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SYSTEM THINKING IN MANAGING TECHNOLOGICAL INNOVATION SYSTEMS IN MANUFACTURING COMPANIES

Sistemsko razmišljanje pri upravljanju tehnološkega informacijskega sistema v proizvodnih podjetjih

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Abstract

This paper discusses models for managing Technological Innovation System (TIS) in a manufacturing setting. It reviews the existing six models for managing TIS: Technology Push, Market Pull, Coupling Innovation Process (CIP), Functional Integration Innovation Process (FIIP), System Integration and Networking Innovation Process, and System of Innovation models. Major drawbacks of the model for managing TIS in manufacturing settings were identified. System thinking approach was then proposed as a suitable alternative for addressing these drawbacks. The basic principle of system dynamics on which system thinking is hinged is used to explain the proposed model. However, understanding and using this model are premised on the availability of knowledge and skills in computer modeling and simulation software (e.g., Ithink, Vensim, and Powersim).

Key words: Nigeria, technology, innovation, Technological Innovation System model, manufacturing, simulation, system dynamics, system thinking.

Povzetek

Članek obravnava modele za upravljanje tehnološkega informacijskega sistema (TIS) v kontekstu proizvodnje. Preučuje šest obstoječih modelov za upravljanje tehnoloških informacijskih sistemov, t.j. tehnološko vzpodbujene inovacije, tržno vzpodbujene inovacije, proces združevanja za inovacijo, funkcijska vključitev v proces inovacije (FIIP), sistemska vključitev in mrežni proces, model sistemskega inoviranja. Članek identificira glavne pomanjkljivosti modela za upravljanje tehnološkega informacijskega sistema v kontekstu proizvodnje. Kot ustrezno alternativo reševanja teh pomanjkljivosti predlaga pristop sistemskega razmišljanja. Za razlago predlaganega modela je uporabljen osnovni princip sistemske dinamike, na katerem temelji sistemsko razmišljanje. Vendar pa razumevanje in uporaba tega modela temelji na dostopnosti znanja in spretnosti za uporabo programske opreme za modeliranje in simulacije, kot so med drugim Ithink, Vensim in Powersim.

Ključne besede: Nigerija, tehnologija, inovacija, tehnološki informacijski sistem, model, proizvodnja, simulacija sistemska dinamika, sistemsko razmišljanje

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1 Introduction

The phrase *technological innovation system* is a combination of three key words: technology, innovation, and system. Many definitions of *technology* abound in the literature. For example, Burgelman (1983) defines it as a production process, a key competitive factor, an applied science, a specific process, a core competence, a dynamic capability, knowhow, and improved quality of life. It is the current state of humanity's knowledge of how to combine resources to produce the desired result, solve problems, fulfill needs, and satisfy wants. It can also be regarded as the purposeful application of information in the design, production, and utilization of goods and services and in the organization of human activities (BusinessDictionary.com, 2013). The word technology can be used to refer to the making, modification, usage, and knowledge of tools, machines, techniques, crafts, systems, and method of organization in order to solve a problem, improve a preexisting solution to a problem, achieve a goal, handle an applied input/output relation, or perform a specific function.

Meanwhile, *innovation* has been defined as a process from idea generation to commercialization, bringing the idea or invention to the market as a new product, process, or service through the phases of idea generation, research and development, product development, marketing, and selling a new product or service (Du Preez & Louw, 2008). Innovation is also regarded as the commercial and practical application of ideas or innovations (Trott, 2008; Vajonen, 2006). It can be the development of new customers' value through solutions that meet new needs in new value-adding ways. This is accomplished through more effective products, processes, services, technologies, or ideas that are readily available to markets, governments, and society.

The Technological Innovation System (TIS) is a scientific field of innovation studies to explain the nature and rate of technological change (Smits, 2002). Calsson and Stankiewicz (1991) defined TIS as a dynamic network of agents interacting in a specific economic/industrial area under a particular institutional infrastructure and involved in the generation, diffusion, and utilization of technology. The purpose of analyzing TIS is to evaluate the development of a particular technological field in terms of the structures and processes that support or hamper it. TIS can be analyzed in terms of its system components and/or its dynamics.

Base on the discussion thus far, TIS can be defined as the totality of know-how by which organizations produce new products, processes, and systems, resulting in sustaining or repositioning them in the emerging competitive global market. It includes those products that emerge. Thus, it means that the very survival of an organization, not to mention profitability or breakeven, depends largely on the proper management of TIS. Therefore, all efforts must be made to ensure that TIS is effectively managed in organizations.

