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Introduction to Techno-Sectoral Innovation System Modeling and Functions Formulating

S. M. Azad, H. Ghodsipour, F. Roshannafas

***Abstract*—**In recent years 'technology management and policymaking' is one of the most important problems in management science. In this field, different generations of innovation and technology management are presented which the earliest one is Innovation System (IS) approach. In a general classification, innovation systems are divided in to 4 approaches: technical, sectoral, regional, and national. There are many researches in relation to each of these approaches in different academic fields. Every approach has some benefits. If two or more approaches hybrid, their benefits would be combined. In addition, according to the sectoral structure of the governance model in Iran, in many sectors, such as information technology, the combination of three other approaches with sectoral approach is essential. Hence, in this paper, combining two IS approaches (technical and sectoral) and using system dynamics, a generic model is presented for a sample of software industry. As a complimentary point, this article is introducing a new hybrid approach called Techno-Sectoral Innovation System. This TSIS model is accomplished by Changing concepts of the 'functions'-which came from Technological IS literature- and using them into sectoral system as measurable indicators.

***Keywords*—**Innovation system, technology, techno-sectoral system, functional indicators, system dynamics.

I. Introduction

In recent years, the margin between 'science, research and technology policy making' and 'innovation, creation, and entrepreneurship management' fields has been faded and as a result a comprehensive approach named "innovation system" is emerged in literature. Recognition, evaluation and analysis of national, regional, sectoral, and technological innovation systems provide several fields of researches in social and economic sciences, management, system engineering and policymaking in science and technology. As an example, [1] reviewing evolutions in science policymaking and innovation studies, presented a list of researcher's efforts in different related fields in recent 50 years.

However, because of the complexity of concepts and multi-directional and interrelated communications, the literature of the sectoral innovation system is less extended in contrast to the other parts of IS approach, those other parts are also limited to just explain and express and are less concentrated on analyzing current situation and designing ideal system.

Also, lack of the clear definition of policymaking concept and neglecting proper modeling methodologies causes decrease in scientific efforts efficiency in this approach.

S. M. Azad, H. Ghodsipour, and F. Roshannafas are with the Department of Industrial Engineering and Management Systems, Amirkabir University of Technology, Iran (Tehran Polytechnic) (phone: +98-912-510-32-21; fax: +98-21-660-330-60; e-mail: s.m.azad.m@aut.ac.ir, f_roshann@yahoo.com, h.ghodsipour@yahoo.com, respectively).

According to classification presented by [2], system dynamics is one of the possible options in facing to complex systems. Each innovation system is comprised from three Aspects: 'structure', 'function', and 'motores'. The structure of the innovation system includes all important factors in the field of economic, politic, society, organization, law and other factors affecting on the development, diffusion and utilization of the science and innovation [3].

The literature of this approach issued in the late of 1990's and progressed in the recent decades, determines the four directions of innovation systems: national, regional, sectoral, and technical [4]-[6].

Based on the literature each innovation system comprises 7 functions [7]: Entrepreneurial activities, Knowledge development, Knowledge diffusion, Guidance of the search, Market formation, Resource mobilization, Support from advocacy coalitions.

Interrelations between different functions in various stages of technology lifecycle accelerate technology development. Meeting each function facilitates complying other functions. This connections between functions can create closed loop (includes different functions) which follow a united goal.

In literature this closed loops which create momentum in meeting functions are named as innovation motors [7]. These motors are: science and technology push motor, entrepreneurial motor, system building motor and market motor.

Below, the links between mentioned topics relating to techno-sectoral approach are discussed.

In order to viewpoints of the sectoral approach founder [8], four fields can be considered to shape this approach:

1. Special attention to sector evolution: industry lifecycle, extended analysis of long-term evolution of the sector
2. Concentration on relations and dependencies and sector margins: dynamic edges of production and service according to innovation growth.
3. Innovation system approach: attention to players, structures, functions and collective process of innovation
4. Evolutionary framework: attention to scientific and economic evolution and cooperation of heterogeneous firms

According to the resemblance of concept, tools and methods in the literature, sectoral, and technical approaches place in a cluster and national and regional approaches place in another one. As a confirming example, [9] directly presented this classification and also [10] verified this structure and also separated national approach from regional. As well as [9], [10], this classification is used in [11].

