Technology scenario planning with system multi methodology: In the Petrochemical Research and Technology Company

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Abstract:

This paper contains a practical case for using two systems approaches together to achieve reliable and comprehensive results. At first, the theoretical and methodological assumptions of soft system methodology and system dynamics are briefly described. Subsequently, particularly in order to capture the essence of the problems that Iran's Petrochemical Research and Technology Company is facing, SSM through using QSEE Superlite software is applied. Therefore a rich picture of the system is depicted in addition to proposing the ideal system's root definition and its conceptual model. Afterwards, through SD with the help of Vensim PLE, causal loops and dynamic models of two most important functions- technology development and technology commercialization- are presented, models are validated according to structure verification, behavior reproduction, and behavior prediction tests. Additionally, the behavior of the system is analyzed and some scenarios concerning technology development and commercialization in order to improve the system are proposed. The results show that financing in both sectors is a major obstacle in growth and development. Consequently, the scenarios are recommended regarding increasing technology development and particularly technology commercialization through increasing the initiation and completion rates in both sectors. The paper closes with a description of the suggested scenarios.

Keywords: Modeling; System methodologies; Simulation; Mixing methods

1 Introduction

Technology is one of the significant factors in the arena of international competition; however the developing countries are not yet able to compete with the state-of-the-art technology in the world (Putranto et al., 2003). In developing countries, the concern of failing to implement the transferred technologies efficiently is associated with the development of technologies which are necessary for the industrial needs. This issue is of great concern to the governments, especially of developing countries helping their industries to develop higher technologies as a major contributing factor to their industrial development (Chang et al., 1999). As argued by Choi (1988), the difficulty of establishment of technology development policies and plans in the developing countries is due to their very short experience in the area of technology development.

The main agents in technology development are research and development (R&D) organizations in industry, thus in many developing countries public research institutions and research policies have recently conducted major transformations (Ekboir, 2003). For instance, Iran's petrochemical industry has been transforming its direction from library and laboratory research into technology development through scaling up from bench to industrial scale. Kumar and Jain (2002) stated that successful technological development and commercialization are hardly achieved by diffused and undirected efforts, and for such complex activity hard-working and high spirits are not an adequate support. In other words, companies need to have a defined and specified plan to indicate the direction of technological development and its commercialization.

In case of determining the direction of business and what it will look like in the future by defining the business strategy lead to higher performance, as pointed by Phillips (1996), about two-thirds of the studies report a significant link between strategic planning and performance. So, specifying the direction of technological development and its commercialization can lead to improving the performance of both sectors. Meanwhile, technology development and commercialization especially in the case of new technology are challenging and uncertain processes. Modeling has a key role in supporting the analysis of complexities and managing the dynamics of research and technology organizations. As in modeling, an electronic copy of real life systems are built enabling us to perform the analysis on the system without intervening with the operation of the real life systems (Agyapong-Kodua and Weston, 2011).

In this paper two different systems thinking paradigms, soft system methodology (SSM) and system dynamics (SD) are applied in Petrochemical Research and Technology Company (here after referred to as NPC-RT) which is the research and technology center of petrochemical industry in Iran. However, there have been concerns and discussions about linking system methodologies together. SSM is recommended to be used in uncertain conditions to realize the complex system better and find the change initiatives; on the other hand, SD can facilitate understanding of a system and development of scenarios. In the present study, one of the research question is: what are the main problems and sectors in NPC-RT? In this case, SSM is used to support clarifying the existing problems in the company and also to find the most important sectors which are more effective in improving its condition. Based on SSM method and using QSEE Superlite software, a rich picture of the system is given. Furthermore, the root definition of an ideal system and its conceptual model are proposed. In accordance with the suggested conceptual model and the viewpoint of the manager, two most important functions-namely the technology development and technology commercialization- are selected. The other research questions include: what are current behaviors of the system (selected sectors)? And what are the scenarios to improve the performance of the system? In order to answer these questions, causal loops and dynamic models of the system are diagramed based on SD method and using Vensim PLE software. Next, the models are validated according to structure verification, behavior reproduction, and behavior prediction tests. Furthermore, the behavior of the system is analyzed and to improve the system, some scenarios concerning technology development and commercialization are proposed.

2 Literature review

2.1 Soft system methodology (SSM)

SSM is an established systems-based approach to use system concepts in unstructured or ill-structured situations which are problematic for making intervention and identification in the systems (Sgourou et al., 2012). In SSM learning system, participative pathways are developed in a systemic way aimed at better understanding of complicated human problem situations (Tajino et al., 2005). As the ontological principle of SSM, Rose and Haynes (1999) point that systems are the social world of attributing meanings; and epistemologically regard it mainly interpretivist which describes the real world by verbs.

Managers and policymakers can use SSM to develop new perspectives; and benefit from its propriety of reviewing contexts, identifying factors, and complexities of problems which exist in organizational change initiatives (Jacobs, 2004). SSM identifies many potential different ideal solutions, based on the character judging the solution; hence, it seeks to determine a desirable system that contains the needs of various interests. It creates and offers a multitude of acceptable alternatives and helps define the actions and changes that make the desirable future possible (Presley and Meade, 2002).

SSM looks at the objective definition of the problem situation in advance, from people having either diverse concerns or a direct interest in the solution of the problem through using rich pictures. In such a way, the basis for determining various worldviews of the problematic situation and a set of root definitions is formed. In essence, root definition is a verbal statement of the purpose, viewpoints, environmental constraints and transformation of the ideal system which are combined to make a meaningful statement of the system. Thereupon, to identify the principal deliberate functions inferred from the root definition, conceptual models which are the basis for comparison of a system with the real world are formed. The final stage involves recognizing systematically desirable and culturally feasible changes in the real world system. SSM has been applied in numerous research projects (Mehregan et. al., 2012; Kasimin and Yusoff, 1996; Holliday, 1990; Macadam et. al., 1990; Novani et. al., 2014), however, to our knowledge, there is no similar study conducted in a research and technology center.

2.2 System Dynamics methodology (SDM)

SDM extracts core structures of working mechanisms of a system and develops efficient management strategies based on analysis of feedback structures clear to the system and leads to better understanding of a system (Park et al., 2014). Its ontological principle indicates that systems are assumed to exist in the real world; and its essentially positivistic epistemological premise describes the structure underlying the real world regarding stocks and rates (Rodriguez-Ulloa and Paucar-Caeres, 2004).

For the successful use of SD as a learning tool after the identification of problem or policy issues intended by the management, SD models implement casual loops which are positive and negative feedback loops to identify the dynamics from these interactions and disclose the structure of a system. Hence, the system's behavior can be detected over a period of time (Zaim et. al., 2013; Zhang et. al., 2013). Engagement with mental models which hold the most important information about social situations and are the basis of decision making is essential in SD. Hence, through extracting, debating and facilitating change in the mental models of decision makers a system management methods can be improved (Lane, 2000).

In dynamic modeling, the development of a systems diagram showing the main variables and issues involved in the system of interest, construction of computer simulation model, simulation over time, generation and comparison of the model behavior, historical trends, and model verification are carried out. Subsequently scenarios cited as policies or strategies are postulated and tested.

2.2.1 Mental modeling in SDM

Mental modeling deals with experiences which can influence the ability to respond through prior knowledge; it may also lead to create presumptions on how to respond (Wilner and Birnberg, 1986). Moreover, it can function as a filter that the actor uses to see the problem (Kolkman et. al., 2005). Mental model is the final product of perception, imagination, and the comprehension of discourse (Goldvarg and Johnson-Laird, 1983) which all exist in the decision-maker before the decision situation and affect the understanding of task description and the problem itself (Wilner and Birnberg, 1986).

The mental models are also used for explaining the behavior of industrial and economic systems (Forrester, 1971). Managerial mental models represent the simplified knowledge structures or cognitive representations which show how the business environment works. Some of the characteristics of mental models include: 1) they are not always accurate (Gentner, 2002); also 2) they are fuzzy, incomplete, and imprecise (Forrester, 1971); and 3) their dynamic consequences could not be simulated mentally (Doyle and Ford, 1998).

Changing mental models requires learning i.e. a mental model needs to be constantly updated to get along with circumstance changes (Li, 2011). When major changes in the environment occur, a timely adjustment in the mental models of firm’s top managers is necessary for organizational renovation (Barr et al., 1992). The organizational learning has been identified by both managers and academics in which common understandings or shared mental models change (Senge and Sterman, 1992).

