a budget of 12 billion won in 1994, to 430 billion won in 2011 as shown in Figure 2-2. (Ministry of Land, Infrastructure and Transport, 2011). This is 4% of the total government R&D budget which is 14.8 trillion won, and has increased by more than 30% annually since 2005. This is substantially large investment comparing with the United States, Europe and other OECD countries. (KAIA, 2008; OECD, 2012)

Table 2- 3 Present State of Construction R&D Projects (KAIA,2012)

(Unit: million won)

Field	**Time Period**	**2011 Budget**	**2012 Budget**	**Goals**
Technology Innovation	2007- now	72,957	75,710	Future Intelligent Road Technology, Long-Lived Bridge Technology and Next-Generation Eco-Friendly Water Resource Technologies, Advanced Construction Materials and Process Development, Technology for Disaster Prevention
Plant Technology Advancement	2007-now	42,394	36,711	Increase the national wealth through domestic commercialization by core process demonstration of high value plant construction business and overseas plant exports
Advanced Urban Development	2007- now	69,572	62,157	U-Eco City, High-Rise Building Complex, Urban Regeneration, Intelligent Land Information Technology Innovation, Smart Home Healthcare, Huge Space Architecture, Advanced Environmentally Friendly Dismantling, Han-ok Technology
R&D Policy And Infrastructure	2007- now	9,900	8,710	R & D policy and infrastructure for activating efficient R & D projects, and spreading and commercializing the outcome. Support for establishment commercialization
Regional Technology Innovation	2005-now	7,000	6,300	Achieve self-reliance of the construction industry and the development of research capacity in the region through technological development reflecting the characteristics
Policy Research & Development	1999-now	2,867	2,867	Development of Land, Transport and Maritime Policy for the people’s life and to resolve pending issues
Construction & Transportation Research Planning	2011-now	2,000	2,215	Identify promising technology of Construction and Transportation field and secure new business feasibility, Investment in R & D to improve the efficiency
Total		**206,690**	**194,670**	

(Unit: 100 million won)

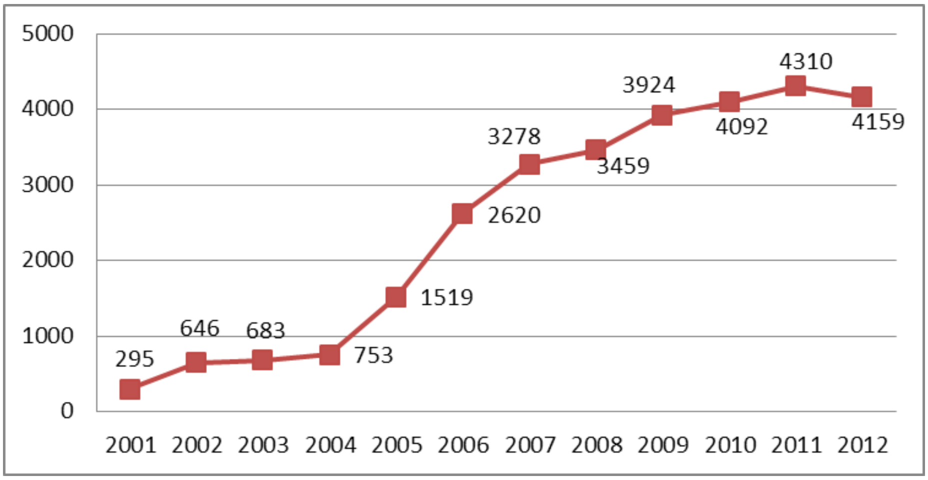


Figure 2-2 Construction & Transportation R&D Budget

However, unlike other industries such as science, technology, information technology, industrial technology, etc., the construction industry has strong publicness, and it is hard to find out the effect of construction R&D. (Park,2010). So, even though the government invests to the development technology which can derive visible effects such as revenue generation and shortening the construction period, the rigidity of industry itself is too strong for a new technology to be applied.

Moreover, most of the R&D investment is focused on experimental development stage. Which means not much effort is done to fundamental research and applied research. However, these two research areas are the source for the R&D pool, and quality of R&D result for the long-term point of view.

Table 2-4 Construction R&D Researches

Topic	Author	Title	Results	Methodology
Spillover effect of Construction R&D	Hwang (2013)	Forecasting Economic Impacts of Construction R&D Investment: A quantitative System Dynamics Forecast Model Using Qualitative Data	A system dynamics model analysis in both qualitative & quantitative data	System Dynamics
	Park (2010)	Analysis of Economic Effectiveness in the Results of Construction R&D	Economical Spillover effect of Construction R&D	Survey& Case studies analysis
	Jeong (2009)	A Study on Developing the Outcome Management System of Construction and Transportation R&D Project	Policy suggestions for better management of Construction and Transportation R&D Outcome	Survey& Case studies analysis
Construction R&D Efficiency	Park (2007)	Data Envelopment Analysis for Evaluating Construction R&D Efficiency	1 and only indicator to measure the construction R&D efficiency	DEA & CCR
Construction R&D Policy	Kim (2007)	A Roadmap for the Innovation of Construction and Transportation R&D and the Policy Direction for Construction R&D	Roadmap suggestion for the future of Construction and Transportation R&D Policy	Case Study
	Kim (2009)	Construction and Transportation R&D policy coherence and companies involved in the R & D project-induced activation	Frequent policy changes of construction R&D should be limited for the success of the results	Policy analysis
	Lee (2006)	Systematic Management of R&D Activities in Construction Industry	Systematic management system for construction R&D will improve the efficiency	Survey

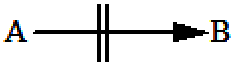
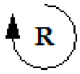
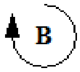
2.2.3 System Dynamics

System Dynamics Methodology was first created in 1961 by Dr. Jay W. Forrester of the Massachusetts Institute of Technology. .It was originally founded for the management and engineering sciences but has gradually developed into a tool useful in the analysis of social, economic, physical, chemical, biological, and ecological systems (Sterman, 2000). System Dynamics is a helpful methodology used to understand how system changes over time.

One of the distinguishing properties of system dynamics is that it can provide a dynamic, which refers to change over time, methodology to analyze a nonlinear complex system. By the structure model, systematic phenomenon analysis is possible and also can help to prevent errors of the logic (Lee, 2007).