Thus, it can be said that in IS literature, sectoral and technical innovation systems are similar. Hence, it seems that utilizing benefits of both these approaches can be useful and connections between them are worth investigating.

Generally, formation stage of an innovation system includes: knowledge creation and research, knowledge conversion into products and entrepreneurship; shaping coherent administrator institutes and market formation.

Reference [12] according to policymaking of innovation system in subsystems of renewable energies reviewed innovation problems in this field. Also [13] with special concentrating on innovation policy making concept and considering missions in it, studied general procurement for innovation systems. Reference [14] considering sectoral edges and technologies in a sector, and using benefits of extended technical innovation system (TIS), surveyed effective technologies on an IS in the field of energy in Switzerland (as a case study). Reference [15] formed an innovation system in real world. Reference [16] with concentrating on the technical and social dimensions of sectoral innovation system (SIS), and based on the interactions between technical systems and a sector, presented an analytical framework relating to sectoral system. Also [17] linking evolutionary and semi-evolutionary approaches, investigated social and technical dimensions in SIS.

Based on the mentioned, although there have been some efforts to link TIS and SIS recently, techno-sectoral innovation system (TSIS) approach is a less surveyed approach in the literature yet. In this paper functional indexes are defined, and their values according to techno-sectoral model are quantified. Finally, model is applied on a real example (using dynamic system concept) and model Performance is assessed.

II. Modeling

In this paper the presented model included 5 key players and is applied to a proper sector. Bellow, these players are illustrated:

I. Policymaker, II. Research center, III. Private contractor, IV. Governmental contractor, V. Market.

Policymaker controls supportive and supreme actions in the system. Research center (as a research part) controls knowledge creation and distribution in the system. Private contractor is considered as a representative of the private sector. Governmental contractor is considered as a part that competes with the private sector and is controlled and supported by policymaker. Market is considered as a part of system which controls product (indeed, technologies which resulted in product) and exchange of resources. As an example, connections of policymaker in 'I think'–as a system dynamic simulator- is as below:

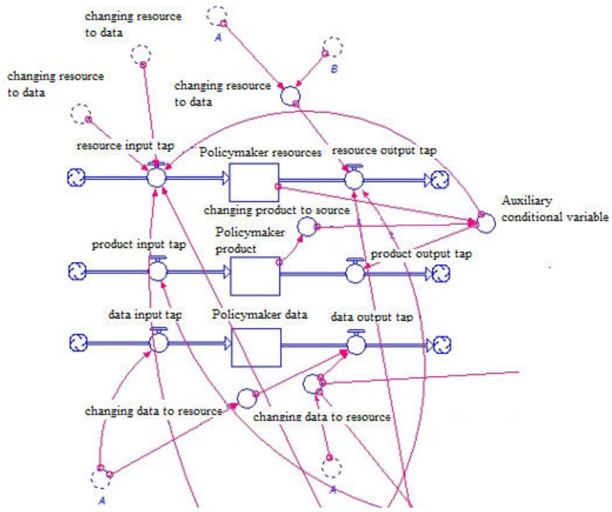

Fig. 1 Schematics of the connections of the policymaker

In SIS, According to [8], connections are defined as: exchange, communication, command, competition, cooperation.