2.2.2 Scenario planning in SDM

The recent important developments in SD have made better access for the policymakers; where SD can process mapping policymakers’ knowledge or mental model and other information about the business or social system, and convert them into models and simulations (Morecroft, 1988). SD also fits into the strategy formulation process through three phases: analysis, planning, and control along with learning. In other words, SD supports the analysis phase of the strategy planning process by iterative structuring the problem, testing and refining the problem structure. Therewith SD is applied for planning which is also an iterative process and engaged with evaluation, selection and implementation of strategies. By prediction of expected performance, SD offers an essential element to the control phase and deviations make a signal for additional analysis (Lyneis, 2009).

SD can be also employed in scenario planning. Scenario depicts the future picture of system´s certain developments through interlinking qualitative and quantitative elements and sustaining system’s internal consistency (Zahradníþková and Vacík, 2014). As an important tool of support for the governments, industries and communities, scenario planning helps them to prepare and plan for the future, manage risks and seize the opportunities (Greiner et. al., 2014). Scenario planning method can be used as a way for creating or considering the transformational changes by the companies (Tushman and Romanelli, 1985).

According to Buytendijk et al. (2010), scenario planning has some differences with other planning methods, including:

- Scenarios seek for the shared effect of diverse uncertainties, which are equal and stand side by side.
- Scenarios altar numerous variables at a time, without necessarily keeping others unchanged.
- Scenarios go beyond objective analyses to achieve subjective interpretations.

As a general concept learning in scenario planning often refers to challenging the presumptions about the organization and its environment (Chermack, 2005). Transformation and changing the mental models in line with strategic learning is one of the ways that scenario planning uses to produce new insights and different views to see the world. In this view, one can share and challenge the knowledge about implicit processes and functions (Kortea and Chermack, 2007)

Companies may count on scenario planning to develop or improve their dynamic capabilities by implicit collecting of experiences such as hypothetical responses, knowledge representation in the simulations, and knowledge codification through the written representation of scenario planning decisions and results (Zollo and Winter, 2002). SD is applied in various research literature (Feng, 2012; Liuguo et. al., 2012; Hoffmann et. al., 2013; Rasjidin et. al., 2012; Kusumaningdyah et. al., 2013; Lee and Chung, 2012; Abada et. al., 2013). Choi and Kim (2009, 2015) studied the process of introducing a new product by SD by considering the interactions of the R&D investment that reflect the technology capacity of technological change, new product development, and the manufacture of a product. But, rare researches exist regarding the application of SD in technology development and commercialization.

3 The main objective and the process model of the company

Creating required technical knowledge is the main objective of NPC-RT which can be achieved according to Porter's value chain model. The company's process model is shown in fig.1 which depicts the primary and support activities of the company.

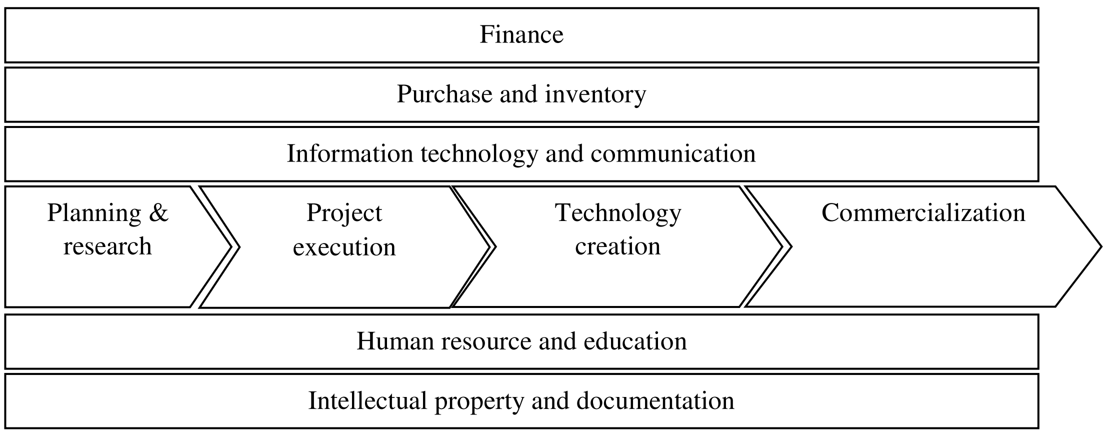

Figure 1. Value chain model of the company

So far the company has been focusing on research as its first priority, targeting innovation in every research project. Since the company is project-based, all activities are performed through communication among teams. Meanwhile, in order to enhance the revenue and meet the needs of the industry, the company takes technology development and commercialization into account as well.

4 Research methods

4.1 SSM in the company

In order to capture the essence of the problems that NPC-RT is facing, SSM is implemented using QSEE Superlite software. The issues in this system are complex and non-structured and multiple stakeholders define the problems according to their perspectives.

4.1.1 Rich picture

At first, through interviewing with experts, preliminary information about the problems was gathered. The stakeholders including individuals, groups, and companies whose expectations affect and shape each decision were specified and analyzed. Afterwards, the rich picture of system was depicted, as shown in the figure below (see figure 2).

This figure can be described as a company which is affiliated with the parent company and producers in the industry. At the end of each year, the company prepares and submits the short term annual plan and required budget to the parent company. Usually due to the new plans and rising inflation rate, a greater budget is requested each year. In contrast, parent company exerts more control over the budget. Hence, the major concern of the parent company is how it can afford the requested budget. By receiving the amount of fund, the company should provide research and technological services to the producers in the industry such as diagnosing and treating the process related problems, producing required raw materials mainly catalysts, and technology development. These requirements are notified to the company by the parent company or directly by producers.

Poor technology transfer and localization in addition to imposing extravagant costs for buying technology have reduced the industry to a mere importer of foreign technology. Although the company strives to understand various aspects of imported technologies, create technical knowledge, and localize and develop these technologies; but due to the importance and vitality of their works in the national economy and their position in the market, producers still do not trust the company's technical knowledge or developed technologies. Accordingly, the main concern of the producers is how they can trust the technical knowledge and developed technologies of the company.

The company reviews and approves many proposals from numerous universities and initiates collaborative researches. But the main concern is that many of the received proposals do not conform to the needs of industry.

The company's manager is highly concerned with the following issues:

- What objectives and strategies: technological competencies, amount of investment, technology sourcing and competition need to be managed based on a strategic point of view, and the company provides annual plans in accordance with the industry needs and knowledge availability.

- How to increase international cooperation: due to lack of knowledge and expertise in technology and level of financial resources, developing international cooperation would facilitate efficient and effective technology development.
- How to increase revenue: by virtue of article 44 in the constitution of Iran on the subject matter of privatization and restriction concerning the budget allocation, the company should attempt to increase its revenue.
- How to enhance technology: to provide the industry needs, reduce the expenditures incurred by importing technologies, and reduce the impact of budget shortage, the company should develop greater technologies.
- How to improve the structure and process: since the structure of company is designed solely on the basis of a research company, it is difficult for the company itself to reconcile with new processes such as technology development and technology commercialization. In addition, these issues are associated with the limitation of employing new staffs.
- How to improve regulation infrastructure: in order to support technology developers and to make contracts and agreements with customers, the regulation infrastructure needs to be improved.
- How to evaluate and improve the performance: decision making can be facilitated for the manager by providing a comprehensive view of the current situation and anticipation of the future through the implementation of a performance evaluation system.
- How to motivate the personnel: to retain and absorb experienced employees, incentive mechanisms should be promoted.

As well as trying to have an acceptable practice in process–based problem solving, researchers should strive to increase technical knowledge. Meanwhile, due to the limitation of organizational chart, researchers should manage several research projects at the same time including reviewing the received research proposals. Additionally, the more technical knowledge is related to industry needs, the more relevant technologies are developed.

In spite of the fact that NPC-RT has been producing technical knowledge and technologies, it rarely could commercialize its technologies. Therefore the marketer has two concerns: how to price and commercialize technologies and how to identify potential customers. Besides, lack of full knowledge and experience in the field of technology development, knowledgeable developers sometimes leaving the company as a result of a better job offer, and also shortage of systematic identification of industry needs include the main concerns in technology development area.

In all mentioned concerns, the main issue is understanding the needs of industry which will be facilitated by having a better communication between the company and the other companies in the industry.

