



A Dynamic Risk Analysis on New Product Development Process

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Dynamic Simulation,
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ABSTRACT

In the dynamic and competitive market, managers seek to find effective strategies for new product development. Since there has not been a thorough research in this field, this study is based upon the review of the risks existing in the NPD process and on the analysis of the risks through FMEA approach. Therefore, we can prioritize existent risks and then model the behavior of the NPD process and main risks through system dynamics. At first, we present new product development concepts and the key definitions. We base our study on the literature review of the NPD risks and then provide an FMEA approach to define risks priority. Using the obtained main risks, we model the NPD process risks applying system dynamics to analyze the system and the risk effects. A safety clothing manufacturer is considered as a case study

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1. Introduction

Today, markets are generally perceived to be demanding higher quality and higher performing products, in shorter and more predictable development cycle-times and at lower cost. (Buyukozkan et al., 2004). The new product development (NPD) and innovation are often recognized as the key processes of competition in a variety of markets (Poolton et al., 1998).

New product development is a critical endeavor in today's globally competitive environment (Song, 2006).

New product development (NPD) is a business process for developing new products for a company, whether it is an upgrade of an existing product or a new concept

(either for the company or for the customer). It includes all activities from the development of an idea or a concept for a product, to the realization of the product during the production stage and its introduction into a market place (Hohenegger, et al., 2007).

To obtain best performance from NPD, the efficient and effective management of the product development process is vital. Thus, a new product development (NPD) strategy is an important activity that helps enterprises to survive and make continuous improvements (Liu et al., 2005).

The NPD process, that its objective is to translate an idea into a tangible physical asset, is structured around well-defined phases; NPD can be defined as a process including many "generic decision" points. Urban and Hauser (1993) recommend a five-step decision process for NPD: opportunity identification, design, testing, introduction and life cycle management. Another NPD

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process proposed by Cooper (1979) is based upon the steps illustrated in table 1.

For detailed information about the process, we refer the readers to Buyukozkan et al. (2004). Another conceptual model is shown by figure1 that was a dominant model during 1980's for innovation process (Galanakis, 2006). Our study is mainly based on this model.

All stages of the process are affected by uncertain, changing information and dynamic opportunities, as described in the section 3.

In this paper, we first describe the NPD definition, then its concepts and process. In the second section, we present the effective factors of NPD. In the third section, we consider the risks in the NPD process. In the fourth section, we analyze the risks firstly through a case study by FMEA then by system dynamics for process modeling and risk effects on the process. Section 5 contains a brief conclusion on the discussed issues. Figure 2 shows the procedure of our work in a frame work.

Tab. 1. The NPD process (Buyukozkan et al., 2004)

Opportunity identification
Market Identification Idea generation
Design and development
customer needs product positioning segmentation sales forecasting Engineering Marketing mix
Testing
Advertising and product testing pre test and pre launch Forecasting Test marketing
Introduction to the Market
launch planning tracking the launch
Life cycle management
Market response analysis competitive monitoring and defense Innovation at maturity

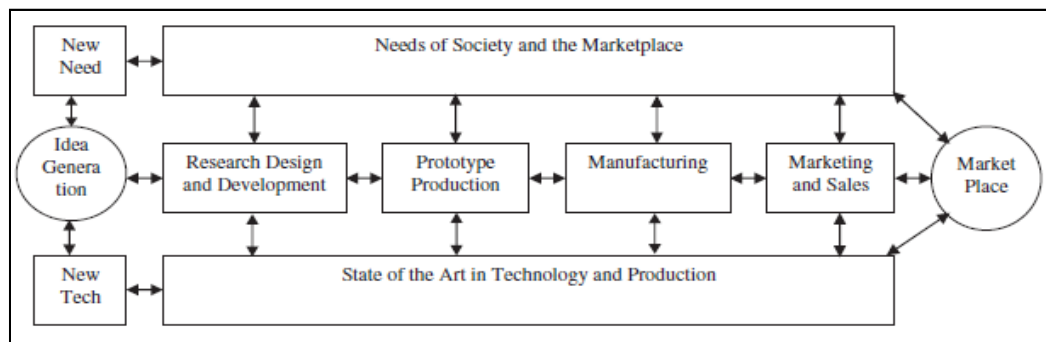


Fig. 1. Innovation process (Galanakis, 2006)

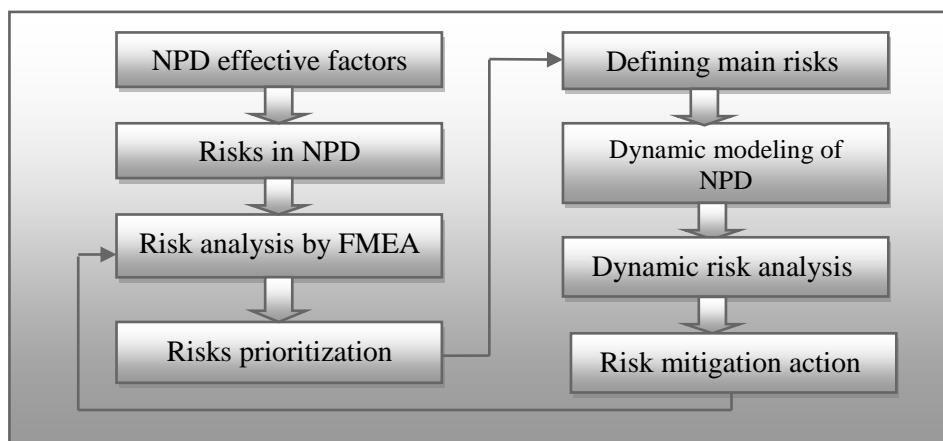


Fig. 2. The NPD risk analysis framework

2. New Product Development and its Effective Factors

NPD is an interdisciplinary activity (Davila, 2000) including marketing management, organizations, engineering design, operations management and requires contributions from nearly all the functions of

an enterprise, whether it is an upgrade (an improvement of an existing product) or a new concept either to the company or to the market. One emerging area of research in the literature is the impact of internal firm variables/organizational variables on the ability of firms to minimize the time and cost of new

product development (NPD). Thus, time and cost are two important factors in NPD process. NPD is also defined as the transformation of a market opportunity and a set of assumptions about product technology into a product available for sale (Buyukozkan et al., 2004). Case studies of actual innovations showed that the market place played a major role in stimulating the need for new and improved products (Poolton et al., 1998).

Market predictability, marketing skills and resources, recognition of long-term relationships, cross-functional interface, compatibility emphasis, cost and service emphasis and leadership style of project manager are some other factors introduced by Song (2006) for NPD.

The reduction of NPD cycle time may create relative advantages in market share, profit, and long-term competitiveness (Afonso et al., 2008). Empirical results suggest that successful projects differ from unsuccessful projects in project environment, skills and resources, project leadership, strategic fit, efficient NPD process, and effective product-positioning strategies (Song, 2006).