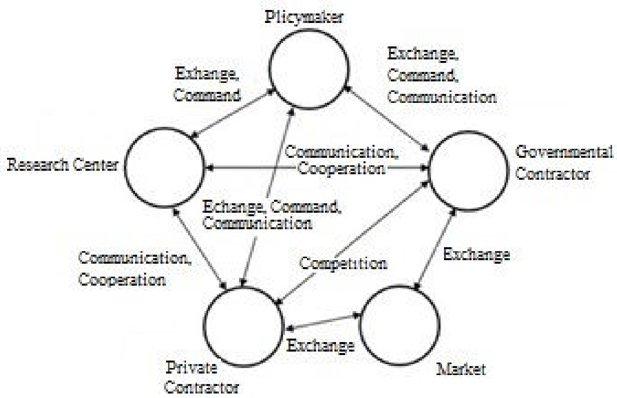

Fig. 2 Sectoral connections in the system

Also some mechanisms designed in the system, such as investment capability and loan payment to the contractors, paying subsides or gaining tax by policymaker to the governmental and private contractors. The existed flows in the model are generally defined as: resources, products and knowledge. These flow would be exchanged to each other in order to make a specific added value. These exchanges take place both internally in each player and externally through interaction between two players with determined coefficients.

For each player Internal exchanges are mission based and externals are based on their benefits and market mechanism. For example, research center as a player can exchange its resource into knowledge internally and is able to sell its own knowledge to privet contractor and earned money in regard (external exchange). Below, a diagram of the connections defined for the designed system is depicted.

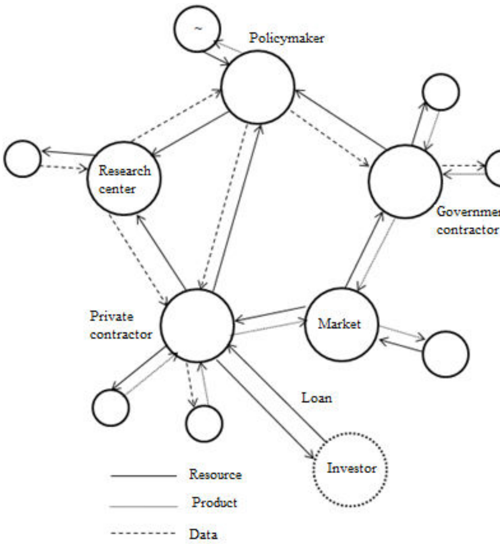

Fig. 3 Connections between players of the system

Each flow is determined as a ‘level variable’ and most connections are defined as ‘auxiliary variables’.

It is essential to explain some specific conditions which are assumed for different players in the modeling:

- ✓ Policymaker internal exchanges are defined as conditional terms: if the product inventory is less than the initial value, policymaker can exchange some parts of the inventory into resources.
- ✓ For the market, assumes that this player can exchange purchased products into resources with proper coefficient.
- ✓ Investor is defined as an optional part in the model: policymaker can handle the system with and without this part and evaluate the effect of its existence. As depicted in Fig. 3, this part is relating to the private contractor.
- ✓ At the end, governmental contractor provides its resources through policymaker with the incentive policy which is presented by government.

III. Functional Indexes

In the literature, relating to functional indexes some explanations are presented. In this section this indexes are more introduced and formulated upon model characteristics:

A. Promoting Entrepreneurial Activities (F1)

Entrepreneurship is one of the most important functions of IS. Indeed, its role is to exchange sciences, networks and potential markets into a new emerged technology. In other words, entrepreneurs are newcomers to the market which extend new technology and diversify its applications. This index is defined in the model as below:

$$F1 = \frac{Contractor's\ resource\ and\ product - Initial\ value\ of\ Contractor's\ resource\ and\ product}{Initial\ value\ of\ Contractor's\ resources\ and\ products} \quad (1)$$

Above phrase shows the percentage of the success to increase resources and products. Hence, it is considered as the index of promoting entrepreneurial activities in model.

B. Knowledge Development (F2)

Another important part of the IS is learning or knowledge creation. Generally learning can be happened in 4 patterns:

a) Learning during the study: systematic or organized process for research activities or R&D
b) Learning during the implementation: Increasing production skills in firms which finally resulted in improving operations efficiency.
c) Learning during the application: this type of learning happens during usage of technology and can result in the acquisition of knowledge relating to the new technology which is not available through research activities.
d) Learning during the interactions.

This index in the model is defined as below:

$$\text{F2} = \frac{\text{Final knowledge of the system} - \text{Initial value of knowledge of the system}}{\text{Initial value of knowledge of the system}} \quad (2)$$

This index shows the percentage of knowledge increase in the model. In other words, increasing in the final value of the knowledge in the system shows an index of knowledge development in the system.