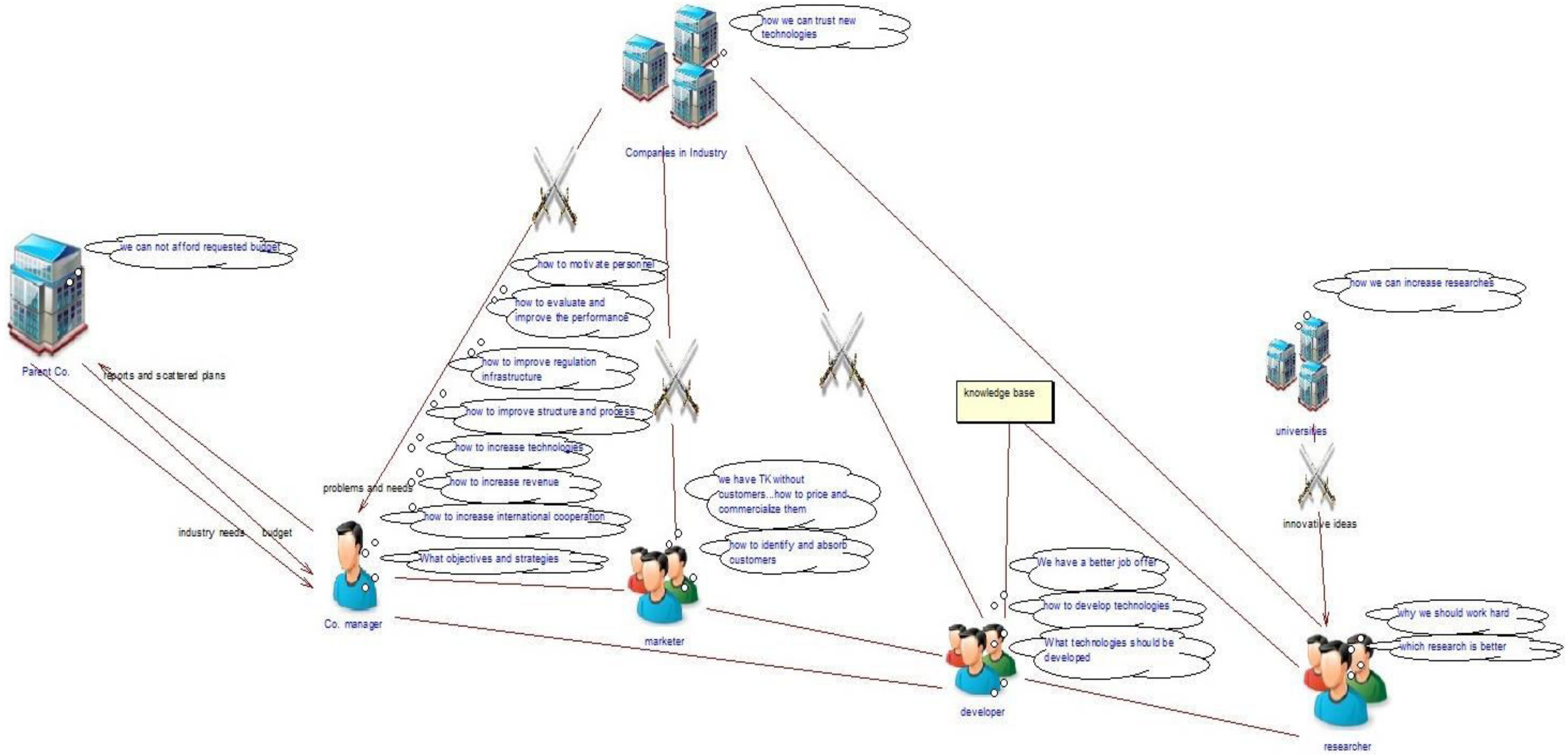

Figure 2. Rich picture of the company

4.1.2 Root definition

After specifying various concerns, root definition technique through CATWOE analysis is applied. In other words, the ideal system is defined according to the definition of CATWOE which is the acronym for following factors:

- Clients are stakeholders for whom the system exists such as producers in the industry,
- Actors are stakeholders responsible for implementing the changes, usually employees who are professionals in the industry,
- Transformation is the change that the system or process brings about including creating technical knowledge, developing required technologies, and solving the problems in the industry,
- Weltanschauung known as worldview is the justification for the transformation of the system or process which includes improving the company's market position, and increasing its revenue,
- Owners, usually the entrepreneur or the investor, who has the authority to make the changes, stop the project, or decide on whether to go ahead with the change including company's manager and parent company,
- Environmental constraints are the external constraints such as political, legal, economic, and cultural pressures under which the system works, and which may hamper or restrict the changes to the system.

According to the customer perspective, the ideal system is defined as a system which provides their raw material and technological needs without disrupting operations. Based on the definition of experts in the industry, the ideal system facilitates creating technical knowledge and developing technologies. Conforming to the manager's point of view, ideal system enhances the revenue of the company, the position of the company in industry, and prepares the company for privatization.

4.1.3 Conceptual model

After defining the ideal system, its conceptual model consisting of main functions and their relations is proposed. All the presented functions are interrelated together, but in the fig. 3 only the main relations are shown.

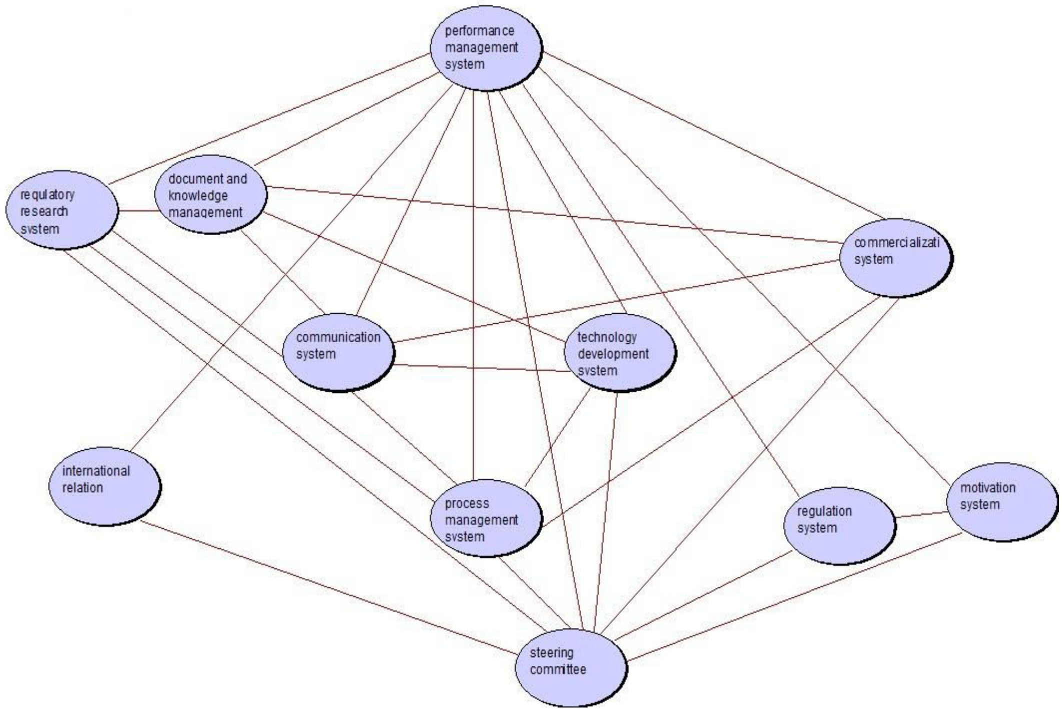

Figure 3. The conceptual model of the system

It is necessary for the company to create a steering committee made up of other companies and individuals such as experts of technology, marketing, management, law, and international relation from industry, universities, research centers, and engineering companies, the manager of the parent company and company managers in the industry, and a representative from government to specify plans and strategies. Through initiation of the steering committee, tracing new technologies, determining and predicting market needs, effective decision making, and providing long term plans will be carried out.
To define and improve the process and changes of the organizational structure aligned with the proposed processes, it is essential for the company to have a process management system as a result of definition of organizational processes, as well as benchmarking the best practices, suggesting the desired processes and structure, and defining an action plan for progressing from current conditions to desired one. Additionally, in order to evaluate and improve the performance namely to have performance management system, determining the performance criteria aligned with the objectives, evaluating company's performance, finding obstacles and problems, and resolving them should be performed.
Since the company basically needs to improve the regulation infrastructure, the regulation system is proposed for recognizing the problems related to the lack of regulation, finding the solutions, and dealing with the problems. Furthermore, it is required to reform the international interactions and cooperation through specifying the international opportunities and negotiating bilateral or multilateral agreements or contracts in order to develop and commercialize technologies cooperatively.