Additionally, project environments including nature of market and level of competition play an important role in project success and failure. Suppliers have also a large and direct impact on the cost, quality, technology, and time to market of new products (Primo, et al., 2002).

The project leader is another factor critically affecting both process performance and product effectiveness and facilitates communication between the project team and senior management. NPD process proficiency and the role and commitment of senior management were key distinguishers between success and failure. In addition, good communication has been identified as critical to innovative success (Song, 2006).

Client-supplier collaboration is rather a complicated and difficult issue. Clients (some authors call it buyers) and suppliers are facing a number of problems in managing collaborative NPD (Lam and Chin, 2005). Good planning is taken to include well-costed project control procedures, production planning and control, and the readiness to predict meaningful sales forecasts for new products. Good after-sales service and providing a good technical service to customers is also recognized as a factor that can cause major shifts in new product markets, especially in those industries where loss of service entails lost revenue (Rothwell, 1977). The importance of cumulative know-how is also critical to success. (Poolton et al., 1998). A life cycle view of a product encompasses all activities related to NPD such as market analysis, manufacturing, design, service/maintenance, recycling of materials, packaging, distribution and many others (Hohenegger, et al., 2007).

The main factors affected on NPD process obtained from other researches are summarized in table 2 below.

We found 34 significant factors affected on NPD yet there are some more factors related to the subject.

3. The NPD Risks and Uncertainties

Risk is defined as the degree of uncertainty and potential loss that may follow from a given behavior or set of behaviors (Mullins, et al., 1999). Uncertainty may be defined as the difference between the amount of information required to perform a particular task and the amount of information already possessed (Galbraith, 1973). It arises from a multiplicity of sources including technical, management and commercial issues, both internal and external to the project. It is also widely recognized and accepted that successful management of uncertainty is associated with project success, as the proactive project manager constantly seeks to steer the project towards achievement of desired objectives (Buyukozkan et al., 2004).

New product development (NPD) is a major driver of firm growth and sustainable competitive advantage, yet risks are intrinsic in NPD in all industries (Afonso et al., 2008, Buyukozkan et al., 2004). Thus understanding, identifying, managing, and reducing risk is of strategic importance for firms.

High-tech industries are characterized by technological uncertainty, market uncertainty, and competitive volatility (Mohr, 2001). Fox et al. (1998) combine three dimensions of uncertainty as technical, market and process.

They rate and categorize uncertainty along each dimension as being either low or high. For technical uncertainty, when uncertainty is low, the technologies used in the development of the project are well known to the organization and relatively stable. When technical uncertainty is high, technologies used in the development of the project are neither existent nor proven at the start of the project, and/or are rapidly changing over time.

For market uncertainty, when uncertainty is low the organization has good market data on both customers and competitors, and product is being sold through familiar channels of distribution. NPD managers are uncertain about the market opportunities that a new technology offers. When market uncertainty is high, the organization has little information regarding who the customer is, how the market is segmented and what are the needed channels of distribution.

For process uncertainty, when uncertainty is low the engineering, marketing, and communications (both internal and external) processes used in this project are well tested, stable, and embedded in the organization. When process uncertainty is high, a significant portion of any or all of the engineering, marketing, and communications processes are relatively new, unstable, or evolving. (Buyukozkan et al., 2004).

Tab. 2. The effective NPD factors

	NPD factors	reference		NPD factors	reference
1	Capital expenditure	(T.L. Lee, 2005); (G. Blau & B. Mehta, 2000)	18	project management	(M.Song, 2006)
2	R&D expenditure	(T.L. Lee, 2005); (R. Calantone & R. Garcia, 2003)	19	product cost	(M.Song, 2006)
3	Productivity per employee	(P.Helo, 2004); (T.L. Lee, 2005)	20	quality	(M.Song, 2006)
4	Capital turnover rate	(T.L. Lee, 2005)	21	design	(Buyukozkan et al., 2004)
5	Net income	(T.L. Lee, 2005)	22	Market predictability	(M.Song, 2006);(Rothwell,1977); (T.L. Lee, 2005)
6	human resources	(M.Song, 2006); (T.L. Lee, 2005); (G. Blau & B. Mehta, 2000)	23	knowledge management	(P.Liu, et al., 2005)
7	production operation	(T.L. Lee, 2005)	24	communication	(Rothwell,1977)
8	innovation commercialization	(T.L. Lee, 2005)	25	after sale services	(J.Poolton, 1998)
9	Demand	(Miller and Lessard, 2001); (T.L. Lee, 2005); (R. K. Tyagi, 2006)	26	Client–supplier collaboration	(P. Lam & K.Chin, 2005)
10	time to market	(T.L. Lee, 2005)	27	political issues	
11	Profit	(T.L. Lee, 2005)	28	government support	(D.D.Wu, 2010); (T.L. Lee, 2005)
12	product cost	(R. K. Tyagi, 2006); (T.L. Lee, 2005)	29	product newness	(T.L. Lee, 2005); (R.M. LEB CIR)
13	Sales	(Rothwell,1977), (J.Poolton, 1998)	30	in house R&D	(P.Liu, et al., 2005); (T.L. Lee, 2005)
14	customer satisfaction	(J. Mu & G.Peng, 2009)	31	knowledge and technology transfer	(L. P. Cooper, 2003); (J. Mu & G.Peng, 2009)
15	project environment	(M.Song, 2006)	32	advertisement	(F. H. Maier, 1998)
16	leadership	(M.Song, 2006),(Brown & Eisenhardt, 1995); (Clark & Fujimoto, 1991); (Thieme et al., 2003)	33	Facilities for creativity	(R. McAdam & J. McClelland, 2002)
17	Workforce education	(R. McAdam & J. McClelland, 2002)	34	Workforce Education	(R. McAdam & J. McClelland, 2002)

NPD managers are uncertain about how to turn the new technologies into new products that meet customer needs. This uncertainty arises, not only from customers' inability to articulate their needs, but also from managers' difficulties in translating technological advancements into product features and benefits. Finally, senior management faces uncertainty about how much capital to invest in pursuit of rapidly changing markets as well as when to invest. Managers also should recognize that turbulent environments heighten the need to make risky investments, and sometimes, risky decisions; risk-taking decisions ought to be encouraged in such environments (Calantone, 2003)

Mu, et al. (2009) categorized NPD risks as technological, organizational, and marketing risks contributing both individually and interactively in affecting the performance of NPD. Technological risk is either endogenous or exogenous to the firm and can arise from two major sources.