Below figure shows the usage of this index in the model:

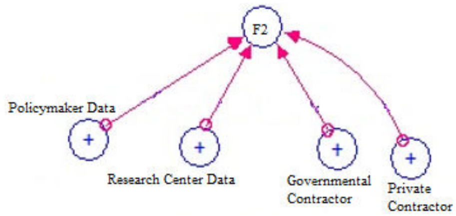

Fig. 4 A view of the model relating to F2 index

C. Knowledge Diffusion (F3)

Third index is a kind of learning which is take place during the interaction or knowledge diffusion. This function transfers knowledge among different players of an innovation system. Specially, in the complex IS, the extension of endogenous development of the knowledge by a firm or special player is very difficult and it needs mutual and serious interactions of different factors. Generally it can be said that the process of knowledge diffusion needs to factors such as the existence of players interest in learning, existence of necessary norms and even geographical neighborhood and also existence of common language and culture. This index is defined in the model as below:

$$\text{F3} = \frac{\text{Sum of the turnover between parts of the model}}{\text{value of exchanging resources to knowledge in the system}} \quad (3)$$

Above index shows the quality of knowledge diffusion in the system.

D. Guidance of the Search (F4)

If knowledge development function (F2) represents diversification and extension of technology, Guidance of the search function illustrates the process of selection proper issue among this diverse. This selection is important in resource assignment. Also, it is effective in depicting new emerged technologies development landscape. Without this selection and setting direction, widespread range of knowledge creation, diffusion and entrepreneurial activities would not be usable. This index in the model is defined as below:

$$F4 = \frac{Amount\ of\ knowledge\ exchanged\ to\ products\ or\ resources}{Amount\ of\ resources\ exchange\ to\ knowledge} \quad (4)$$

Products are not changeable to data in the model, hence above index always is less than 1. On the other hand, changing more data to products or resources shows the correctness of the Guidance of the search in the model.

E. Market Formation (F5)

Beside the entrepreneurial function, existence of the market is one of the requirements of technology extension. New technologies entrance and their competition with the existed technologies is very difficult. Forming a safe market -applying subsidies and taxes-for new emerged technologies is one of the functions of an IS. This index in the model is defined as below.

$$F5 = \frac{Amount\ of\ benefits\ gained\ from\ using\ subsidies\ and\ taxes}{Average\ amount\ of\ the\ subsidies\ and\ taxes} \quad (5)$$

Above index shows the effect of using subsidies and taxes applied by policymaker on the amount of profit that governmental and private contractor would earn. Indeed higher amounts of the above index represent the successful performance of policymaker in market formation.

F. Resource Mobilization (F6)

Providing required resources, to supporting related activities with technology extension, such as financial, human, material and supplemental resources is another important function of IS. This index is defined in the model as below.

$$F6 = \frac{Amount\ of\ contractor's\ profit\ using\ loan}{Average\ amount\ of\ loan} \quad (6)$$

Above index shows the contractor's profit from loan. In the other word, this index measures the effects of the loan invested by policymaker on the amount of profit in the system as a functional index.

G. Support from Advocacy Coalitions (F7)

In each system existence of some factors such as investments, benefits and Current Procedures seriously challenge the existence of a new technology. On the other hand, main performance of supporting unions would be the establishment of a suitable environment for new emerged technologies growth. Hence, it is expecting that these unions overcome the market resistances and lead sufficient resources through technology development. This index is defined as below.

$$F7 = \frac{Amount\ of\ exchanging\ products\ of\ contractors\ to\ resources}{Sum\ of\ products\ and\ rsources\ of\ the\ market} \quad (7)$$

This index represents the ratio of the market potential relating to the market value. In other word, this index shows the acceptability of the market against amount of products which are supplied by contractors.