To promote research and decrease the time duration of doing the research projects, it is recommended to delegate the projects to the universities and other R&D centers and research staffs in the company play the role of supervision. This regulatory research system composes of functions such as: categorizing universities and R&D centers based on their expertise, defining the supervisors, idea generation, idea revision according to market needs and plans, proposal approval, library studies, laboratory studies, and bench scale.

To embellish technology development, technology development system consisting of pilot plant scale, demonstration scale, and industrial scale should be implemented. Due to the importance of increasing the company's revenue, it is essential to advance technology commercialization. With regard to the existence of the patent system in the company, three functions ought to be executed including: providing and using effective pricing and marketing techniques, finding potential customers, and applying customer retention strategies.

With the help of communication system, interaction and works among researchers, developers, marketers, producers in the industry, universities, research centers, engineering companies, and the company's supporters will be facilitated. For having communication system, three basic functions should be implemented: defining the information and knowledge, developing an effective application and infrastructure, and educating system users. Moreover, by way of putting documentation and knowledge management system into practice the company can manage the reports and experiences now being able to create, review, save, and share them.

It is necessary for the organization to motivate employees in order to retain them and enhance the productivity. Therefore employees' needs should be diagnosed; and the mechanisms which satisfy employees' needs ought to be defined and executed.

4.2 SDM in the company

In accordance with the findings based on SSM, the important sectors of the company which need to be ameliorated are technology development and commercialization. In this regard, the dynamic model developed in this paper fits to the situations of technology development and commercialization processes based on two-year data and managers' forecast patterns up to three years using the modeling software VENSIM PLE. The basis of the dynamic model is consistent with the following figure which shows the technology development and technology commercialization mechanisms. In technology development sector, there are two stock variables: current technology projects refer to the accumulation of projects that have not been started or have not been finished yet. In other words, current technology projects variable is equivalent to the difference of development finish rate and development initiation rate. Besides, finished technology projects occur as the consequence of the accumulation of completed technology development projects. The technology commercialization sector can be explained the same way as technology development sector. Related to this system, Kumar and Jain (2002) argued that when there is a shortage of funds, in particular in the developing countries, creating a balance between developing and commercializing technologies which fulfills the maintenance needs and warrants regular activities is a hard task. As declared by Lassere (1982), there are also some important external factors including market condition, investment situation, and government policy which can influence on the performance of developing and commercializing technologies. Bar-Zakay (1977) stated that investment, development capability, the number of experts, experience, and management strategy are among the main factors of commercialization.

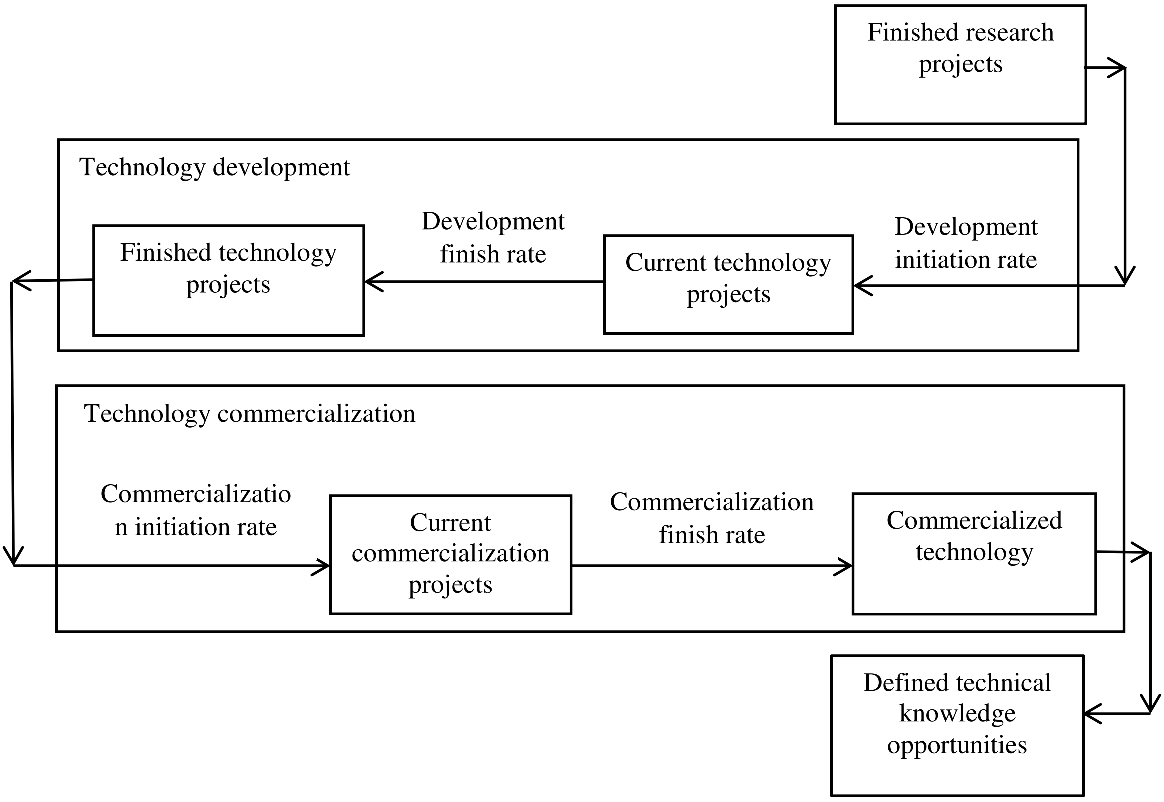

Figure 4. General view of technology development and commercialization sectors

4.2.1 Causal loop diagram

After main stock and rate variables, the variables that influence them are identified. The finish rate of both development and commercialization are influenced by time duration of performing the project which is the main factor that affects the performance of the company. If all resources to develop and commercialize technology including budget, equipment, and staff are available and also staffs have enough experiences related to current projects then the time duration will be as a time schedule without delays. Namely, lack of experience and inadequate resources bring about delays in technology development and commercialization. Here only the most important causalities for technology development are considered, because the causal-loop diagrams for technology development and commercialization are the same.

Figure 5 shows that the more current technology projects exist, the more staffs for technology development are required. If there is adequate technology development staff for doing the current technology projects, then technology projects will be completed at the expected time. In contrast, if the existing technology development staffs are not sufficient to meet project requirements, then there will be a lack of staff which results in increasing the time needed to perform technology development.

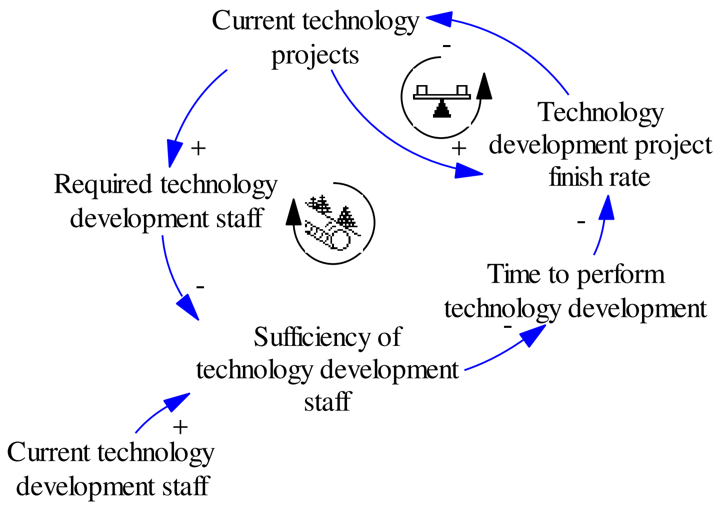

Figure 5. The effect of staffs in the technology development sector on time to perform technology development like other resources including equipment, and budget

Besides, figure 6 shows that through performing technology projects, the technology experience in technology development sector will be enhanced. The higher the finishing rate of technology projects, the greater technology related experience will be created. Increased technology experience will reduce the time to perform technology development, enhance the finishing rate of technology projects, and result in self-reinforcement of this mechanism.