Organizational risk refers to the uncertainty of a firm's income stream due to organizational rigidity, leading to inability to adapt to environmental changes (Palmer

and Wiseman, 1999). Marketing risk refers to ambiguity about the types and extent of customer needs that can be satisfied by a particular technology or new product (Moriarty and Kosnik, 1989). Marketing risk is high when consumers have had little consumption experience with a product, thus making product requirements difficult to define.

Marketing risk also involves ambiguity about competitive behavior and substitutes that may appear. Customers have fear, uncertainty, and doubt regarding whether a new product can meet their needs and whether there may be possible problems with its use, changing needs new product failure has been largely due to faulty understanding of customer needs (Mu, et al. 2009).

The prediction of future revenue and possible profit depends not only on forecasting total quantity that can be sold, but also on forecasting future costs of production, prices and price elasticity, which are formidable tasks for a product not previously used by customers. Market competition volatility makes NPD success more unknowable and unpredictable. Firms must accurately recognize the psychological worlds of

potential customers and match them correctly to products (Mu, et al. 2009).

Miller and Lessard (2001) present three main risk categories for engineering projects: completion risks, group formed by technical, construction and operational risks, market related risks, group formed by demand, financial and supply risks and finally, institutional risks, group formed by social acceptability and sovereign risks. Also, Riek (2001) identified NPD risks into three general categories such as technical risks, commercial risks and NPD personnel. In another research (Dash Wu, et al., 2010), three typical enterprise risks in the process of technological innovation are introduced: technology R&D risk, research-findings commercialization risk, and market applications risk.

Technology R&D risk refers to possible risks during the stage of the technical development. Specifically it includes technical risk, financial risk, and personnel risk at this stage. Commercialization risk of research findings refers to possible risks from scientific and technological development until mass production. The main risk, market risk, includes uncertainties and exposures faced by market players engaging in economic activities. When the new products are in the market, competitors intervene rapidly, which will lead to a competitive risk.

In this study, we can briefly classify NPD uncertainties in two main categories based on the literature reviewed: external and internal risk factors. Each main factor can be further divided into sub-groups. Internal risks include economical, managerial, project management, organizational and quality risks and external risks include market, customer, economical, social, legal, political, technical, and supplier risks. Table 3 represents the detailed risks obtained, gathered and integrated from our literature search.

3.1. Risk Reduction Factors for NPD Process

Langerak et al. (1999) states that there are more than 14 techniques that new product teams can use to accelerate NPD, for example, identified 50 individual techniques that teams can adopt to achieve cycle time reduction. They formed nine NPD acceleration approaches by clustering similar techniques aimed at (1) supplier involvement; (2) lead user involvement; (3) speeding up activities and tasks; (4) reduction of parts and components in the new product; (5) training and rewarding employees; (6) implementing support systems and techniques; (7) stimulating inter-functional cooperation; (8) emphasizing value for customers; (9) simplifying the organizational structure (Langerak, 2008).

The necessary factors for successful NPD are: (1) top management support for innovation; (2) R&D, marketing and manufacturing competence and coordination; (3) involvement of suppliers and customers in the design process; (4) product quality; (5) nature of market; and (6) development time.

Knowledge gained from external sources can also be a valuable means to reduce technological risk (Afonso et al., 2008).

Additionally, NPD activities are interdependent in the sense that decisions made on one of them influence the performances of the other activities. A simultaneous consideration of NPD activities is also another approach that can reduce the new product time to market (Hohenegger, et al., 2007).

Firms with a proactive market orientation can better identify, differentiate, and meet the expressed and latent needs of customers (Narver et al., 2004), reduce the risks of incompatibility of technology and customer needs (Su et al., 2006), and respond quickly to market signals to improve the likelihood of NPD success. Firms with strong NPD teams learn to better manage complex NPD projects through the development of general NPD capabilities and the establishment of organizational routines that aid in risk recognition and reduction (Afonso et al., 2008).

4. NPD Risk Analysis Approach

Although new product development is one of the riskiest activities of a modern corporation, relatively little account is taken of risk measurement in NPD literatures. Thus, understanding, identifying, managing, and reducing risk is of strategic importance for firms. Mu, et al. (2009) proposes a three-dimensional risk management framework for NPD. Those authors empirically test whether risk management strategy affects the performance of NPD using survey data from Chinese firms. Appropriate risk management strategies can significantly improve the odds of NPD success. One of the major management challenges in product development is to deal with development risk in the design process. Ahmadi, et al., (1999) provide a strategic guideline as to how the design process should be managed and controlled. A new risk mitigation methodology is developed for new product and process design in concurrent engineering projects (Kayis, et al., 2007). Cooper (2003) presents a practitioner view of the desired characteristics of tools to support NPD and suggests a research agenda for the use of knowledge-based tools from the perspective of balancing benefits and risks. Mullins, et al. (1999) Consider the organizational and managerial concerns for selecting the projects based on the amount of risk accompanied with. Hellstrom (2003) analyses the forms of 'systemic innovation' and its associated risks.

Most studies analyzed NPD risks for one Phase of NPD process specially the concept and design phase (Chin & Chan, 2008). But there has not been a complete risk analysis for new product development process. Thus, this study is dedicated to such analysis by FMEA and system dynamics approach to first identify and prioritize main risks and then to analyze the dynamic effects of main risks obtained by FMEA on NPD process. In order to achieve this objective, FMEA is applied for a textile industry case and then a

general dynamic NPD model is proposed considering the main risks. A simulation work model is also presented for the case to analyze the risk factors on the NPD process factors.

4.1. FMEA Approach to NPD Risk Analysis

Failure modes and effects analysis (FMEA) has long been used as a planning tool during the development of processes, products, and services. In developing the FMEA, the team identifies failure modes and actions that can reduce or eliminate the potential failure from occurring. Input is solicited from a broad group of experts across design, test, quality, product line, marketing, manufacturing, and the customer to insure that potential failure modes are identified. The FMEA is then used during deployment of the product or service for troubleshooting and corrective action. The standard FMEA process evaluates failure modes for occurrence, severity, and detection. The multiplication of these values leads to what is known as the risk

priority number (RPN) as shown by the following formula:

$$\text{RPN} = \text{Occurrence} * \text{Severity} * \text{Detection}$$

4.2. CASE Study

Textile industry is one of the riskiest sectors in Iran. The purpose of this paper is to examine the risks exist in the textile sector with respect to new product development. The trend towards the production of commodity textiles in low wage cost countries is forcing the closure of many Iran's textile companies. Thus, a number of these companies have moved away from general textiles, and now specialize in technical textiles. The ability to develop new products can be a source of competitive advantage for these companies. Based on the key literature themes and the survey findings, a manufacturer of safety and technical clothing (ie., fire fighting suits, pilot suits, etc.) in Iran is selected as a case study of this research as these products are completely in contact with human lives.