It is expedient to look at the models by which TIS has been managed since the beginning of the Industrial Revolution to situate our current thinking in the right perspective. Six models have been identified, each representing different generations (Du Preez & Louw, 2008; Tayaran, 2011):

1. Technology Push Model
2. Market Pull Model
3. Coupling Innovation Process Model
4. Functional Integration Innovation Process Model
5. System Integration and Networking Innovation Process Model
6. System of Innovation Model

2 Technology Push Model

The first-generation model representing the technology push theory is a linear model. This theory was the first publically articulated thought of the founding fathers of management. The theory was based on a simple linear process by which new products from organizations go to the market based on scientific and technological advances. Consideration was not necessarily given to the market situation, which might be expected to be a period marked by big jumps in scientific and technology advancements. Scientists and technologists were primarily interested in the transformation of ideas into inventions. The inventors were not necessarily concerned with the ultimate commercial applications of their inventions.

Figure 1 shows the Technology Push Model, where the consumers in the market are the recipients of the output of scientific research. Figures 1a and 1b show the traditional and modern Technology Push Models, respectively.

Figure 1a: *Traditional Model Technology Push Model*

Figure 1b: *Modern Technology Push Model*

As indicated, innovation is directly dependent on basic and applied research. Therefore, the management of innovation was limited to the management of the activities of the inventors and researchers.

3 Market Pull Model

The market pull theory was the next stage in the understanding of the management of TIS. This model emphasizes the need to explore the market well before the commencement of the production of an innovation. It takes the position that a product is newly produced as the market dictates. Emphasis is placed on the consumers' specifications, to which the manufacturers have to respond positively. The model ensures a receptive market once the appropriate technological innovation is developed. Figure 2 shows the Market Pull Model. Figure 2a shows the Market Pull that does not necessarily involve the users in the generation of ideas whereas Figure 2b takes customers into consideration in the development process.

This model, which is an alternative to technology push, proposes that the stimulus for innovation is societal needs or a section of the market.

The technology push and market pull models are considered linear and were prevalent until the 1960s.

4 Coupling Innovation Process (CIP) Model

The CIP model is a combination of the push–pull theory and was predominant in the 1970s and 1980s. Although it views innovation as a sequential process, it is not considered continuous, as in the push and pull models. It is made up of interdependent stages of inclusive feedback (see Figure 3).

Figure 2a: *Market Pull Model that does not involve users in the generation of ideas*

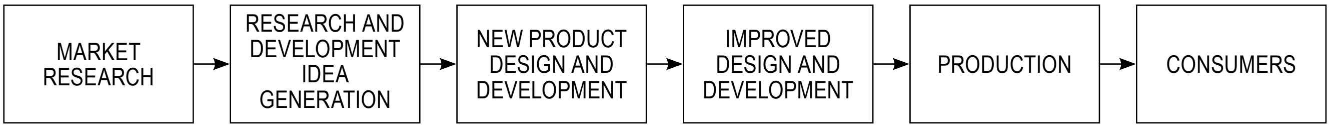


Figure 2b: *Market Pull Model that involves customers in the development of ideas*