When building a system dynamics structure, the diagrams of Table 2-5 are used.

Table 2- 5Legends of System Dynamics Diagrams (Sterman, 2000; Park, 2010)

Legend	Explanation	
	When other conditions are the same	When Factor A increases(decreases), Factor B increases(decreases)
		When Factor A increases(decreases), Factor B decreases(increases)
	Including weighted delay time between two factors	
	Positive feedback or self-reinforcing loop	
	Negative feedback or self-balancing loop	

Besides the arrows that are used to show the relation between variables, there are two kinds of internal feedback loops in a system dynamics system. Those are:

(1) Reinforcing Loop generates reinforcing and growth effect of the system's positive or negative effect.

(2) Balancing Loop generates stable effect of a system and the value of variable gets stabilized.

As shown below, Table 2-6 explains the difference between mathematical economics and system dynamics. Since the variables organizing the process of R&D is hard to analyze in static behavior, system dynamics methodology is implemented in this paper.

Table 2-6 Difference between Mathematical Economics & System Dynamics (Kim, 1999; Hwang, 2013)

Characteristic	**Mathematical Economics**	**System Dynamics**
Inference Method	Experience Data	Causal Relationship between the Variables
Analysis Target	Static Behavior (Dot estimation)	Dynamic Behavior
Focus	Correlation between the two variables	Circular Relationship among various variables
Objective	Pursuing the numerical accuracy	Pursuit of structural Correctness
Policy Prediction	Short-term forecasting	Long-term forecasting
Target of the Knowledge	Objectively observable phenomenon	Invisible Feedback Structure

Furthermore, system dynamics can also be used to analyze how structural changes in one part of a system might affect the behavior of the system as a whole. Small change in a system allows one to test how the system will respond under varying sets of conditions (Forrester, 1961). Thus, analyzing the system's effect of alternative policy is possible so it is very effective when seeking for counter-intuitive and discerning alternative

2.3 Summary

For better understanding of current management polices of Korea, definitions of important terms (e.g., Research & Development and Research Capability) were stated in chapter 2.1., and relevant researches and government reports to this paper were reviewed in chapter 2.2. As the history of R&D is not long in comparison with other researches, not many numbers of studies were conducted and especially very rare in the construction field.

Preliminary studies were mostly focused on the linear analysis of R&D process, and how the investment is changed in to an outcome. Since those methodologies have limitations in long-term analysis, System Dynamics is considered as the appropriate methodology to improve these limitations. Also, there were only two studies that were done with the basis of peculiarity of construction R&D and there were no studies done analyzing the policy changes in R&D field.

Chapter 3. Korean R&D Management Policy

In this chapter, Korean management policy for construction R&D will be stated in the basis of government's official reports. Background knowledge of each policy is stated and also how it has changed until today.

3.1 Achievement-oriented R&D Policy

In the year 2005, Law on the national research and development projects, and etc. performance evaluations and performance management was legislated. After the application of the law, Ministry of Education and Science Technology made regulations for government R&D projects.

As the regulations and laws were applied, both the adiministrators and policy makers pursued for fast and superior achievement of R&D. As stated in chapter 2.2.2., construction field gets it's R&D outcome very slow, more even might not be seen because of the publicness.

But for the KAIA, they needed outstanding results to get more budget from the government, so they started to push researchers for quick achievements, and not paying much attention to the basic research and applied research. These kinds of policy is well shown in KAIA's annual reports.

From the "2013 R&D Implementation Plan of Land, Infrastructure and Maritime Technology", published by KAIA, states that

(1) Planning specifically vision and performance goals.

(2) Establishing advanced planning system for mature planning

(3) Element-centric → achievement-oriented R&D management

(4) Aggressive promotion and utilization of the performance of R&D

3.2 Limited Participation Rate of Research Director

Before the “Limited Participation rate of Research Director” policy was applied in 2007, most of the research directors were in responsible of much more projects than they could afford. This lead to poor quality of the R&D result and also concentration of the projects to few research institutes.

The size of a single R&D institute may vary from small laboratory to national research institute. In Korea, there is no strict regulation that limits the number of researcher per research director, so one research director takes charge of many researchers, except for some small laboratories. This becomes very risky if there are not enough projects going on in the laboratory or institute.

For some of the institutes were having too much projects the research director and the researchers can handle. On the other hand, there were some research institutes that can barely meet the required expense for the institute.

Therefore, the government made the regulation of limiting the minimum participation rate of a research director. In this way, if a research director used to take charge of 10 projects by participating only 10% each, she or he only can choose 3 to 4 projects because the minimum participation rate is 30%. For some projects, there are special regulations which can limit the minimum participation rate as 40 or 50%.

3.3 Limited Maximum Labor Cost of Researcher

Maximum quota of researcher’s labor is defined by regulation from Ministry of Education and Science Technology. So, unless the law changes, the maximum quota of labor cost for doctoral program students is 2.5 million won per month, and for the students in master’s course is 1.8 million won per month.

Mostly, a single research institute does not do a large scale projects alone. Even it has the ability to manage the project, a gathering of several institutes or laboratories participate in the project.

There are two reasons for this:

(1) If more institutes participate in one project, then the work load of the research can be divided. It will cut down the burden of research result.

(2) Because of the limited labor cost, sometimes it is impossible for one institute to take responsibility for certain project.

In chapter 4.4 the structural model caused from limited maximum labor cost of researcher will be analyzed.

3.4 Changes in the Scale of the Projects

From the establishment of KAIA, management of government funded construction R&D was their duty. As the achievement-oriented R&D policies and law are applied, KAIA pursued fast outcome from construction R&D. Moreover, the administrators recognized the inefficient aspect of large scale R&D projects.

As you can see in Figure 3-1, total number of project decreases from 2005 till 2008. It shows that small scale projects are combined and large scale projects were placed during that period. The number of projects by scale in year 2008 is stated in Table 3-1.