Tab. 3. The Failure modes effects and analysis approach for NPD risk analysis

		Risks	Risk mitigation actions	severity	occurrence	detect	risk score	RPN	
INTERNAL RISKS	economical	financial	better prediction	9	5	2	45	90	
		investment	better planning & market prediction	9	7	4	63	252	
	managerial	entrepreneurial team decision making	team working	5	3	6	15	90	
		management changing		5	6	7	30	210	
		knowledge	knowledge management	5	3	6	15	90	
	project management	resources	personnel	rewards	8	5	7	40	280
		technical			3	4	7	12	84
			delays	cycle time reduction techniques	7	6	5	42	210
	organizational	inability to adapt environmental changes		6	3	7	18	126	
	Quality	safety		8	2	6	16	96	
reliability			8	2	6	16	96		
performance			8	4	6	32	192		
Market	Market turbulence	risk-taking decisions	5	5	4	25	100		
	substitute products	speed up time to market, less life cycle	5	4	6	20	120		
	changing needs		4	5	3	20	60		
EXTERNAL RISKS	customer	customer fear		3	2	3	6	18	
	economical (country)			6	5	2	30	60	
	Social			3	3	2	9	18	
	legal (legal limitations)			8	4	3	32	96	
	Political		political effects reduction by independent investment	6	7	5	42	210	
	technical			8	3	3	24	72	
	Supplier		substitute suppliers	9	5	5	45	225	

A failure analysis is applied for this manufacturing company. The case findings reveal the highly critical risks in this industry are as illustrated in table 2. The scores are obtained by the expert managers. The evaluation resulted in 23 risks among which above 9 risks have critical score and RPN values. Thus, risks plan seems to be vital for such an industry. The most critical risk is the risk of personnel which is completely in conformity with the reality that textile personnel are always in strike!

The other two significant risks are related to the investment and supplier delays which are mostly pertain to political problems. Other risks are also considerable in their place. For a better understanding of the critical risks in comparison with each other, Figure 3 shows the scatter plot for the risks in table 3 based on the RPN & risk scores (the last two columns). The experts chose the critical values for both the risk score and the RPN. The risk critical values are considered as 150, 40 for RPN and risk score respectively and separate by two lines. The scatter plot shows that there are four critical risks that have high values both in risk scores and in RPN, (shown in the circle) that require early risk planning actions. Investment, personnel, delays, political and suppliers are considered as the critical risk factors for the mentioned technical textile manufacturer.

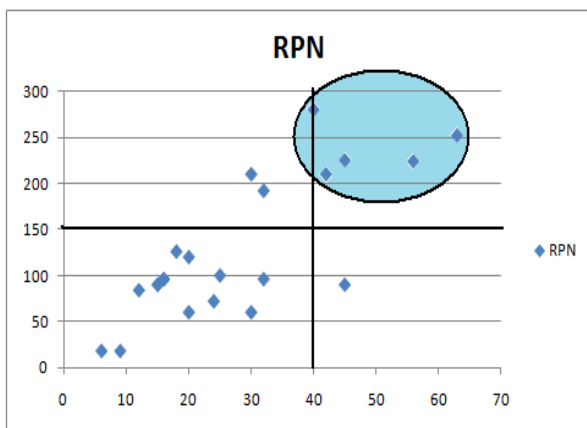


Fig. 3. The FMEA scatter plot of table 3.

4.3. Dynamic Risk Analysis

4.3.1. System Dynamics Definitions and Concepts

System dynamics originated in the late 1950s and early 1960s and was pioneered by J.W. Forrester of the Massachusetts Institute of Technology. The system dynamics philosophy rests on a belief that the behavior (or time history) of an organization is principally caused by the organization's structure.

A second aspect of this philosophy is the concept that organizations are viewed most effectively in terms of their common underlying flows instead of in terms of separate functions (Roberts, 1978). System dynamics deals with the time-dependent behavior of managed systems with the aim of describing the system and understanding, through qualitative and quantitative

models, how information feedback governs its behavior, and designing robust information feedback structures and control policies through simulation and optimization (Coyle, 1996). System dynamics is recognized as an approach to studying the behavior of complex systems: it aims to demonstrate how policies, decisions, structure, and delays are interrelated and influence growth and stability (Lee and Tunzelmann, 2005). This methodology is based on the development of a series of influence diagrams (often called causal loop diagrams), which were first suggested by Maruyama (1963). These diagrams represent the forces that occur in a system and between its parts.

There are four constituents of system dynamics explained as follows by (Forrester, 1976):

1. The closed boundary. This focuses interest on systems as the cause of dynamic behavior. Emphasis is on interactions within the system that produce any specified behavior. It is recognized that there are factors that cross the boundaries, but in this case the point is to define a boundary within which the dynamic behavior being studied is generated.
2. Feedback loops, which can be negative or positive. The feedback loop is a path that integrates decision, action, condition, and information, with the path returning to the decision point. This decision controls action, which changes the system conditions, which influence the decision, and so on. The more complex systems are composed of interconnected feedback loops.
3. Stocks or flows (levels and rates). Interacting feedback loops form any system, but each feedback loop contains a structure consisting of levels and rates. A 'level' reflects the state or accumulations of the system at any specific time. The levels change over time. A 'rate' is the activity or flow that changes the value of the level.
4. Observed conditions within the system. There is a discrepancy between observed conditions and goals, and the objective is to identify desired actions that will decrease differences between observed goals and conditions.

Dynamic complexity arises because systems are dynamic, tightly coupled, governed by feedback, nonlinearity, history-dependent, self-organizing, adaptive, counter-intuitive, policy-resistant, and characterized by trade-offs, etc. Dynamic complexity arises from the interactions among the agents over time (Lee and Tunzelmann, 2005).

4.3.2. The NPD Process Model using System Dynamics

There has been little research in the new product development scope using system dynamics and also

there has been little or no concern to dynamic analysis of NPD risks.

Some important studies in this area are explained in table 4. As illustrated in this table, there has not been a complete dynamic research to new product

development process or is in a specific field or phase. In this paper, we focus on the whole NPD process and model its dynamic behavior so as to be able to analyze the effects of the main risks (obtained from table 2 and FMEA) on the NPD factors.