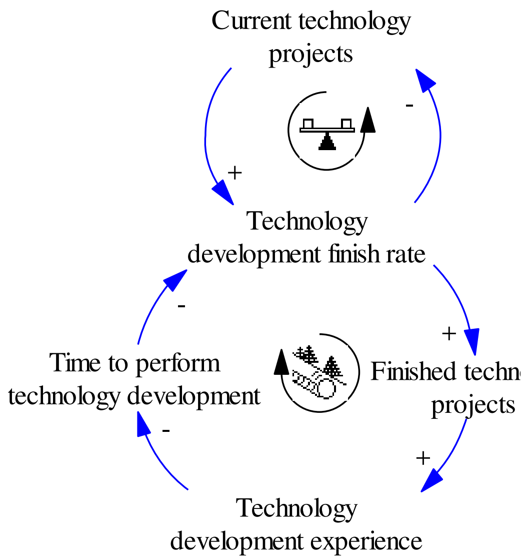

Figure 6. The impact of technology development experience on time to perform technology development

In addition to the completed research projects, the perception concerning the company's development capacity impacts on the initiation rate of technology projects. Development capacity is also influenced by the technology project finish rate. Therefore, if performing technology development takes longer, the initiation rate of technology projects and also the current technology projects will be reduced.

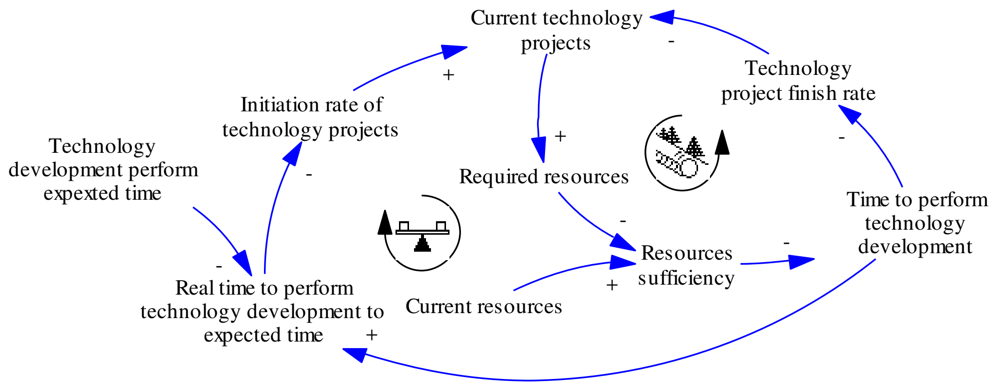

Figure7. The initiation rate of technology projects causal loop

4.2.2 Dynamic modeling

However, the causal-loop diagram needs to be complemented by a quantitative implementation based on the stock-and-flow diagram. These diagrams can be considered as an interface between reality, the model, and computer simulation. In dynamic modeling, variables are used for calculation purposes. Variables such as: stocks representing the status of a system, giving a measurable value at each time step, and the inflows pointing at a stock increase this value which is against to outflows pointing away from a stock; also, auxiliary variables can contain constants or other parameters. A simplified extract of the dynamic model of the technology development sector is showed in figure 8. Here only the most important variables and equations for technology development are presented:

$$\text{Current technology projects} = \text{Technology development initiation rate} - \text{Technology development finish rate} \quad (1)$$
$$\text{Initial value} = 10$$

$$\text{Technology development initiation rate} = (\text{Rate of utilizing completed research projects} \times \text{Feffect development initiation}) + \text{Industry innitiation for development} + \text{Management initiation for development} \quad (2)$$

$$\text{Time to finish technology development (TFD)} = \text{ATFD} + \text{ATFD} \times (\text{Effect of development budget availability} + \text{Effect of development Equipment availability} + \text{Effect of development staff availability})/\text{Effect of DE on TFD} \quad (3)$$
$$\text{ATFD} = 18$$

$$\text{Perceived technology development capacity (PDC)} = \text{Effect of TFD} \times \text{C perceived development capacity} \quad (4)$$

$$\text{Technology development finish rate} = (\text{Current technology projects})/\text{TFD} \quad (5)$$

$$\text{Finished technology projects} = \text{Technology development finish rate} - \text{Completed development projects obsolescence} - \text{Transfer to commercialization project} \quad (6)$$
$$\text{Initial value} = 4$$

$$\text{Completed development projects obsolescence} = (\text{Finished technology projects})/(\text{Time to obsolete completed development projects}) \quad (7)$$

$$\text{Transfer to commercialization project} = (\text{Finished technology projects})/(\text{Time to initiate commercialization projects}) \quad (8)$$

$$\text{Development Experience} = \text{Development experience accumulation} - \text{Development obsolescence} \quad (9)$$
$$\text{Initial value} = 100$$

$$\text{Development experience accumulation} = \text{Technology development finish rate} \times \text{Experience per unit of development projects} \tag{10}$$

$$\text{Development obsolescence} = (\text{Development Experience})/(\text{Development experience obsolescence time}) \tag{11}$$

$$\text{Development staff} = \text{Development staff acquisition} - \text{Development staff lay off} \tag{12}$$

Initial value = 20

$$\text{Development staff acquisition} = (\text{Development staff deficiency})/(\text{Time to acquire development staff}) \tag{13}$$

$$\text{Development staff lay off} = (\text{Development staff})/(\text{Time to retire development staff}) \tag{14}$$

$$\text{Development equipment} = \text{"D. Equipment providing"} - \text{"D. Equipment depreciation"} \tag{15}$$

Initial value = 40

$$\text{"D. Equipment providing"} = ((\text{Equipment deficiency})/(\text{Time to acquire})) \times \text{Effect of development budget availability} \tag{16}$$

$$\text{"D. Equipment depreciation"} = (\text{Development equipment})/(\text{"time to depreciate D. Equipment"}) \tag{17}$$

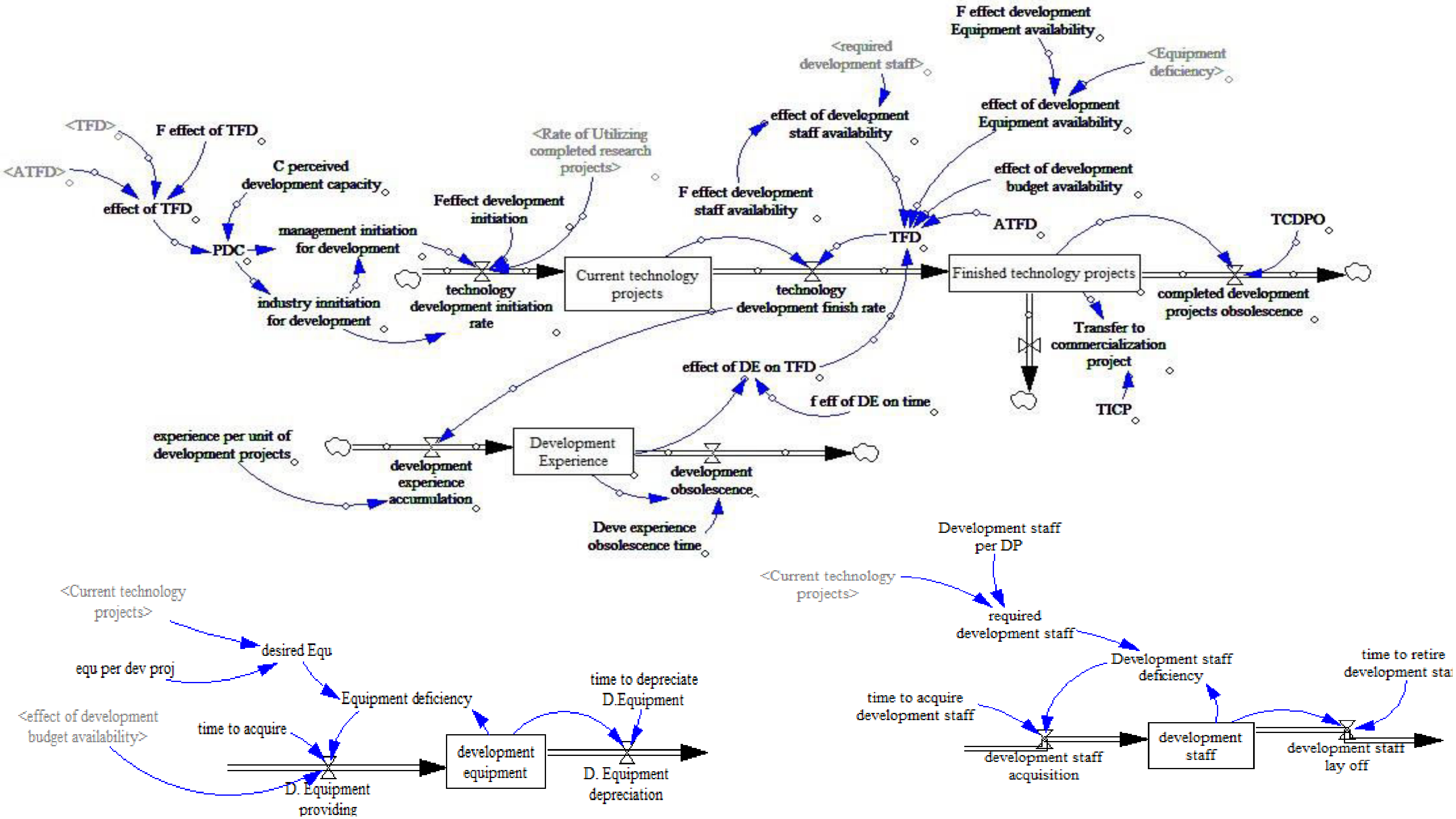

Figure 8. Dynamic modeling of technology development sector

4.2.3 Model valuation

For calibration and model validation, in addition to model check in the software, these three methods were used (Forrester and Senge, 1979):

- Model's structure- structure verification test
- Model's behavior - behavior reproduction test
- Behavior prediction test

Verifying structure means comparing the structure of a model directly with the structure of the real system that the model represents. In other words, to pass the structure verification test, the model's structure must be consistent with the structure of the real system. Hence it involves comparing model assumptions with managers and decision makers. In this regard, based on the viewpoints of the general manager, research and support managers, the model structure matches the real life of the company.