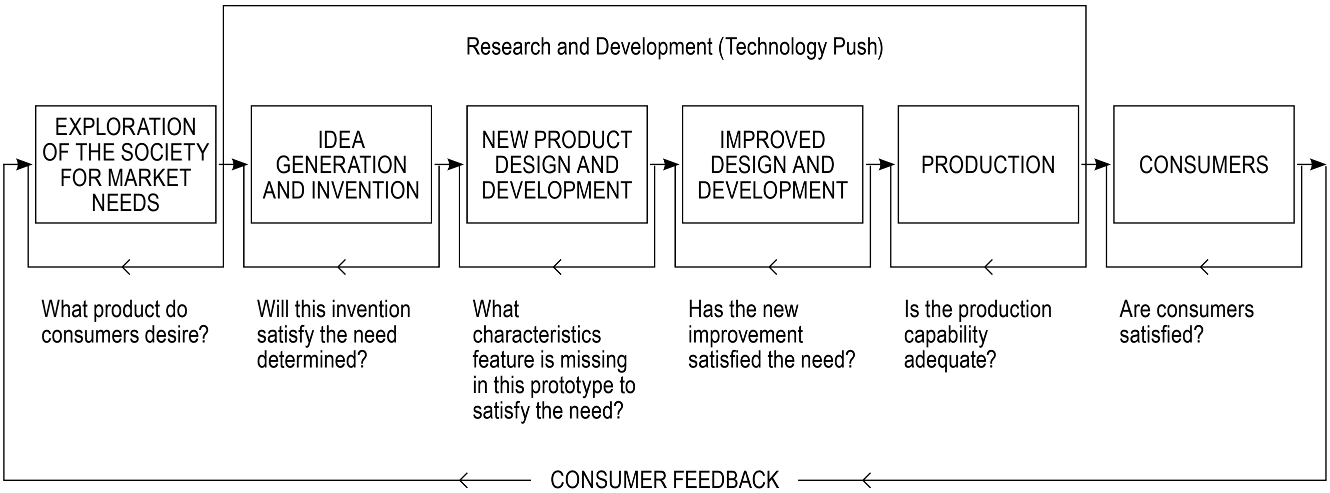
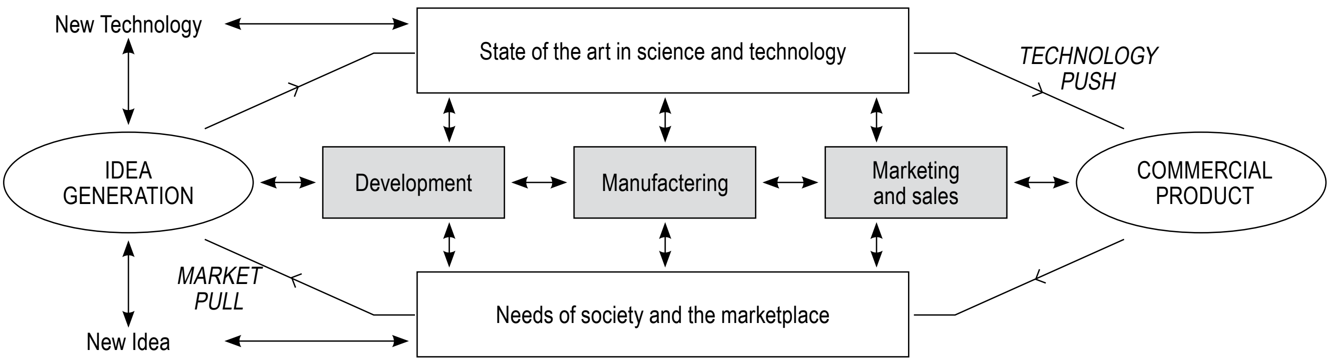


Figure 3: *Coupling Innovation Process (CIP) Model (Adapted from Du Preez & Louw, 2008)*



Close interaction occurs among internal and external mechanisms, including the market. Of course this model is not linear; it consists of interdependent stages with feedback such that innovation is represented as a sequential process with limited functional integration.

5 Functional Integration Innovation Process (FIIP) Model

The FIIP Model has much to do with linkages and alliances between the upstream (supplier) and downstream (customer). The fourth in the series of innovation models was developed in the mid-1980s based on the knowledge gained from the Japanese automobile and electronics industry. The model (Figure 4) takes into consideration the use of concurrent/simultaneous engineering techniques in its different stages of innovation process to design a parallel model instead of the sequential model adapted by the CIP Model (Tayaran, 2011). This method allows linkages of the activities of operational groups at each stage through structural feedback mechanisms to connect the other stages.

According to Zhang, Maniar, and Fire (2001), this model is functionally woven around a core project, making it easier to combine expertise from different fields of specialization and thereby reducing the cycle time/time spent on the innovation process in a product lifecycle. An example of the fourth generation of innovation model is the Minnesota Innovation Research Program (MIRP) model, which explains the sequence of core characteristics reflected as an innovative idea is transformed and implemented into a concrete reality (Du Preez & Louw, 2008).