(Unit: EA, million won)

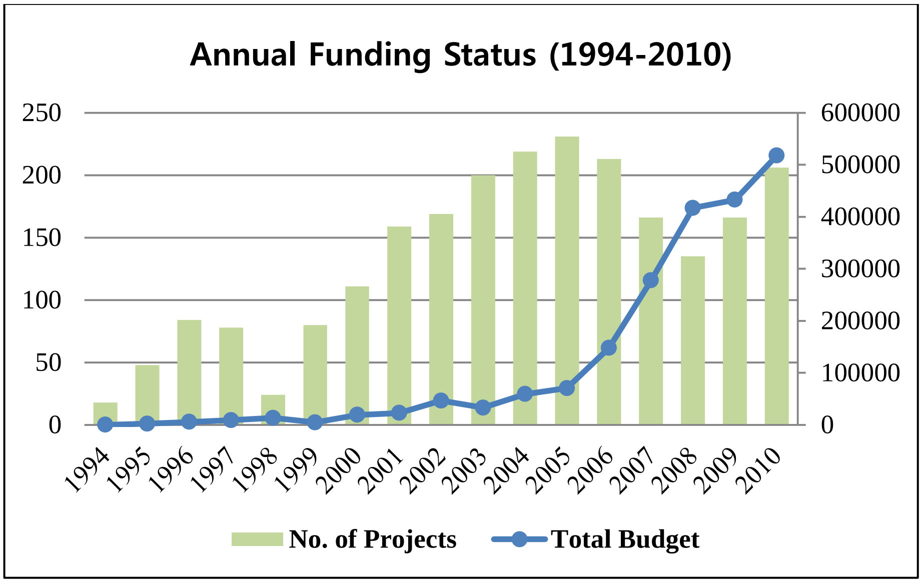


Figure 3-1 Annual Funding Status

Table 3-1 Number of Projects by Scale in 2008 (KAIA, 2010)

Project Scale	**Budget**	**Project Period**	**Number**
Agency	50-100 billion won	More than 5 years	12
Group	10-25 billion won	3-5 years	49
Normal	Less than 3 billion won	Less than 3 years	59

However, according to interview with the administrator of KAIA, they found out that increasing the large scale, total of agency project and group project, wasn't effective as they expected. That's the reason which increased the total number of projects from year 2008 in Figure 3-1.

In the "2013 R&D Implementation Plan of Land, Infrastructure and Maritime Technology", the KAIA have changed their policy again and will increase the large scale project from 2013.

3.5 Summary

From many kinds of report and statistical data, four main factors of Korean R&D management policy were decided in this chapter. Those are achievement-oriented R&D policy, limited participation rate of research director, limited maximum labor cost of researcher, and changes in the scale of the projects.

The background knowledge of why those policy or limitations were made was analyzed throughout chpter3. As an administrator, KAIA tries to increase the effects of construction R&D, and because they do not have long experience, they are still having troubles to find out the best policy which works well for both researcher and the research institute.

Chapter 4. R&D Policy Analysis using System Dynamics Model

In this chapter, System Dynamics model of the relationship between Administrator, Researcher, Research institute and R&D project itself is developed. Each model is separately constructed between two main agents, and there are four parts of causal loop diagram; Administrator – Researcher, Administrator – Research Institute, Researcher – R&D Project, and Research Institute – R&D Project.

The flow of each causal loop analysis is:

(1) Summary of chapter 3, which explains how the construction R&D was working before current policy was derived will be described.

(2) Main expected effect of currently applied policy in administrator and policy maker's stance will be shown through the causal loop diagram.

(3) Not only the good effects but also the side effects, if there are, will be analyzed also by using the causal loop diagram.

4.1 Analysis Model of Administrator and Researcher

Figure 4-1represents the process of R&D and the interaction between administrator and researcher of a project. Before the achievement-oriented R&D policy was established, relation between administrator and researcher was balanced by one reinforcing loop (R1) and one balancing loop (B1).

Loop B1(Administrator's pressure for outcome → Frequency of report from researchers to administrators → Researchers' Pressure → R&D Result Quantity → Perceived Construction R&D Efficiency → Industrial Competitiveness → Administrator's pressure for outcome) shows the effectiveness of frequent report demand in a short-term perspective. From short-term perspective, administrator's demand for frequent reports may work well to increase the R&D result quantity and the perceived construction R&D efficiency.

However, as it becomes a long-term cycle, the frequent reporting may greatly influence the R&D result's quality. Loop R1 (Administrator's pressure for outcome → Frequency of report from researchers to administrators → Researchers' Concentrativeness → R&D Result quality → R&D Commercialization → Perceived Construction R&D Efficiency → Industrial Competitiveness → Administrator's pressure for outcome) visualizes how frequent reporting can negatively affect the construction R&D efficiency.

Furthermore, when achievement-oriented R&D policy is applied to the model, it influences both Administrator’s Pressure and R&D Allotted Time. As the pressure of administrators gets higher, it might result more quantity of result from R&D, but in the long-term it will decrease the quality of R&D. The achievement –oriented R&D policy also affects the R&D Allotted Time. Although R&D projects needs certain amount of time for a better outcome, newly applied policy makes it hard to be fulfilled. As the allotted time for each R&D project decreases, it will affect to the quality of R&D result. This process is explained in the Loop R2 (Achievement-oriented R&D Policy → R&D Allotted Time → R&D Result quality → R&D Commercialization → Perceived Construction R&D Efficiency → Achievement-oriented R&D Policy) in Figure 4-1.

To sum up, the application of Achievement-oriented R&D Policy will force the increase of R&D result quantity, which can affect the Perceived Construction R&D Efficiency (Loop B1). But, the application of Achievement-oriented R&D Policy may lead adverse effect to the quality of R&D result (Loop R1 & R2) in the long-term. As it takes a long time for the quality of R&D result to affect the Perceived Construction R&D Efficiency, policy makers and administrators may not foresee the side effect of applying Achievement-oriented R&D Policy.