Furthermore, behavior reproduction test examines how the behavior of the model conforms to the observed behavior of the real system. For instance, the symptom generation test examines whether or not a model recreates the symptoms of difficulty that motivated construction of the model. In this case, the most important problems of the system are dependence on the financing from the parent company and manager's concern to increase the revenue. Complying with these problems, the model represents the problems by fluctuations in funding and time to perform projects which results in a decline in performance. Additionally, the model behavior is consistent with the past two–year data.

Behavior prediction tests examine whether or not a model generates qualitatively correct patterns of future behavior. The model behaves similar to the forecasting patterns up to three years by managers.

5 Discussion and policy implications

5.1 Behavior analysis

From figure 9, it is clear that the time to perform technology development after a year has been dropping sharply over time. The reasons for the time reduction include increased experience and resolving equipment deficiency. Time volatility is due to the fluctuation in the budget effect.

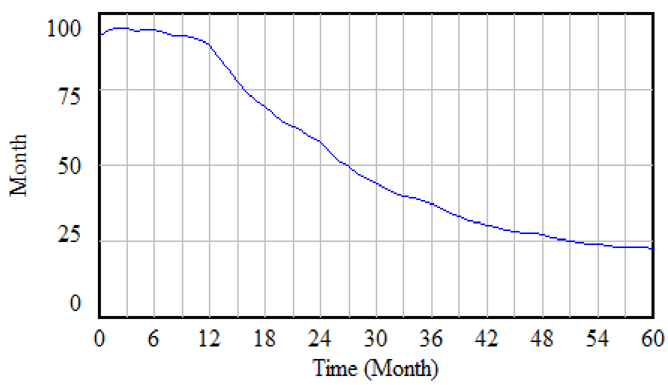

Figure 9. Time to perform technology development

Moreover, as shown in figure 10, technology development finish rate has been rising as a consequence of a sharp decline in time to perform technology development. On contrary, technology development initiation rate has fallen considerably and then has been fluctuating slightly around a certain amount. Meanwhile, both have similar volatility that occurs due to the effects of funding volatility. Strictly speaking, the technology development initiation rate is influenced by the rate of utilizing completed research projects impacted by time to perform research projects affected by the effect of research related budget. Additionally, initiation rate and finish rate depend on time to perform technology development. Therefore, it is obvious that the dependency on funding is the major problem which causes diverse difficulties.

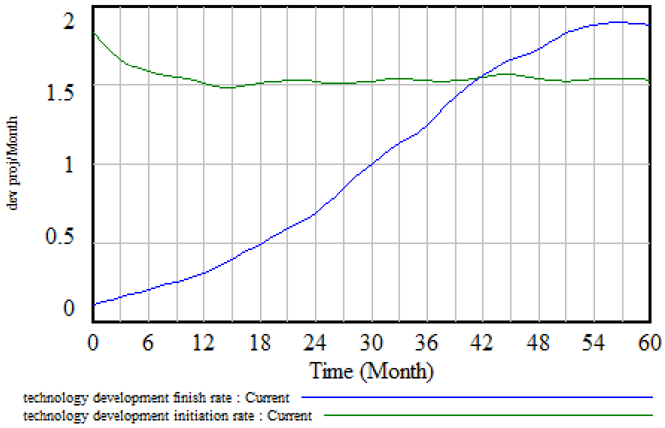

Figure 10. Technology development initiation and finish rate

It is obvious from figure 11 that the time to perform technology commercialization has had a sharp decline. The drop has occurred because of supplying equipment needs and the required staffs, besides the positive impact of experience.

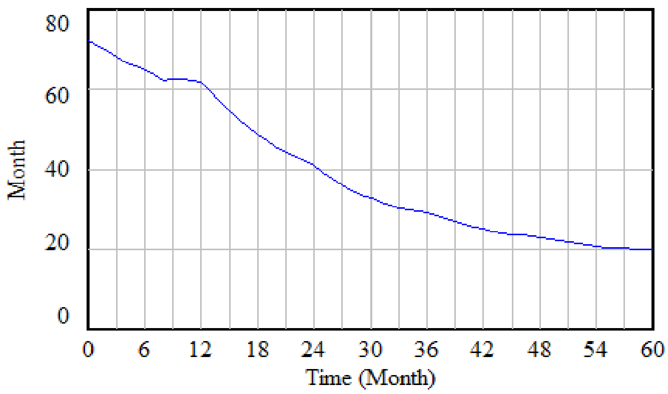

Figure 11. Time to perform technology commercialization

Therefore, as it clear from figure 12, technology commercialization finish rate has been going up considerably and also technology commercialization initiation rate has been rising slightly. Mainly, by decreasing time, initiation rate increases with much lower intensity than commercialization finish rate. Additionally, it is obvious that volatility and uncertainty are caused by the dependence on the budget.

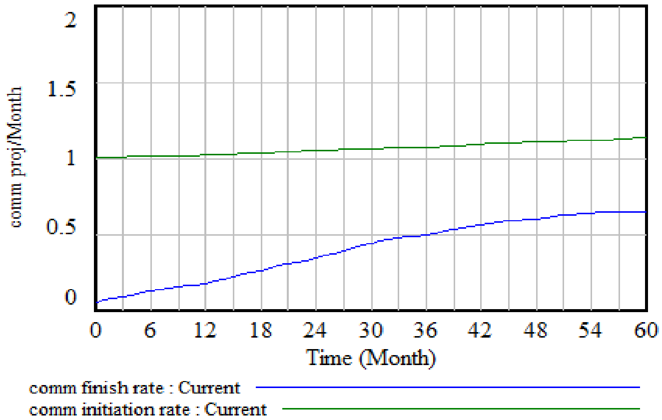

Figure 12. Technology commercialization initiation and finish rate

5.2 Scenario planning

At first, the dependence on the budget in both technology development and commercialization sectors should be reduced because it impacts on both initiation and finish rates. In technology development sector, budget fluctuation causes a lot of volatility in:

- Time to finish technology development (TFD)
- Technology development finish rate
- Technology development initiation rate
- Perceived development capacity (PDC)
- Management initiation for development
- Industry initiation for development
- Technology development experience accumulation rate
- Development equipment providing rate

Consequently, as a scenario it is proposed to reduce the effect of dependence on funding annual 10 percent. This scenario is applied after two years.

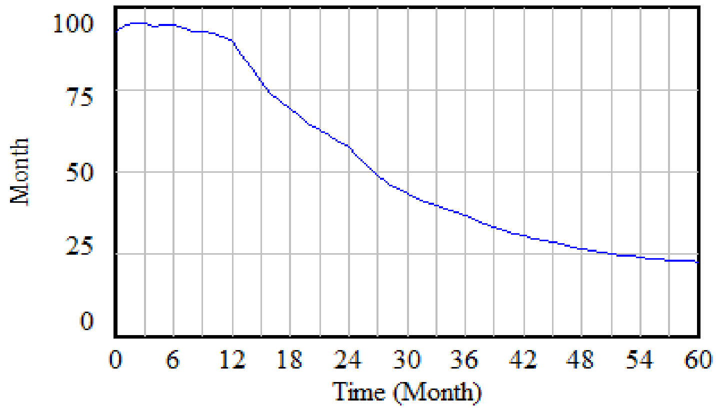

Figure 13. Time to perform technology development after applying funding scenario

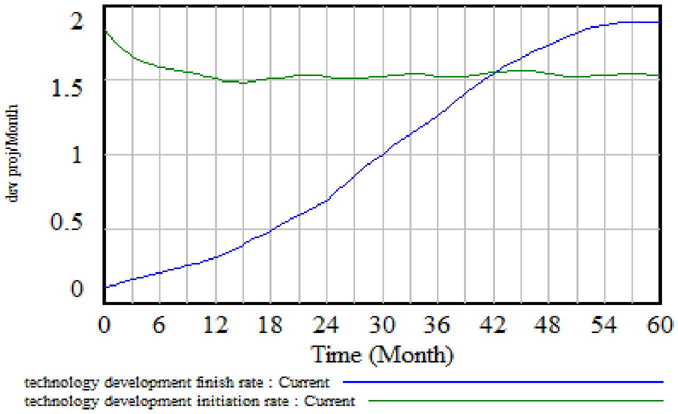

Figure 14. Technology development initiation and finish rate after applying funding scenario

Due to applying this scenario, despite the minimal changes in time and other related patterns, the fluctuation has considerably resolved.