Figure 4: *Functional Integration Innovation Process Model (Adapted from Du Preez & Louw, 2008)*

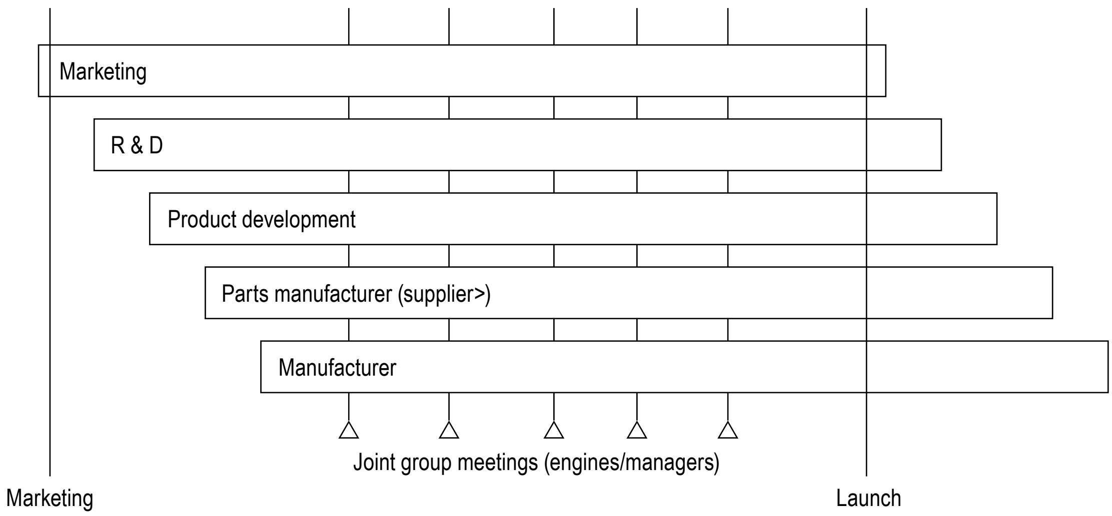
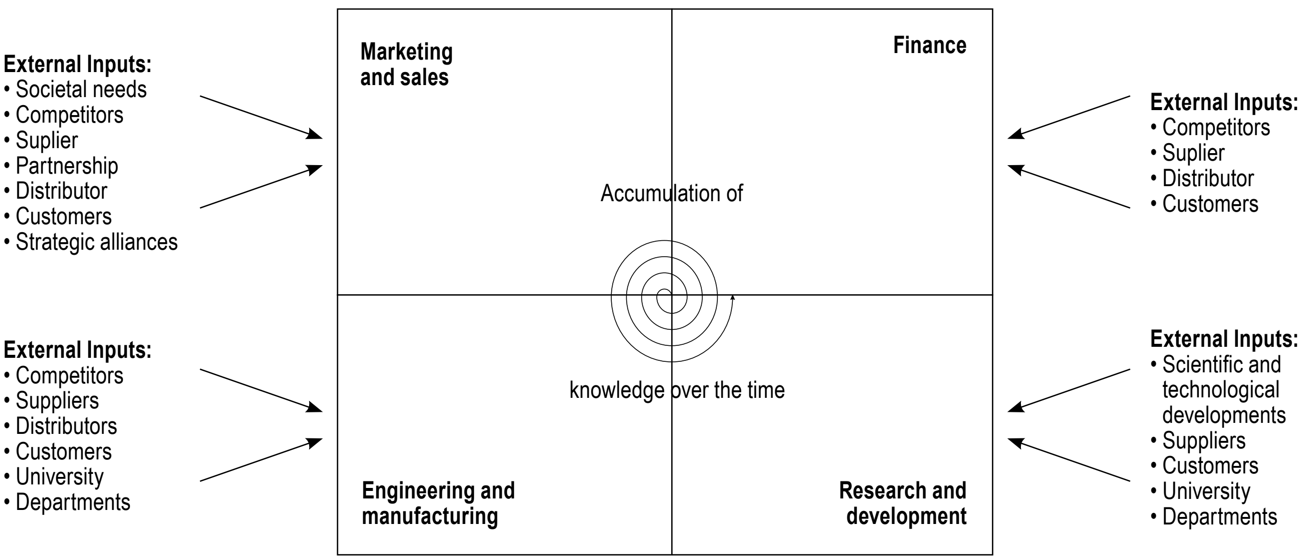


Figure 5: *System Integration and Networking Innovation Model (Adapted from Du Preez & Louw, 2008)*



6 System Integration and Networking Innovation Process Model

The fifth in the generation of innovation models originated in the early 1990s. It emphasized the need for continuous change and attempted to explain the complexity in the innovation process (Du Preez & Louw, 2008; Tayaran, 2011). This model develops a network that encompasses both internal and external stakeholders. Unlike other models that limit the external more to the customers, the fifth generation includes all relevant stakeholders (e.g., supplies, other firms). To take advantage of the influence of the external environment, effective communication with the external environment was developed. In this way, an innovation that is not useful to an organization at any point in time can be sold or licensed to another organization, thereby ensuring that the idea is not wasted.