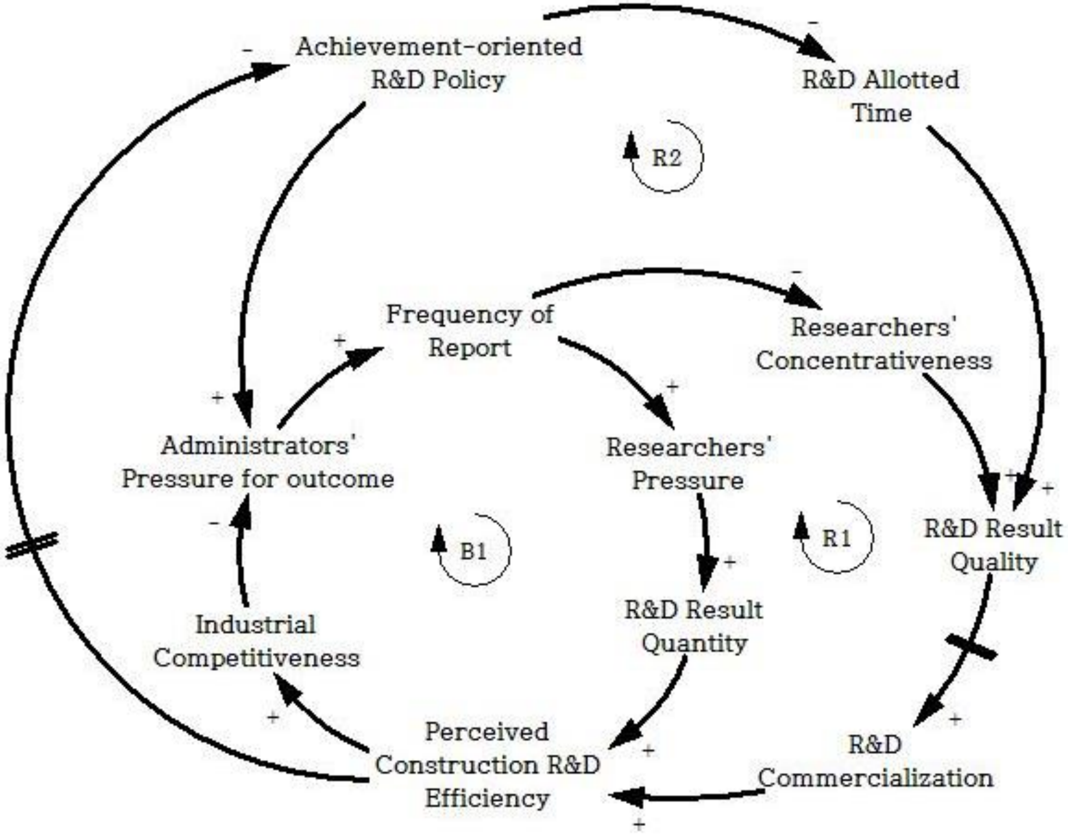


Figure 4-1 Causal Loop Diagram of Administrator and Researcher

4.2 Analysis Model of Administrator and Research Institute

The influence of limiting participation rate of research director can be explained with Figure 4-2 This newly applied policy was first proposed because of the fact that many research directors were doing much more projects than they can afford. By participating only 5-10% of a project and doing much more than they could pay attention, the outcome was unsuccessful. Therefore, to limit the number of projects per researcher and research director, the government decided to increase the minimum participation rate of research director to a single project.

From the Figure 4-2, the causal relationship between number of projects per researcher and R&D result quality is defined. Since the policy makers' perceived construction R&D efficiency was low, government increased the participation rate of research director. They expected that if the minimum participation rate is limited, then research director can only contract with fewer projects than before and that will lead to lower the number of projects per researcher which will increase the researchers' concentrativeness. This process is shown in the Loop R3 (Perceived Construction R&D Efficiency → Participation rate of Research Director → Total Number of Projects → Number of Projects per Researcher → Researchers' concentrativeness → R&D Result Quality → Perceived Construction R&D Efficiency) in Figure 4-2.

However, as spoken in chapter 3, there is a certain amount of required expenses per every institute. Loop B2 (Perceived Construction R&D

Efficiency → Participation rate of Research Director → Total Number of Projects → Expense Coverage per Institute → Number of Extra Service Projects → Number of Projects per Researcher → Researchers' concentrativeness → R&D Result Quality → Perceived Construction R&D Efficiency) shows the flow of counter effect caused from increasing the participation rate of research director.

If the total number of projects is limited, some institutes could not cover the expense only from the research funds. Then they would try to do more extra service projects to cover the required expenses. Since service projects are not considered as a factor that influences the participation rate of a research director, this is the only one breakthrough.

Based on the Figure 4-2, the government wanted to decrease the number of projects per researcher to increase the researchers' concentrativeness and the quality of R&D outcome. But, because of the financial troubles, the policy is not working as it was predicted.