IV. Case Study

In this paper as a case study, production of a software package in ministry of culture of I. R. Iran is considered. Key players of this model are:

Policymaker: deputy of Quran and etrat of the culture ministry
Private contractor: Naghsh-negar e ghadir firm
Governmental contractor: Noor-e-hekmat cultural institute
Research center: Center of promotion and development of Quran

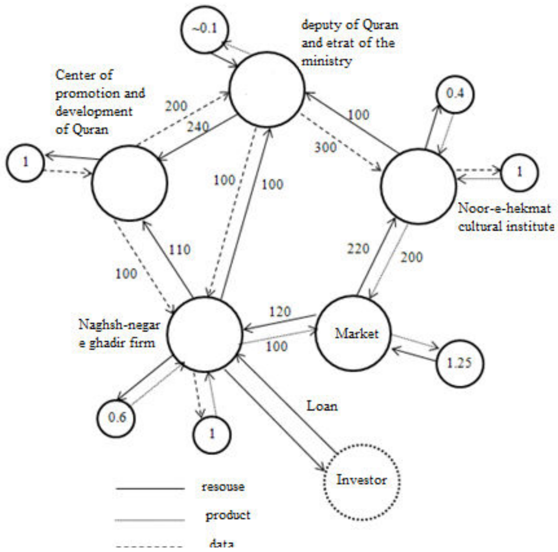

Fig. 5 Connections between players based on the case study

Numbers depicted in the diagram Fig. 5 are 2 types:

1- Numbers placed on the lines are values of the exchange among players of the model. These numbers are multiples of 10^5Rials.
2- Second type numbers are placed in the circles. These numbers are multiple of the amounts of players' resources which change to another flow.

Investor is an auxiliary player which lends a loan to the contractor with 20% interest and regains the money with its interest based on the reduction formula as below:

$$\text{Installments} = \frac{\left(1+\left(\frac{X}{2}\times 0.2\right)\right)\times \text{loan}}{X} \quad (8)$$

X is the time periods which loan is regained.

Schematic model of investment in Ithink is depicted below:

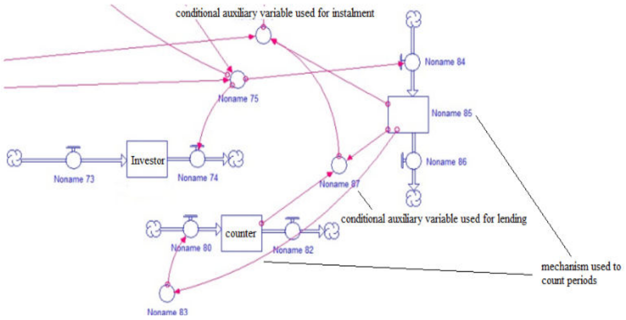

Fig. 6 Schematic model of investment in the model

Model is run in 5 periods. Policymaker based on the sold items by contractors, first give them subsidies and after a time contractors should pay tax instead.

The pattern of the subsidies and tax (as percentage of soled items by contractors) are as below:

TABLE I
TAX AND SUBSIDIES PATTERN BY POLICYMAKER

Percentage of tax (+) and subsidies (-)		Period
G Contractor	P Contractor	
10% (-)	10% (-)	1
10% (-)	10% (-)	2
10% (+)	10% (+)	3
10% (+)	10% (+)	4
10% (+)	10% (+)	5

Also, market based on the product life cycle pattern and with certain ratio purchases products. This pattern is showed in the below table.

TABLEII
PURCHASING PATTERN OF MARKET FROM CONTRACTORS

Percentage of market purchasing		Period
G Contractor	P Contractor	
50%	50%	1
70%	70%	2
100%	100%	3
100%	100%	4
90%	90%	5

Hence product life cycle diagram considered in the model is as below.