The use of computer simulation and other advanced technological tools has led to a quick response to the design and development stages and reduced prototyping costs in the innovation process. Hence, Tayaran (2011) suggested that efficiency and speed in this process are the key benefits derived mainly from continuous interactions across the innovation network.

7 System of Innovation Model

The System of Innovation Model is the sixth generation of innovation models. Although adopted from Friedrich List's concept of the "National System of Political Economy" (1841), Lundvall was the first to introduce the concept of system of innovation in 1985, which gradually became popular, particularly among policymakers and innovation researchers, in the 1990s. By 1988, after studying the success story of the Japanese economy, Freeman labeled it "the national innovation system" because the model identifies the social and economic effects of the process that generate innovation across a nation (Du Preez & Louw, 2008).

According to Chang and Chen (2004), this sixth generation of innovation models enables the system to have a clear understanding of the factors/variables that affect innovation and how they influence the process of innovation. Although this model takes care of much of the limitations of the previous models, the method of analysis is not dynamic.

8 Limitations of the Models Considered

All the models described thus far are based on analytical thinking, which is premised on optimization and econometrics. Optimization-based models are essentially equilibrium models that focus predominantly on the short-term performance of the system. However, this has not precluded the existence of a few long-term market analyses based on optimization techniques. The strength of these models is based on the assumption that resource allocation resulting from the market mechanism is equivalent to the minimization of the discounted, cumulated, operating, and investments costs over the considered period of planning (Olsina, 2005). On the other hand, econometric models are inherently descriptive, aiming at reproducing the actual observed market behavior regardless of whether it deviates from the ideal behavior described by the prescriptive models.

Therefore, these models are data/statistics dependent, with the implication that they leave out many relevant variables, leading to the oversimplification of detailed complexity (Oladeji, 2005). In addition, these methods usually involve paradigms suited for systems that are linear, partly open or near equilibrium, with a short time horizon and are incapable of handling planning for quality in high technology facilities. The models also require detailed historical data and data reconciliation or a choice of details among alternatives at the detailed implementation stage of decision making (Oyebisi & Momodu, 2012).

Tables 1 and 2 compare the stages and attributes of analytical and systems thinking. respectively. Summarily, table 3 shows the contrasts between analytical thinking and systems thinking.

Table 1: *Comparison of the Three Stages of Analytical and Systems Thinking*

Stage	Analytical thinking	Systems thinking (synthesis)
1	Take apart the thing to be understood	Identifying a containing whole (system) of which the thing to be explained is a part
2	Try to understand the behavior of parts taken separately	Explain the behavior or properties of the containing whole
3	Try to assemble this understanding into an understanding of whole	Explain the behavior or properties of the thing to be explained in terms of its role(s) or function(s) within its containing whole

Source: Fasser and Brettner (2002)

Table 2: *A Comparison of the Attributes of Analytical Thinking and Systems Thinking*

Analytical thinking	Systems thinking
Focuses on structure (how things work)	Focuses on function (why things operate as they do).
Yields knowledge	Yields understanding
Enables us to describe	Enables us to explain
Looks into things	Looks out of things

Source: Fasser and Brettner (2002)

9 System Thinking Model

The system thinking model follows the system dynamics principle, which makes it possible to analyze and synthesize both hard "figures" and soft "feelings" as variables of the entire TIS. Here decisions are premised on policy and

Table 3: *Analytical Thinking vs. Systems Thinking*

Analytic thinking (analysis of today)		vs.	Systems thinking (synthesis for the future)	
1	We/they	vs.	1	Customers/stakeholders
2	Independent	vs.	2	Interdependent
3	Activities/tasks/means	and	3	Outcomes/ends
4	Problem solving	and	4	Solution seeking
5	Today is fine	vs.	5	Shared vision of future
6	Units/departments	and	6	Total organizations
7	Silo mentality	vs.	7	Cross-functional teamwork
8	Closed environment	vs.	8	Openness and feedback
9	Department goals	and	9	Shared core strategies
10	Strategic planning project	vs.	10	Strategic management system
11	Hierarchy and controls	and	11	Serve the customer
12	Not my job	vs.	12	Communications & collaboration
13	Isolated change	vs.	13	Systemic change
14	Linear/begin-end	vs.	14	Circular/repeat cycles
15	Little picture/view	vs.	15	Big picture/holistic perspective
16	Short term	and	16	Long terms
17	Separate issues	vs.	17	Related issues
18	Symptoms	and	18	Root causes
19	Isolated events	and	19	Patterns/trends
20	Activities/actions	and	20	Clear outcome expectations (goals/values)