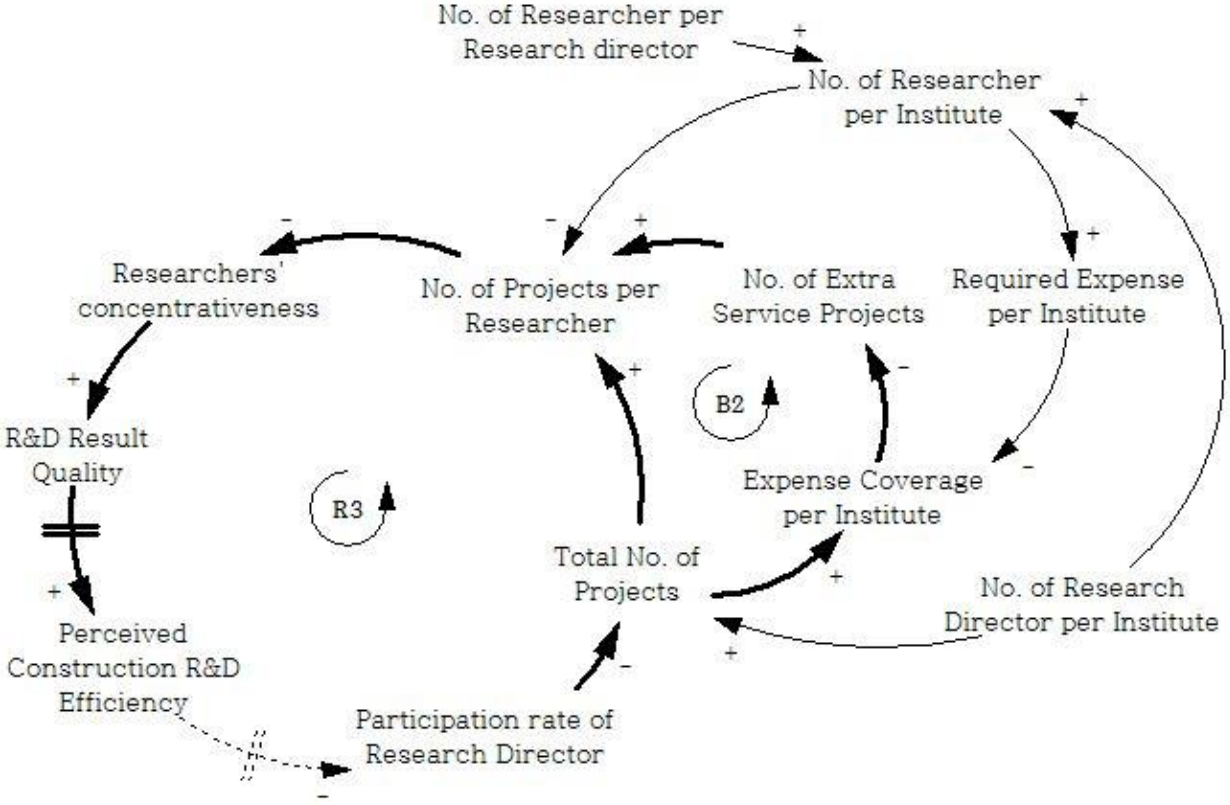


Figure 4-2 Causal Loop Diagram of Administrator and Research Institute

4.3 Analysis Model of Researcher and R&D Project

The policy stream keep changed in term of few years and the large scale project ratio had its ups and downs. Since it’s not been long after the KAIA has been established, they are having difficulties finding out the optimum ratio of large scale and small scale of projects. In Figure 4-3, change of the perceived construction R&D efficiency by the ratio of large scale project is explained.

When the large scale project ratio increases, it leads the growth of large scale project numbers. Since large scale projects last 3-5 years for one R&D project, it will increase the continuity of R&D project. Since the project is continued for long time, it will increase the concentrativeness of the project which increases the quality of R&D outcome. This process is shown in Loop R4 (Large Scale Project Ratio → Number of Large Scale Projects → R&D Project Continuity → Project’s Concentrativeness → R&D Result Quality → Perceived Construction R&D Efficiency → Large Scale Project Ratio) in Figure 4-3.

On the other hand, increased R&D Project Continuity may decrease the perceived construction R&D efficiency. Growth of R&D Project Continuity can affect both Project’s concentrativeness and researchers’ pressure. Which can be seen in Loop B3 (Large Scale Project Ratio → Number of Large Scale Projects → R&D Project Continuity → Researchers’ Pressure → Perceived Construction R&D Efficiency → Large Scale Project Ratio).

The Loop R5 (Large Scale Project Ratio → Number of Small Scale Projects → Number of Responsible Projects per Administrator → Non-fixed Extra Report → Researchers' Concentrativeness → R&D Result Quality → Perceived Construction R&D Efficiency → Large Scale Project Ratio) also reinforces the structure by the feedback effect between researcher's concentrativeness, perceived construction R&D efficiency, and large scale project ratio.

From analyzing the relationship between Researcher and R&D projects, the large scale project ratio can either increase or decrease the perceived construction R&D efficiency. To streamline the construction R&D, optimization of the ratio of large scale project is required.

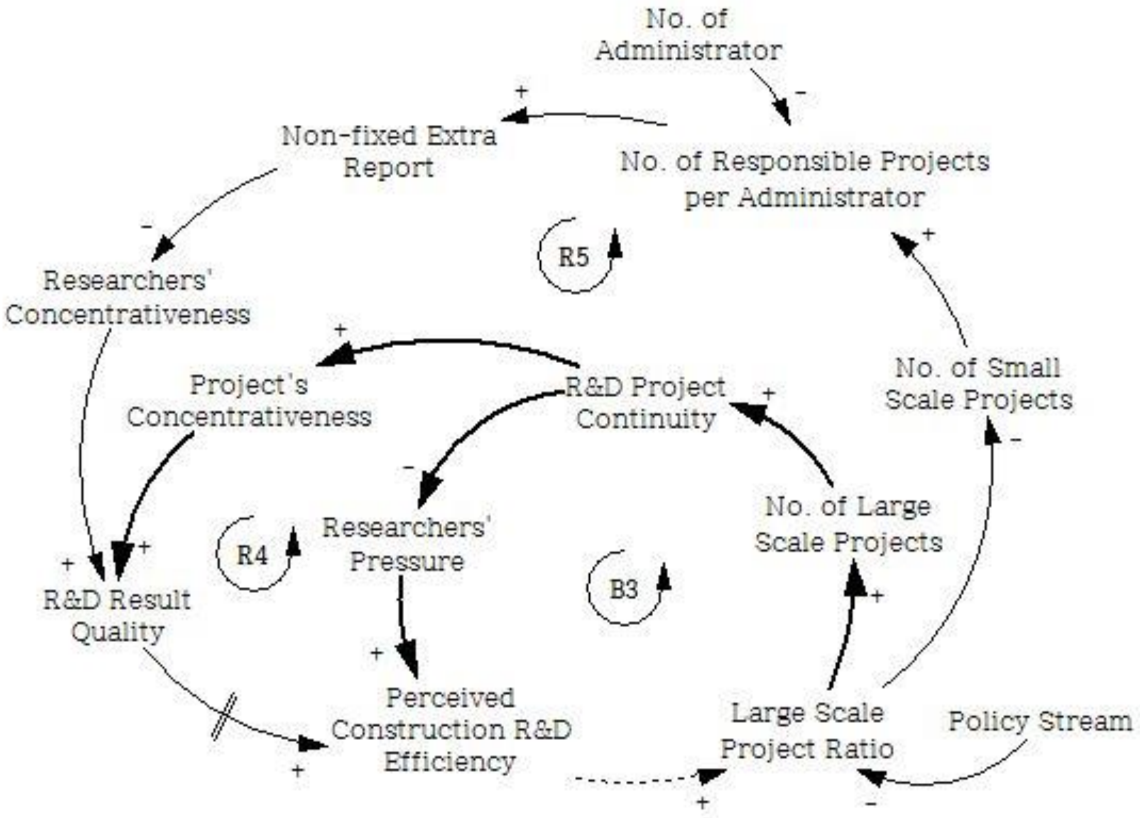


Figure 4-3 Causal Loop Diagram of Administrator and R&D Project

4.4 Analysis Model of Research Institute and R&D Project

In Figure 4-4, Loop R6 (High-quality Human Resources Ratio → Research Capability of Institute → R&D Result Quality → Perceived Construction R&D Efficiency → High-quality Human Resources Ratio) is shown. The delays between R&D result quality, perceived construction R&D efficiency and high-quality human resources ratio makes it hard to see the reinforcing of the system. But in long-term this is a very important structure causing not only the research capability of laboratories and institutes but also the research capability of construction industry.