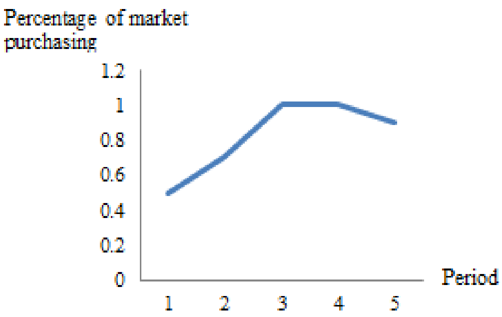

Fig. 7 Product life cycle diagram

Using all explained data, model has been designed and run (with Ithink 9.1.3). Results are as below:

TABLE III
VALUES OF THE FUNCTIONAL INDEXES

Functional index	Percentage
F1	80%
F2	87%
F3	88%
F4	82%
F5	76%
F6	89%
F7	85%

As observed, index values are close to 100% and seem they are in good condition. Only in the fifth index, difference from 1 should be surveyed. This index relates to market formation index and shows that the model faces problem in the market forming. The variation of the triple flows in the model is depicted below:

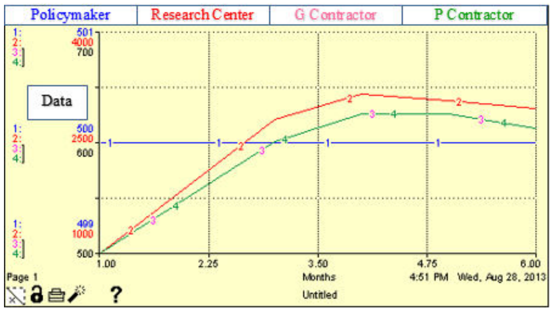

Fig. 8 Variation of the data in the model

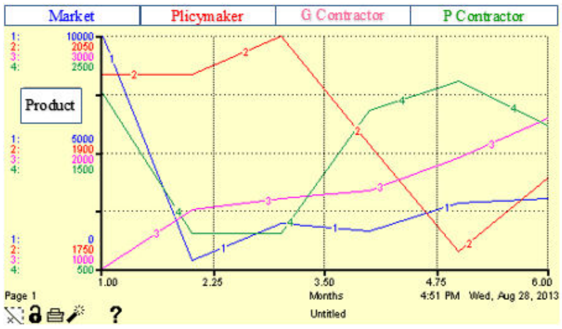

Fig. 9 Variation of the products in the model

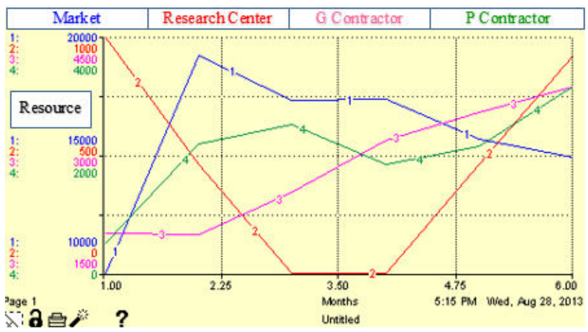

Fig. 10 Variation of the resources in the model

As depicted in the figures, resource of private contractor and also sum of the resources of each contractor is increased. Research center's data is increased. Resources and products of policymaker are relatively constant. Also resources and products of market are increased linearly. These behaviors confirm that system is causal and the model represents the real world in an acceptable way.

V. Research Contributions

a) Applying innovation system approach to the science and technology field with techno-sectoral approach.
b) Extension of the innovation system literature from managerial approach to system engineering approach.
c) Using system dynamics methods in solving complex and multi-dimensional problems.
d) Formulation of innovation systems functions in system dynamics model.
e) Stimulation of structures related to functions align with sector benefits.
f) Using concepts of policymaking in applied researches and extend it to the innovation systems.
g) Implementation of designed model in the software production industry as a case study.

VI. Conclusions

In this paper techno-sectoral innovation system using Ithink 9.1.3 is modeled and applied in one of the software industries in Iran. Then with defining some functional indexes and three flows (resource, data and products), performance of the model is assessed and values of the indexes are calculated. Results shows that defined functional indexes are closed to 100%; hence it can be concluded that model relatively is in a good condition. Also results shows that model and defined indexes are performed as expected. For example, resources and products of the policymaker -which generally manages the system- are expected to be constant, because this part of the system as a manager should not loss or gain considerably. Results meet this expectation. As a further research, extension of the techno-sectoral innovation system and using simulation tools are suggested.

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