Table 4. Researches review on NPD based system dynamics

Title	Year	area of research (problem)	methodology	brief review
A dynamic analytic approach to national innovation systems: The IC industry in Taiwan	2005	Innovation	System dynamics	Develop a mathematical model of the national innovation system (NIS) of Taiwan. The method utilized is that of system dynamics (SD) which aims to increase insights into the dynamic processes of the Taiwanese IC industry system of innovation.
Innovation process. Make sense using systems thinking	2006	Innovation	System thinking	Considers how innovation occurs in a firm and which factors affect the outcome of this process. The main focus is the Knowledge Creation from the New Product Design and Development process.
New product diffusion models in innovation management - a system dynamics perspective	1997	Innovation	System dynamics	The traditional innovation models can be extended to map the process of substitution among successive product generations. A dynamic model of product process development applied to manage product process complex dynamic behavior on system level to reduce product development cycle times, slippages and costs and to improve perceived product quality.
Dynamic simulation of product process	2008	New Product Process	System dynamics	Considers the dynamic concurrence relationships of tasks in multiple phase projects.
Dynamic modeling of product development processes	1998	New Product Development	System dynamics	Simulate the dynamic behavior of the extent of "project complexity" effects on the relationship between the level of integration in a project development cycle time.
Integrative Mechanisms in New Product Projects: Effect of Project Complexity on Project Performance Development A System Dynamics Approach	2002	New project tasks development	System dynamics	Proposed a model for analyzing entrepreneurial team risks in innovation process using SD
Modeling technological innovation risks of an entrepreneurial team using system dynamics	2010	Entrepreneurial team risks	System dynamics	

4.3.3. Elements of the Proposed Model

Typically, the product development and process has been performed in several phases. The product consists of several more or less independent activities that can be developed and maintained separately. In this study, the model is built up on 6 main factors in NPD process and one connector factor based on the information gathered in table 2.

Fig 4 illustrates the structure of the model. Each main factor includes sub factors in which the effects and interrelations are considered. The main factors are resources, financial, market, innovation, planning, and production factors. There are two actors in this model related to government and managers. The properties and behaviors of each actor influence all other factors.

Furthermore, the model is based on the following items of each element.

Resource element

This element includes education, technical know-how, new technology and Inventory. The resource element brings about a support for innovation element.

Financial element

This element mainly includes R&D investment, and advertisement which cause government and management support and the revenue affect positively on it. On the other hand, this support affects on planning element. Financial element could also be in relation with the market element.

Market Element

This element includes market share, demand and sales. This element provides revenue for the organization and it is affected by customer satisfaction.

Innovation Element

It includes creativity, product newness, and design. Resources provide knowledge to innovation items through knowledge transfer. Innovation affects on design and quality.

Planning Element

It includes project planning and customer needs prediction which affects on supplier and delay and caused by management support.

Production Element

It includes production and prototype speed and production capacity mainly affecting on price and affected by planning element.

Connectors connect elements together to bring about customer satisfaction.

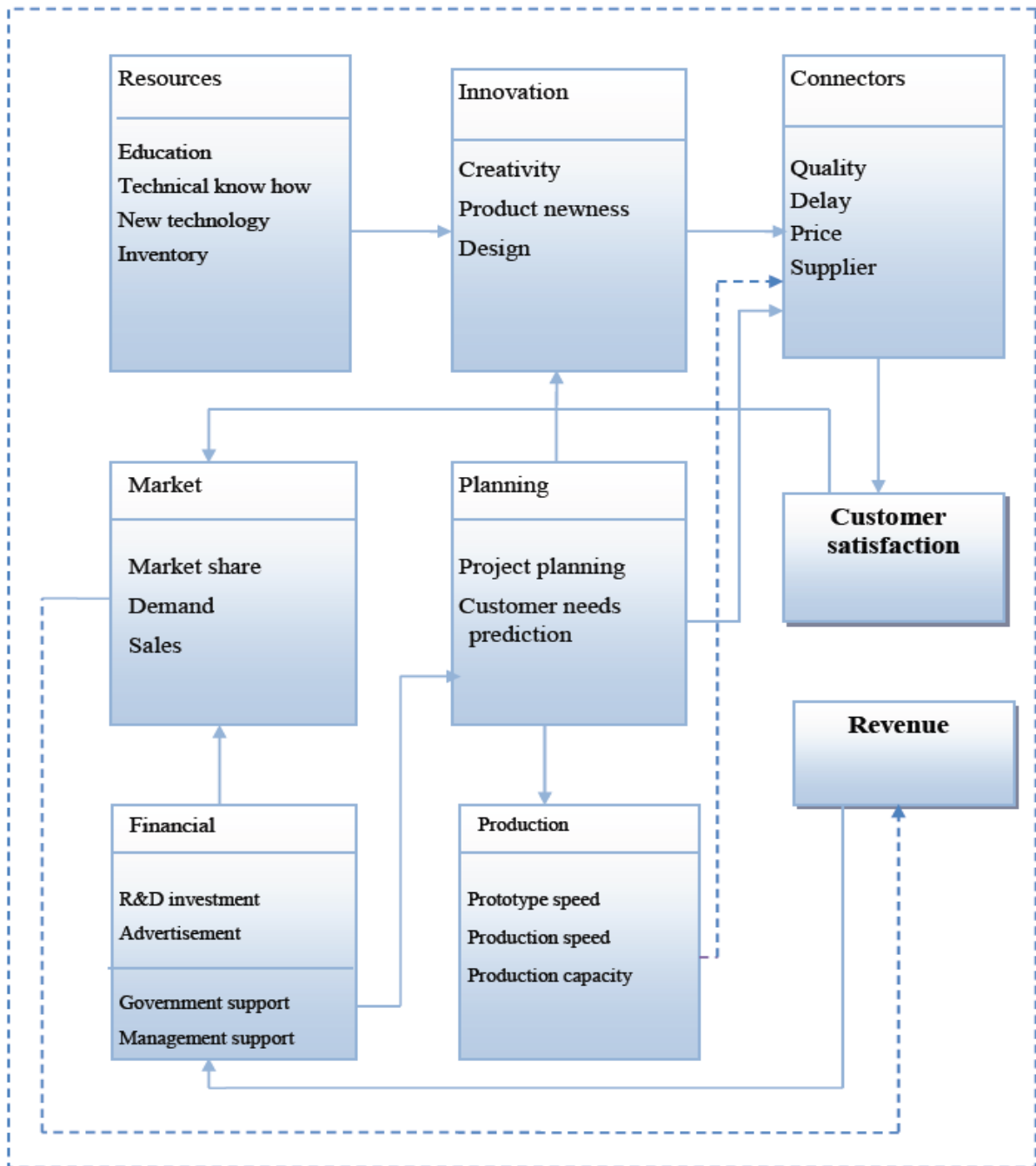


Fig. 4. New product development structure's elements

4.3.4. Causal Loop Diagrams of New Product Development and Related Risks

A causal loop diagram (CLD) is a diagram that aids in visualizing how significant NPD risks affect on new product development process variables. Feedbacks are what make system dynamics. Without such feedback, the system is static. The greater the interaction among the components of a system, the more dynamic it is. In a system with built-in feedback mechanisms, the behavior of a structure which is composed of components, attributes and relationships is constantly changing over time (Lee and Tunzelmann, 2005).