Source: Haines Centre for Strategic Management (2007)

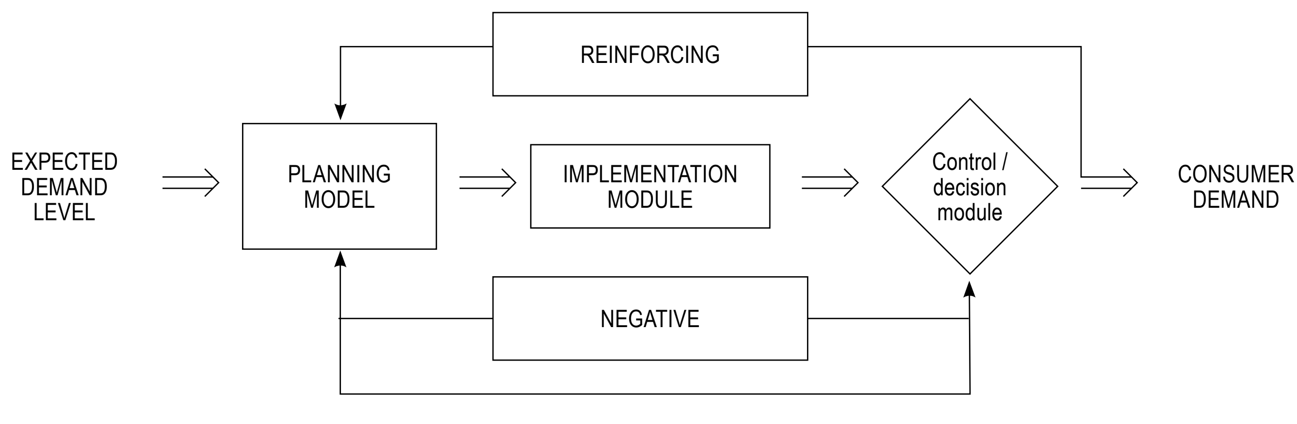
regarded as the software variable. The system dynamics principle involves the following:

- Stock and flow diagramming, dealing with input and output from and to a source
- Causal (feedback) loop diagramming, relating interconnections between actions
- Time delays that affect behavior in the entire system
- Simulation of model using computer

The system thinking concept of managing TIS is depicted in Figure 6. The proposition is adapted from the canonical form of control system. The diagram shows both negative (balancing) and positive (reinforcing) feedback. The planning module represents the point where initiatives inputs are "mixed" and decisions are made and forwarded to the implementation module for actual action.

The system works in a way as to monitor the rate of demand for organizations' products. This information is fed into the planning module, where it is compared with the expected level of consumer demand. If the demand is less, the reinforcing loop is affected whereas the balancing loop is used when the demand is higher. Of course, in business, the demand is expected to be higher—even higher than the set level. The information will assist in the planning stages for the right level/amount of technological capabilities, in-

Figure 6: *Modified Canonical Form of Control System*



vestment, production and linkage capabilities, and other resources to be put into place to maintain the desired level of product demand.

Employing the system dynamics principle offers several advantages. First, all conceivable factors influencing innovation, including the front end of innovation (FEI) and new product design and development (NPDD), are clearly monitored and controlled. Second, the cost, risk, and resources are effectively controlled and managed. Third, the system can be modeled on the computer to allow for simulations using simulation software application packages such as Ithink, Vensim, and Powersim. Fourth, the issue of non-linearity, which the other models cannot address, can be effectively tackled. Finally, knowledge creation occurs in the system as every computer simulation would be part of the database for the organization.

10 Conclusion

The use of systems dynamics as a major tool of systems thinking is highly useful and most desirable for managing TIS in manufacturing settings if the necessary knowledge and skills in computer modeling and simulation are available.

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