In addition, volatility in technology commercialization sector made by budget fluctuation is apparent in:

- Time to finish technology commercialization (TFC)
- Technology commercialization finish rate
- Technology commercialization initiation rate
- Perceived commercialization capacity (PCC)
- Management initiation for commercialization
- Industry initiation for commercialization
- Commercialization equipment providing rate

Thus, same as technology development sector, it is suggested to reduce the effect of dependence on funding 10 percent annually. This scenario is implemented after 2 years.

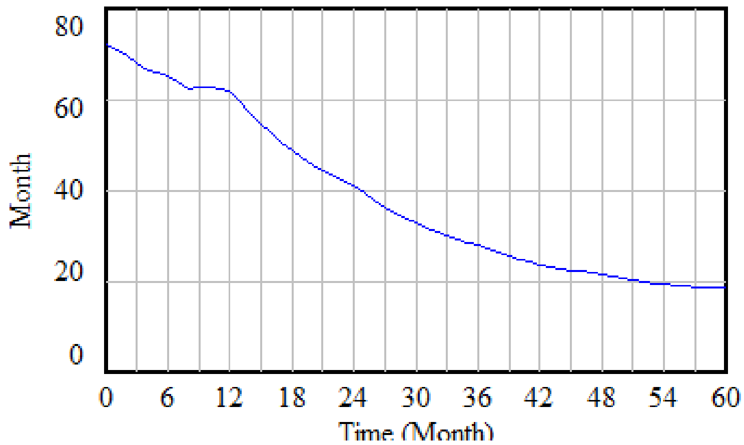

Figure 15. Time to perform technology commercialization after applying funding scenario

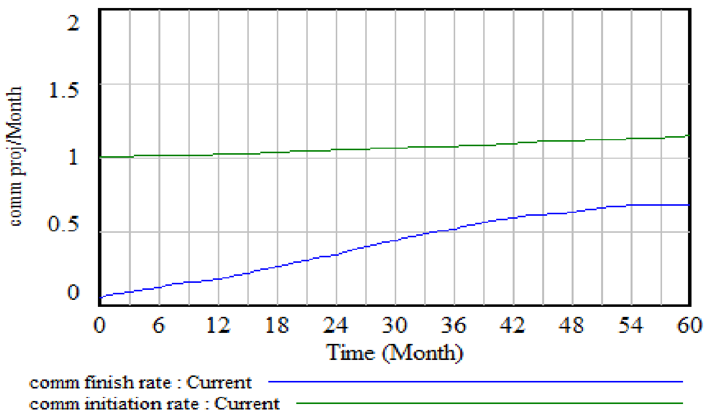

Figure 16. Technology commercialization initiation and finish rates after applying funding scenario

As a result of applying this scenario similar to the technology development sector, despite the minimal changes in time and other related patterns, the fluctuation has considerably resolved.

Besides reducing the effect of dependence on funding 10 percent annually, two times increase in the coefficient of development capacity, two times increase in industry initiation and 50 percent increase in management initiation simultaneously can also be proposed. As a result of this scenario, company's manager initiates technology development because of this perception that company can develop technologies by 50 percent more than collective perception of the company. It shows that by increasing the technology development capacity perception coefficient to less than 60 percent, the development initiation rate will grow (see figure 17). In other words, if the company's manager and the manager of the parent company expect more productivity, then more technologies will be developed. Through applying these scenarios in the case of the technology commercialization sector, similar behavior and result as technology development is achieved. According to figure 18, it is clear that if the company's manager and the manager of the parent company expect more productivity, then more technologies will be commercialized.

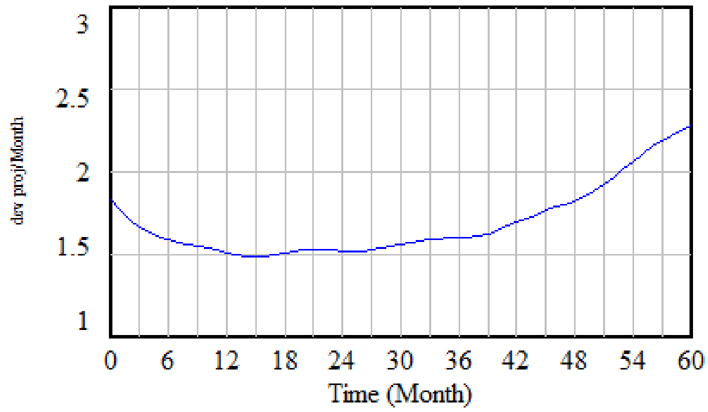

Figure 17. Technology development initiation rate after applying capacity perception policy

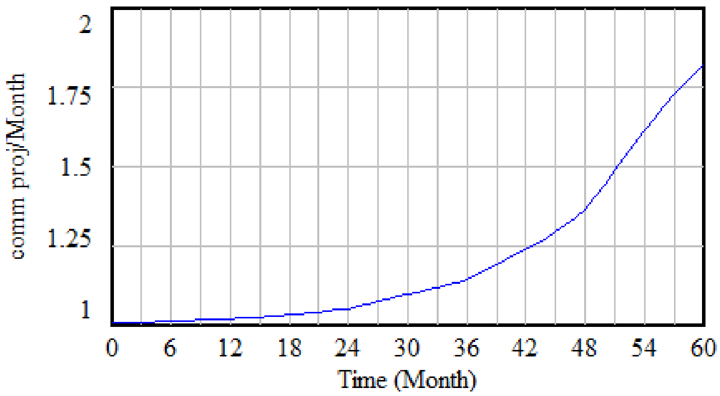

Figure 18. Technology commercialization initiation rate after applying capacity perception policy

Additionally, there are two exogenous variables in both sectors which imply restricting external factors in technology development and commercialization: the factor which effects technology development initiation is equal to 0.03 and the factor which impacts on technology commercialization is 0.01; a lower value indicates that there are greater external limitations in technology commercialization than technology development. In this regard, one of the policy problems is the tendency that decision makers have to attribute undesirable events to exogenous rather than endogenous sources. According to previous experimental researches in the field of SD, the lack of a fully endogenous perspective in decision tasks is found to be the major cause of sub-optimal performance (Ghaffarzadegan et al., 2011). But in the present study, due to the proposed systems in the conceptual model such as the regulation system, these two exogenous variables can be improved. These variables influence the initiation rates; thus, after applying solely this scenario for technology development from 0.03 to 0.04, the technology initiation rate will be increased about 0.09. Furthermore, as a consequence of enhancement of the factors affecting technology commercialization from 0.01 to 0.03, technology commercialization will be increased about 0.03.