The quota of labor cost of institute per project is influenced by 1) Maximum quota of researcher's labor, 2) Number of researchers per institute, and 3) Administrator's restriction. As spoken in chapter 3, maximum quota of researcher's labor is defined by regulation from Ministry of Education and Science Technology. The labor cost will stay constant, unless the law changes. The other two variables are deciding the quota of labor cost of institute per project.

If the quota of labor cost of institute per project decreases, critical mass sufficiency will also decrease. In this model, critical mass is defined as the least proper amount of labor cost of a R&D project. As economic problems have a huge influence to the research capability of an institute, not enough labor cost may cause adverse influence to the quality of R&D results.

Moreover, if the quota of labor cost of institute per project decreases, then the portion of an institute of a project will fall. Inevitably, the number of participating institute per single project will increase and it will reduce the concentrativeness of the project, which will cause the quality of R&D to fall.

On the other hand, if the quota of labor cost of institute per project increases, the quality of R&D will improve and it will lead a long-term effect to the increase of perceived construction R&D efficiency.

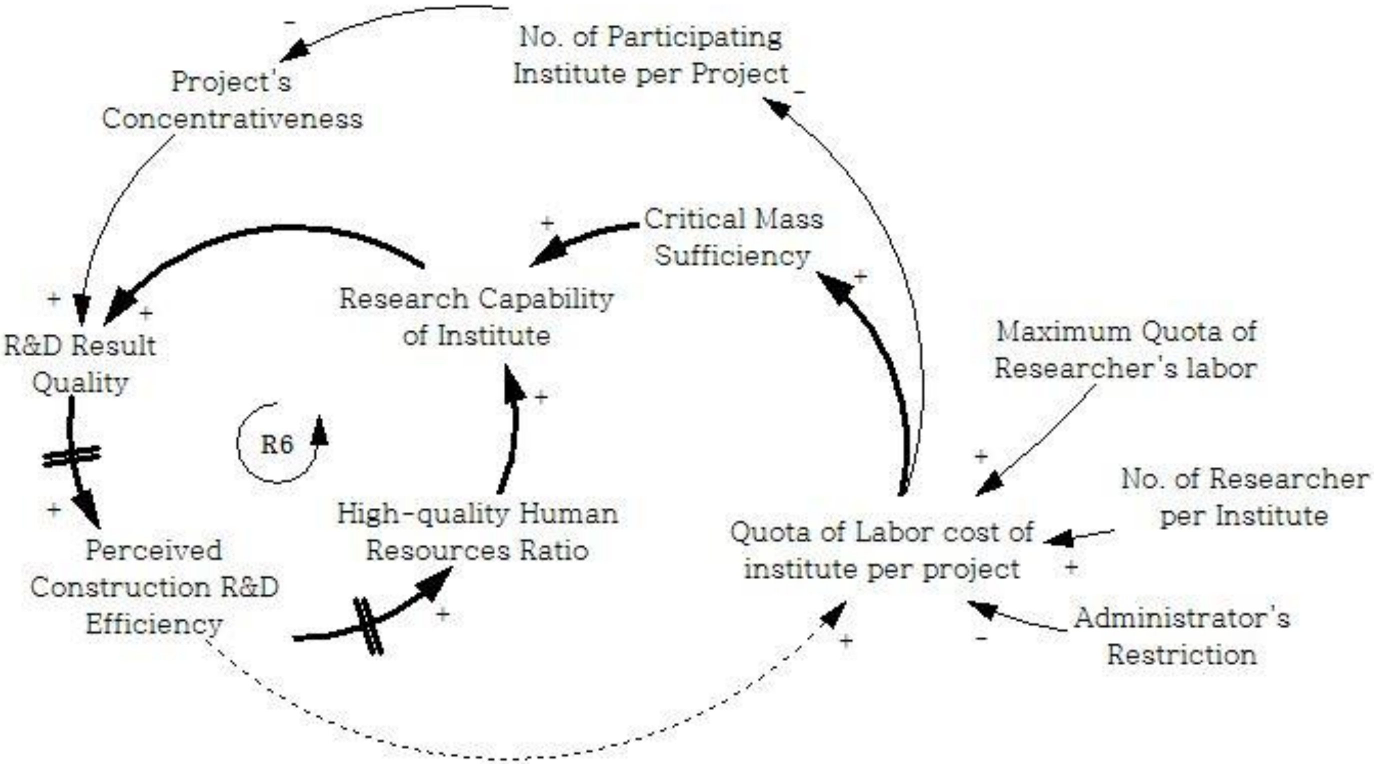


Figure 4-4 Causal Loop Diagram of Research Institute and R&D Project

4.5 Summary

In this chapter, four different System Dynamics causal loop diagrams were introduced.

One is the model defining the relationship between Administrator and Researcher with 2 main policy changes; Achievement-oriented R&D policy and the frequency of report.

Another is the model for Administrator and Research Institute with the main variable; Participation rate of Research .Director.

The other is the model which shows the interaction of Researcher and R&D Project itself. Both reinforcing and balancing loop will be activated by the change of Ratio of large scale projects among total construction R&D projects.

Lastly, flow and causal diagram of Research Institute and R&D project shows the initial variables that controls the R&D result quality.

Many feedback and causal relationship between the subjects were identified. In addition, difference of expected effect and actual effect of a policy application could be analyzed by the model structure. For the streamlining of construction R&D process, optimization of the key variables is needed.