We first mainly focus on both objectives of customer satisfaction and revenue from customer and manufacturer's points of view. We then based our

study on the effects of three main NPD risks obtained from section 4.2 on NPD process performance. The variables are represented by arrows and the risk factors are shown by dotted ones and labeled as positive or negative (The '+' sign means that, when a variable at the tail of the arrow changes, the variable at the head always changes in the same direction. '-' sign has the opposite effect).

In order to highlight the steps to achieve the main model (Figure5) we break the model into five main loops as illustrated in Figures 6-10: (MS) management support, (GS) government support, CDA (creativity-demand-attractiveness), KT (knowledge- technology) and advertisement.

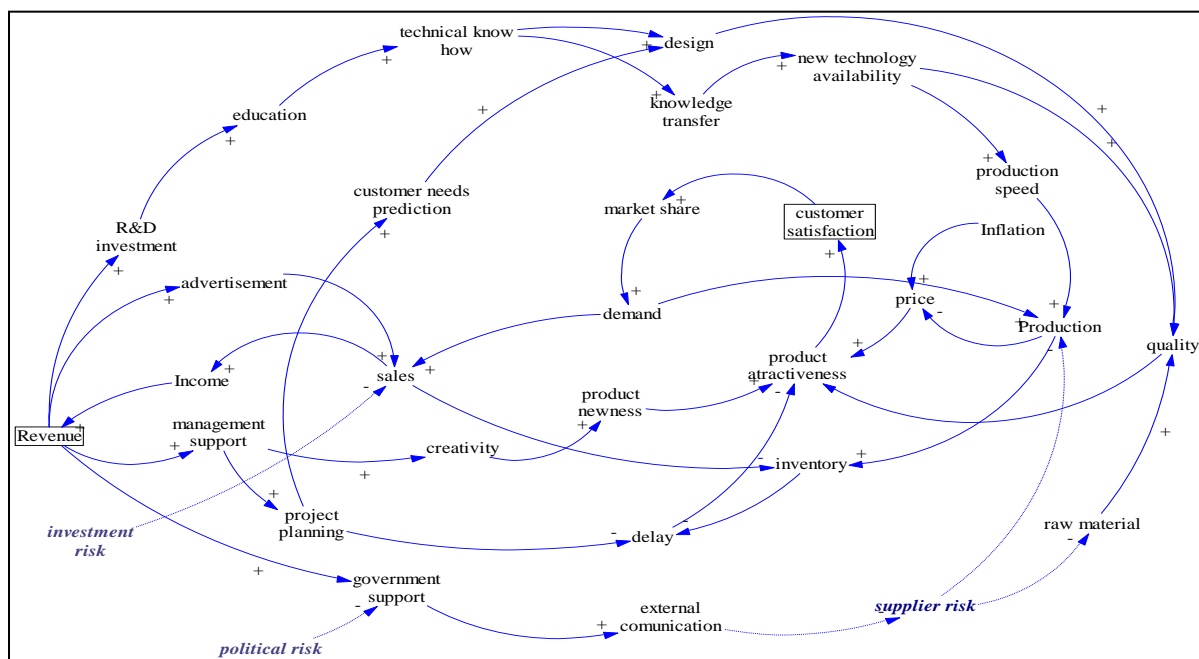


Fig. 5. New product development process model

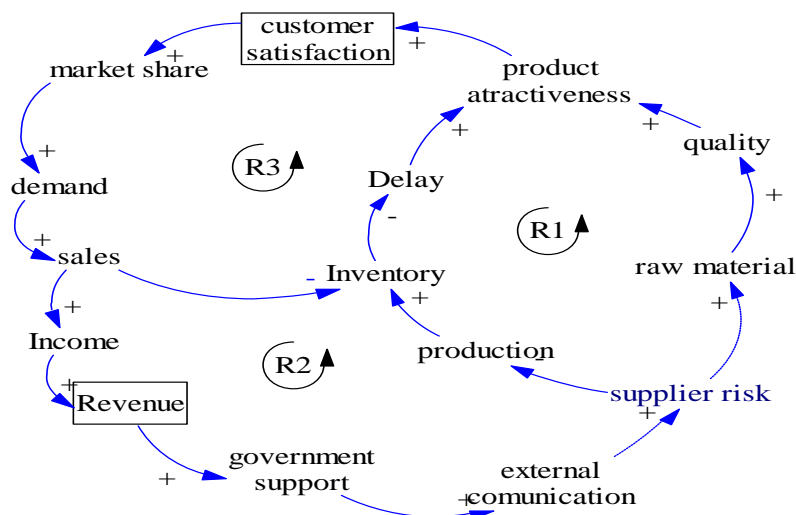


Fig. 6. Government Support (GS) loop (part of main model)

GS loops: Figure 6 shows 2 counter clock loops. As illustrated, the higher the government support, the greater the external communication, leading to lower supplier risk that ameliorate raw material quality. Better raw material enables higher quality, which increases product attractiveness, in turn increasing both

customer satisfaction and market share, and then boosting sales and revenue. Political risk, an external risk factor, influences on government support negatively. R2 shows that the higher supplier risk increases delay in the project and the greater the delay the higher the product attractiveness.

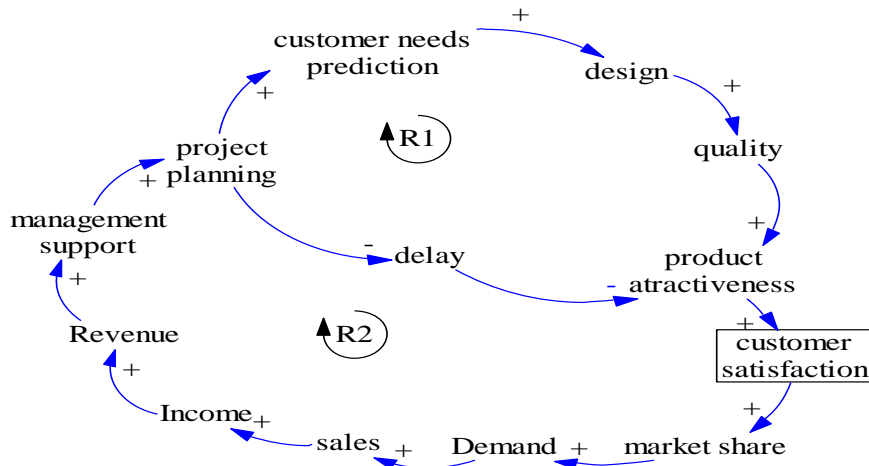


Fig. 7: Management support loop (MS) (part of main model)