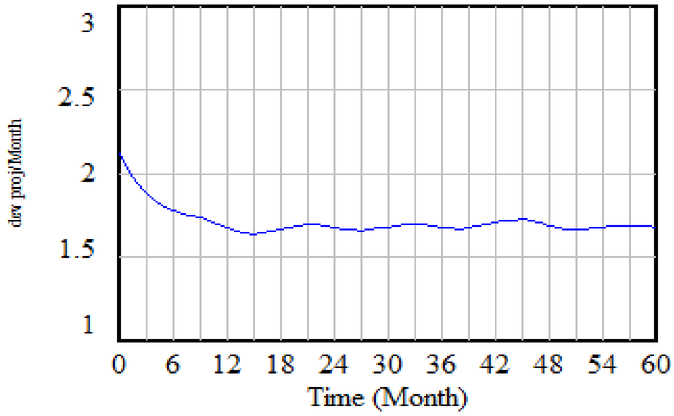

Figure 19. Technology development initiation rate after reducing environmental constraints

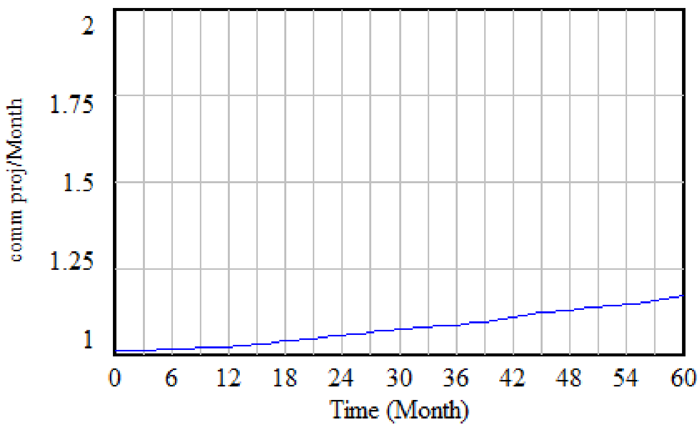

Figure 20. Technology commercialization initiation rate after reducing environmental constraints

In technology development sector, by means of exerting all scenarios related to this sector, as it is apparent from comparing the two following figures, current technology projects will rise about 28 percent and finished technology projects will be improved by about 12 percent.

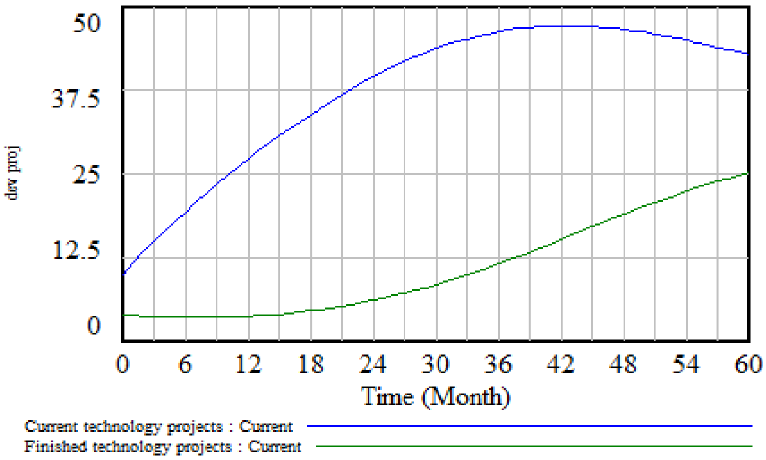

Figure 21. Current technology and finished technology projects before applying scenarios

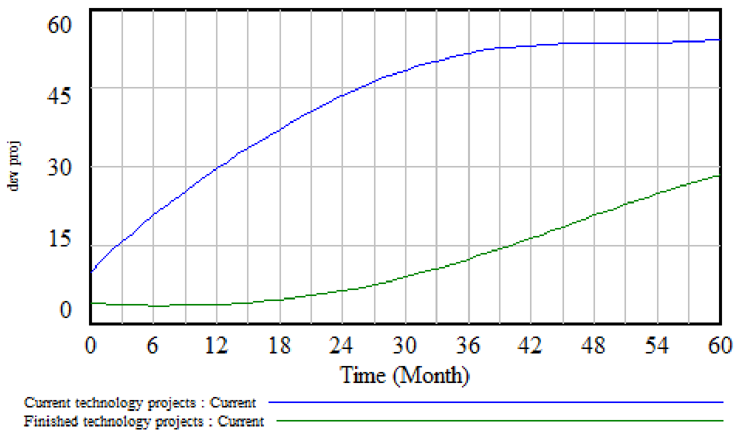

Figure 22. Current technology and finished technology projects after applying scenarios

This change needs an increase of about 15 percent in development staffs and about 7 percent in development equipment.

Besides, in technology commercialization sector, by way of using all scenarios related to this sector, as it is clear from comparing the two figures bellow, current commercialization projects will be risen by about 41 percent and current commercialized products will be improved by about 17 percent.

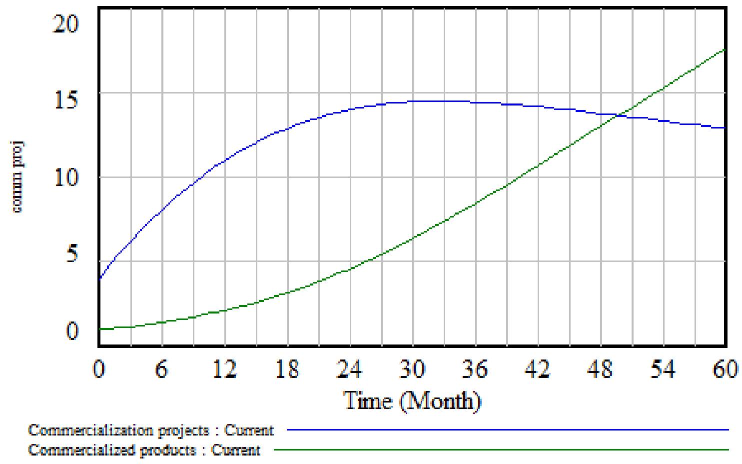

Figure 23. Current commercialization projects and commercialized products before applying scenarios

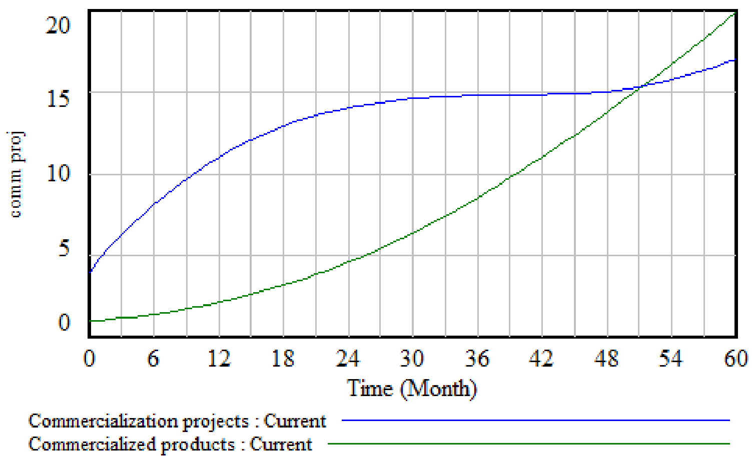

Figure 24. Current commercialization projects and commercialized products after applying scenarios

This change needs an increase in development staffs about 25 percent and about 16 percent rising in using development equipment.

6 Conclusion

In this paper two different systems thinking paradigms, SSM and SD were applied in NPC-RT. In addition, three questions were answered which are 1) what are the main problems and sectors in NPC-RT? 2) What are current behaviors of the system? 3) What are the scenarios to improve the performance of the system? In this case, SSM is used to determine the existing problems in the company and find the most effective sectors. Additionally, SD is applied to define the current structure and possible valid scenarios to improve the selected system.

According to the results, human resources are one of the major success factors in technology development and commercialization. Developing human resources brings about greater competence and experience. As the research results show, time to perform development and commercialization has been declining sharply over time in view of the fact that the expertise and experience have been growing during the months and influenced the time. In this case, the company can reinforce human resources with the help of arranging required and essential training courses and motivate human resources in team working. In addition, entrepreneurial characteristics including risk-taking, creativity, and innovation are necessary for developers and marketers. The ability to attract and retain talented technical employees is a critical success factor for companies pursuing technology-based competitive strategies.

Mainly, another main success factor in technology development and commercialization is the firm's access to financial resources. In this case, the most important problem is related to the budget allocation because it influences multitude volatilities and uncertainties in the system; therefore the proposed scenario makes the company released from the harmful effect of a lack of funding or delays in the allocation of funds. The firm's budget is composed of approved budget allocated by the parent company and the company's revenue. Thus, the company should attempt to grow company's revenue. To accomplish this thread, technology commercialization sector should be improved.

As the dynamic model indicates, the initiation rate of development is based on the output of the research and the initiation rate of commercialization is related to the developed technologies. Thus, to promote the commercialization, technology development should be strengthened. In addition, there are also some important external factors including policies and regulations such as sustaining domestic technologies, property rights, supporting R&D centers especially developers, labor law, long term contracts between the company and customers in the industry which play the key role in progression of technology development and commercialization.

Finally, this paper attempted to develop a dynamic model for managing a research and technology center focusing on technology development and commercialization. It can also provide R&D managers to develop a SD model of their own firm and develop strategies to improve their firms.

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