Chapter 5. Dynamic Strategy Development of R&D Policy Management

In the previous chapters, analysis of Korean R&D management policies and the dynamics models which explains the before & after the policy application was explained.

In this chapter, strategic policy recommendations for both policy makers and administrators will be presented. The policy makers and the administrators are the independent character who can change many variables of the system dynamics structure. Since the researcher and research institute is a passive character of the whole R&D process, there are no policy recommendations for them.

5.1 Strategic policies for Policy Makers

The Policy makers are the ones who can change many external variables of the model.

First, change in perception of R&D and the outcome of R&D is necessary. As R&D has it's characteristic of Time-lag, shown in chapter 2.2.1, the policy makers need to hold on and look forward to the long-term future of R&D.

Second, at the national level, it is necessary to provide continuous empowerment opportunity to the science and technical personnel. In Korea, the maximum labor cost is much less than other countries, and by the application of achievement-oriented policies, it makes the researchers hard to concentrate on the real research which will improve the quality of R&D. If the policy makers offer a researcher-friendly environment, the whole process of construction R&D will be streamlined.

Third, by analyzing Figure 4-2, appropriate number of researchers per research director, and appropriate number of research director per institute should be decided. Quantitative modeling based on this paper’s model may help to find out the proper ratio of researchers, research director and institute.

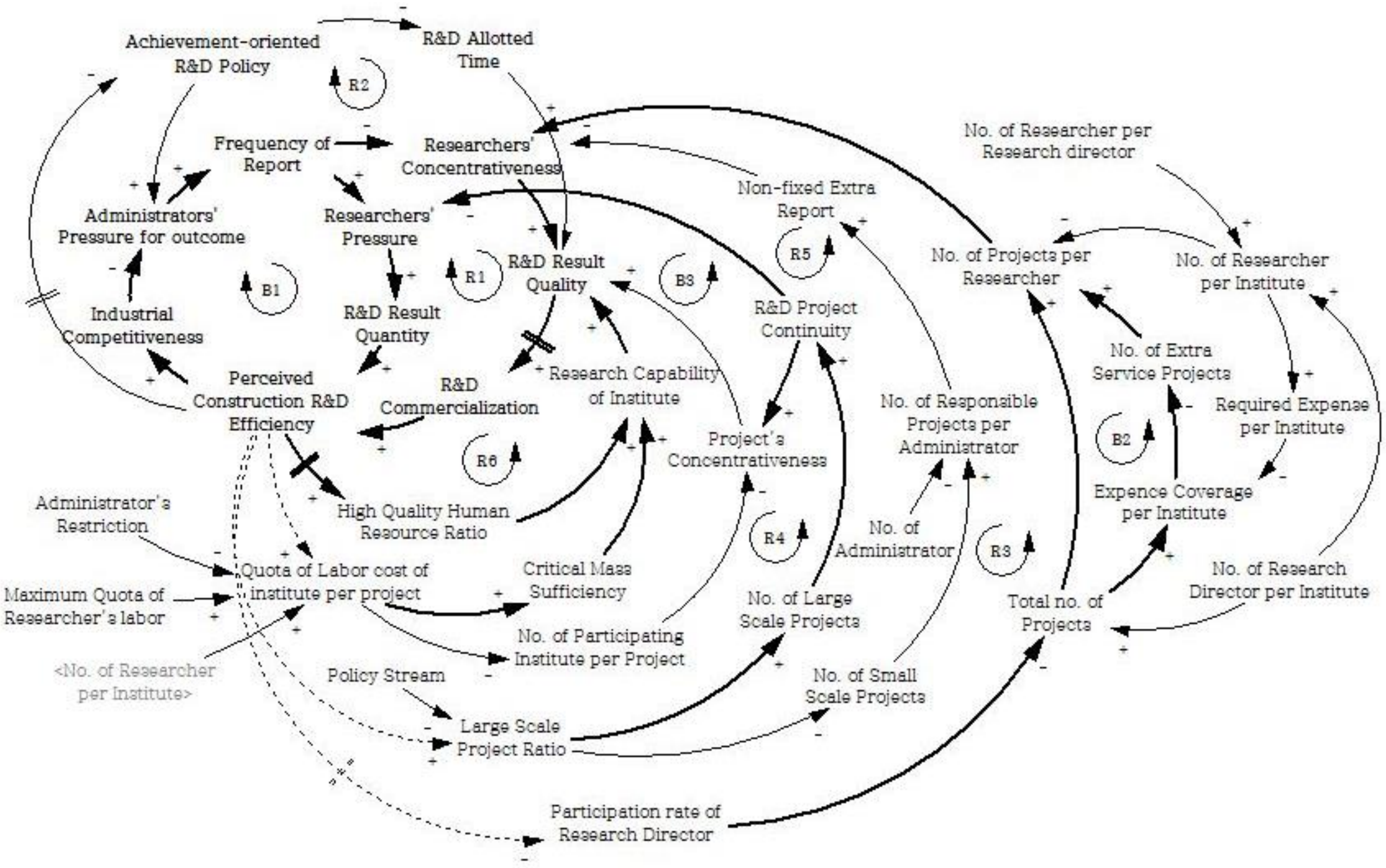


Figure 5-1 Construction R&D Policy Causal Loop Diagram

5.2 Strategic policies for Administrators

Besides from the policy made by policy makers, there are some details that administrators can change to streamline the construction R&D process.

First, change in perception of R&D and the outcome of R&D is necessary for the administrators also. From Figure 4-1, for the continuous budget funding from the government, the administrator needs visible outcomes. But, not only the quantity of R&D affects the perceived R&D efficiency, but also the quality of R&D affect the perceived R&D efficiency through commercialization. However, the process of commercialization needs a long time and it is invisible before it generates benefits. Change of perception to R&D and the recognition of riffle effect of R&D is needed.

Second, decreasing the frequency of report should be done. Administrators only focus on the quantitative result of a R&D project, but for a long-term of view, quality of R&D has more impact than the quantity. For example, in the United States, there is a system called the Grant system. In US, all the paper work for the researcher to do is only a few pages of report after the project is finished.

Third, according to Figure 4-3, optimization of large scale project ratio should be conducted. By changing the ratio of large scale projects, the quality of R&D outcome will be changed and which will affect the construction R&D efficiency. However, it takes a long time for the change to activate in real life, quantification of the model may help for the decision making.