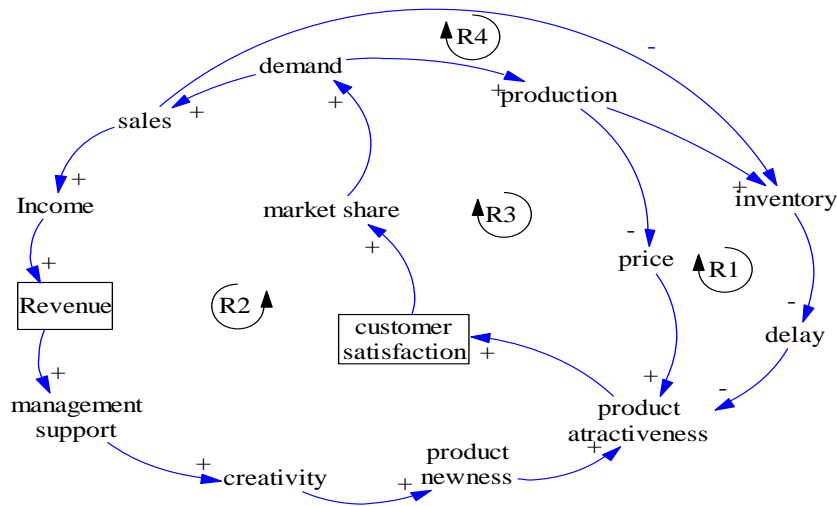


Fig. 8. CDA loops (part of main model)

CDA loops: Figure 8 shows the effect of creativity, demand and product attractiveness on customer satisfaction. The greater the management support of an industry, the more effective the creativity can be. Creativity creates product newness and cause product attractiveness, boosting customer satisfaction, market share, sales and revenue. On the other hand, customer satisfaction increases demand and production capacity in loop R3. Increasing production capacity can decrease price. The lower the price, the higher the product attractiveness is. In loop R1, increasing production capacity causes higher inventory amount and inventory results in less delay. The lower the delay, the higher the product attractiveness is.

Figure 9 mainly portrays the role of knowledge and technology in the system and its impression on the two objectives. Loop R1 describes how more technical know-how leads to more pressure for desired quality and customer satisfaction; in turn, the more the technical know-how, the better the design could be, leading to better performance and quality. the greater the quality, the more the product becomes attractive and customers become satisfied, the higher the market share, hence more sales, more revenues and then more R&D budget reinvested in product development and more personnel would be newly educated. Similarly, in loop R2, the more the technical know-how, the more knowledge could be transferred resulting in new

technology availability. The higher the production and prototype speed, increase inventory and pushing down delays, then raising product attractiveness; the more the

product is attractive, the more the market share, sales, revenues, R&D budgets, leading to increase education in the industry.

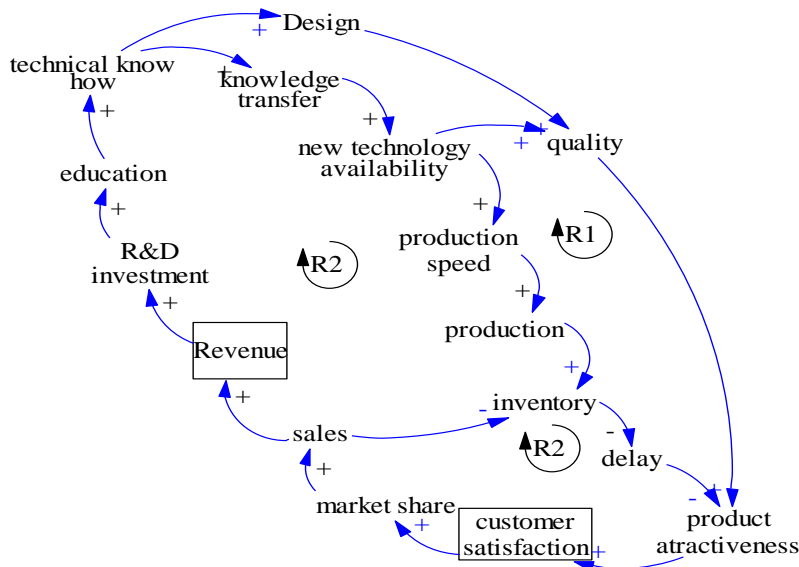


Fig. 9. KT loops (part of main model)

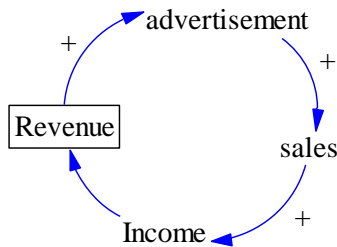


Fig. 10. illustrates the positive effect of advertisement in new product development.

4.3.4. NPD Risks Analysis (System Dynamics Approach)

Table 3 listed main NPD risks with respect to the case we explained. Five main risks are obtained for the mentioned case. We selected three risks to show their effects on the NPD process chain as shown in figure 5. The risks are illustrated in red by dotted lines. One risk is investment risk which is a common risk in a textile industry due to the import of such clothing with a cheaper price to the Iranian markets.

As it is obvious this risk influences on sales factor negatively. This means that the higher the risk of investment is (investment in purchasing new technologies) the higher the risk of sales could be. Because there is another side risk of market share the company may not get the considerable market share by its new investment. Thus, the sales would be lower than expected. If this occurs, all the plans for R&D investment, management support, advertisement and other connected factors due to not getting the revenue expected.

The second important risk, not only in textile but also in all other industries, is political risk. This risk influences on the government support, i.e. if a new rule for raw material approved, the government may increase the tariff of some material which is challenging for the factory. There is another main risk associated with this risk called supplier risk. The supplier risk is completely affected by political risk. With the occurrence of this risk, the quality of raw material will be in danger on one hand and on the other hand, the project may face more delay affecting on product attractiveness and finally in customer satisfaction.

Consequently, it is obvious from the model that how such significant risks influence the product development and its objectives of customer satisfaction and profit which are in close relationship with these risks.

4.3.6. Empirical Analysis

In order to illustrate in reality that how the risks affect on the process, we apply the work flow model to simulate the behavior of the chain of factors considering the impression of main risk factors for the case given in section 4.2 The simulation model flow diagram which simulates the product development process and the effect of 3 main risks are presented in Figure 11. The Vensim modeling language is used. The boxes refer to levels (or state variables) that integrate the flows and rates described with the pipes and valves. Together these generate the corresponding set of differential equations analogous to mass balance in actual flow processes. The thin curved arrows describe the causal information system, in which balances do not apply (Lee and Tunzelmann, 2004). Applying this

model to real world applications could help us understand the systems real behavior under such risks.

4.3.6.1. Scenario Analysis

In order to show the effects of risks and the mitigation strategies, based on the mitigation actions described in section 3.2 on NPD factors, mainly on customer satisfaction and revenue, we applied three different scenarios and compare the results with a reference scenario with initial values. The reference scenario reflects the case's current situation exposing to the 3 risks but no risk management action is taken. The scenario with high risk probability is obtained from the

case study given in Section 4.2. The FMEA table is used to establish the risk values for the reference scenario: risk values are determined by multiplying the occurrence rate and the severity score of the related failure modes obtained in Table 2. We compare the performance of this reference scenario with other scenarios where the mitigation actions are taken into account. As stated, we consider three main risks of political, investment and supplier risks. The political and investment risks are the external risk factors, but the supplier risk is an internal risk factor affected by the other two risks.