Lastly, also according to Figure 4-3, increase of the administrators' number will help for the researchers to concentrate and focus more on only the research and the project, not bothered by administrative process and extra reporting.

5.3 Summary

Strategic policy for both policy makers and administrators were proposed in this chapter using integrated version of causal loop diagrams in chapter 4.

After the analysis, five strategies were proposed.

(a) Change in perception of R&D and the outcome of R&D.

(b) Decreasing the frequency of report; the Korean Grant system.

(c) Optimization of large scale project ratio.

(d) Increase of the administrators' number and the labor cost

(e) Deciding proper ratio of researchers, research director, and institutes.

Chapter 6. Conclusion

This chapter summarizes the research results which are obtained from the newly developed system dynamics model and contribution to the industry.

6.1 Results and Discussion

In this research, the analysis of the construction of R&D process was described by the maximize utilization of qualitative data using the System Dynamics modeling method.

Before the modeling, four main factors of Korean R&D management policy were investigated. The background of each factors were figured out by articles, laws, and statistical data. Afterward, analysis models were constructed, explaining the causal loop and feedback process of administrator, researcher, research institute, and R&D project.

Based on the structure model by system dynamics, the following five strategies are suggested to streamline the R&D efficiency model.

(a) Change in perception of R&D and the outcome of R&D.

As R&D has it's characteristic of Time-lag, the policy makers need to hold on and look forward to the long-term future of R&D. Both the quantity and quality of R&D affect the perceived R&D efficiency through commercialization. However, the process of commercialization needs a long time and it is invisible before it generates benefits. Change of perception to R&D and the recognition of riffle effect of R&D is needed.

(b) Decreasing the frequency of report; the Korean Grant system.

Administrators only focus on the quantitative result of a R&D project, but for a long-term of view, quality of R&D has more impact than the quantity. The Grant system of USA, which reduces the paper work for the researchers, should be applied to Korea.

(c) Optimization of large scale project ratio.

By changing the ratio of large scale projects, the quality of R&D outcome will be changed and which will affect the construction R&D efficiency.

(d) Increase of the administrators' number and the labor cost

The increase of administrators and the labor cost both will help the researchers to concentrate and focus more on only the research and the project, not bothered by administrative process and extra reporting then it will improve the quality of R&D.

(e) Deciding proper ratio of researchers, research director, and institutes.

An appropriate number of researchers per research director, research director per institute should be decided. With the proper ratio, researchers will get proper amount of projects to do and reasonable payment. It also will help to balance the level of research institutes.

6.2 Contributions and Further Studies

Astronomical amount of budget is invested to the R&D of country, and construction R&D shares a part of it. Various types of studies have been done to analyze the efficiency of R&D with different kinds of methodologies. However, they were mainly focused on the linear relationship between the invested budget and the outcome of R&D process.

This study has figured out the 4 main policies which were changed currently or unstable and keeps changing. It also provided a better understanding and a logical basis for R&D process through structuring analysis model between administrator, researcher, research institute and R&D project by System Dynamics.

The developed models will be the foundation for systematic management and analysis, and it will be possible to suggest policy measures to improve the R&D efficiency in the long-term.

However, the developed model is mainly based on the process before the commercialization of developed technologies and has not been testified with quantitative data.

To deal with such limitations, further studies on the similar topic are required and they need to include:

(1). Various case studies comparing to other industries' R&D policies.

As noted earlier in chapter 2, construction R&D has it's own peculiarity which makes difference from other industries. For accuracy of the systematic function of the model, case studies of other industries are needed and to clarify the peculiarity of construction R&D and similarity of R&D procedure.

(2) Quantification and simulation of the causal loop diagram.

Since the model developed in this research is based on qualitative variables and only shows causal and feedback relationships among them. Some of the variables are quantitative, but much more effort will be needed to quantify the invisible variables which play the main role. Therefore, simulation from the quantified system will be needed in the further study to help the decision makers.

(3) Studies about technology commercialization.

In the feedback loop, the delay of technology commercialization has not been clearly defined. In this study the time-lag of commercialization was assumed, not analyzed. Prior to quantification of the model, analysis of commercialization and the feedback process should be done to support the logicality of the causal loop diagrams and proposed strategies.

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국문초록

연구개발(이하 R&D)을 통한 원천지식의 확보와 기술수준의 증가는 가속화되는 국제경쟁 속에서 더욱 더 중요해지고 있다. 건설분야에서는 2002년 국토교통과학기술진흥원이 설립되어, 꾸준한 R&D 예산확보와 과제관리가 진행되고 있다. 그러나, 정부와 관리자는 증가하는 예산에 비례하여 빠르고 가시적인 성과창출을 추구하게 되었고, 정량적 성과위주의 정책은 꾸준한 시간과 노력이 필요한 R&D에 악영향을 미치고 있다.

따라서, 본 연구는 현재 적용되고 있는 건설R&D 관리 정책들을 다각적으로 분석하여 단기적인 효과뿐만 아니라, 장기적인 효과의 통합적인 분석을 목적으로 한다. 이를 위해 국내 건설R&D의 특성 및 다양한 정책들을 조사하였다. 이후, 현재 적용중인 정책들의 실효성의 분석을 위해 시스템 다이내믹스(System Dynamics)를 활용한 모형을 개발하였다. 모형을 통해 각 정책별 수립 배경과 그 목적 그리고 예상했던 결과와 실제 현황을 설명할 수 있었다. 또한, 모델 구조로부터 얻은 정책 시사점을 토대로 건설R&D의 효율화를 위한 주체 별 제안을 제시하였다.

건설R&D 참여 주체들의 인과관계 모델링에 기초한 분석은 R&D과정과 연구자와 관리자 사이의 상호연관성의 이해도를 높

일 수 있다. 또한, 향후 건설 및 다양한 분야의 R&D 정책수립에 도움을 줄 수 있고, 정량적인 분석을 통해 건설R&D 효율화 방안 도출을 위해 활용 가능할 것으로 예상된다.

주요어: 건설 R&D 정책, 연구개발 성과, R&D 효율, 시스템 다이내믹스

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