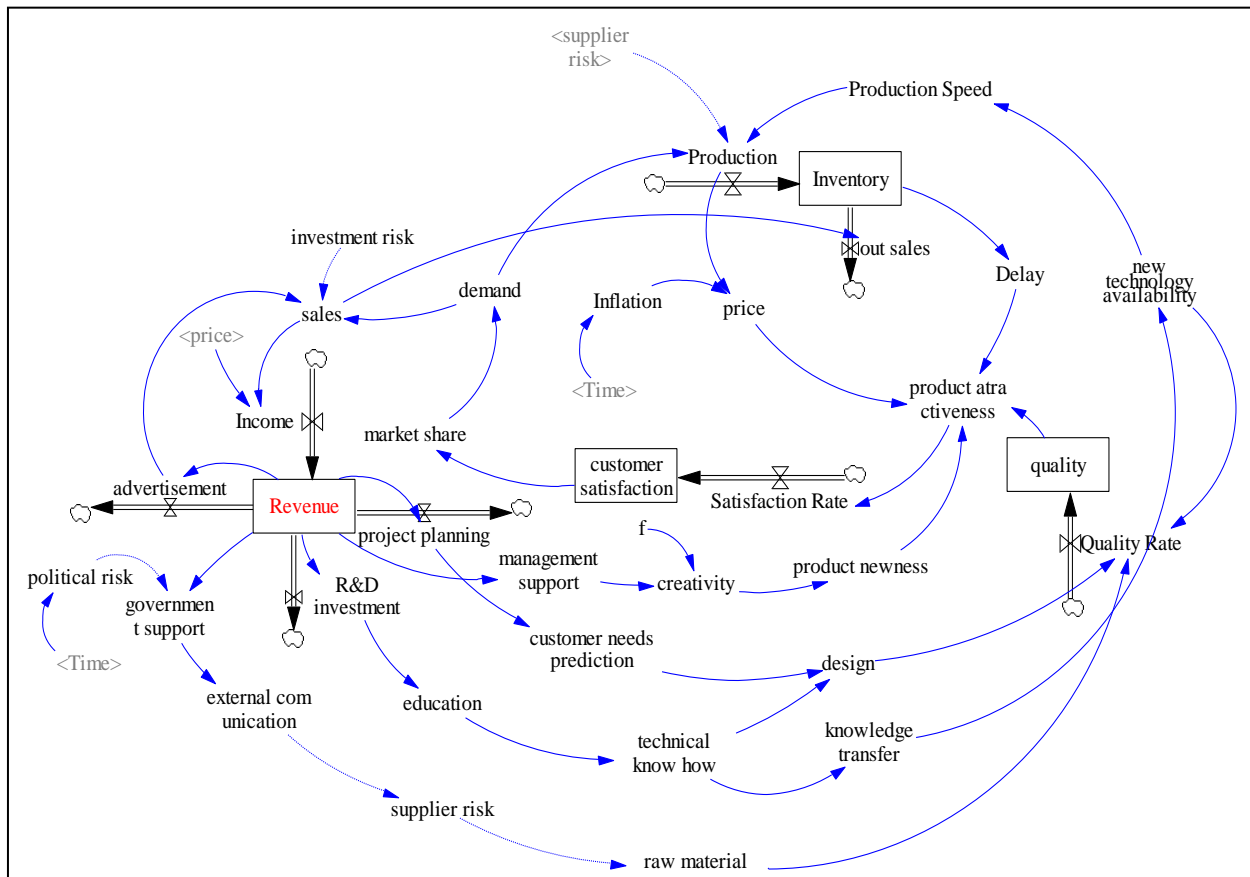


Fig.11. Work flow diagram for real simulation

The simulation is applied for 24 years. The values are related to the information achieved from the 20 past years and the external risk values of the 4 prospective years are predicted. The last 4 years (2011-2014) are for prediction. We insert the 24 years values of the risk factors to predict and calculate other factors.

Thus, we base our scenarios on the changes appeared in the two risks in the 4 prospective years.

We base our analysis from the reference scenario and take into account the mitigation actions on the two risks of investment and political first individually and then both risks mitigation at a time to identify their effects on the NPD objectives. Thus, together with the

reference case we have to analyze 4 options or scenarios.

Table 5 gives the initial risk values of reference scenario and the 3 risk exposure values with respect to different experimental conditions. The reference scenario has high risk values. In the first scenario, the investment risk is diminished by 30% in the last 4 years of prediction (21-24), but the political risk remains unchanged. In the second scenario, the political risk is deducted by 30% and the investment risk remains intact. In the third scenario, both risks have been diminished by 30% in the last 4 years of the prediction (21-24).

Tab. 5. the scenarios for risks effects analysis on NPD

Year	basic scenario (reference)		scenario 1		scenario 2		scenario 3	
	investment risk(IR)	political risk(PR)	investment risk(IR)	political risk(PR)	investment risk(IR)	political risk(PR)	investment risk(IR)	political risk(PR)
21	63%	35%	0.44	35%	63%	0.24	0.44	0.24
22	63%	30%	0.44	30%	63%	0.21	0.44	0.21
23	63%	35%	0.44	35%	63%	0.24	0.44	0.24
24	63%	45%	0.44	45%	63%	0.31	0.44	0.31

As stated the flow diagram based simulation analysis of figure 11 is conducted for the performance evaluation of the above mentioned scenarios and to observe the impacts of the risk mitigation actions under different levels of system parameters. The initial data are set as follows: INITIAL TIME=1, FINAL

TIME=24 (years), TIME STEP=1. Other initial data for the external factors are collected in Table 6 the inflation and the political risk face with remarkable changes every four years due to the presidential elections. The formulas obtained for the model are collected in appendix I.

Tab. 6. The initial values of external factors

year	1	2	3	4	5	6	7	8	9	10	11	12
inflation	0.15	0.15	0.15	0.15	0.27	0.27	0.27	0.27	0.27	0.25	0.25	0.25
year	13	14	15	16	17	18	19	20	21	22	23	24
inflation	0.18	0.15	0.15	0.12	0.13	0.13	0.13	0.25	0.25	0.25	0.25	0.4
year	1	2	3	4	5	6	7	8	9	10	11	12
political risk	0.12	0.12	0.12	0.2	0.1	0.1	0.1	0.25	0.14	0.14	0.14	0.3
year	13	14	15	16	17	18	19	20	21	22	23	24
inflation	0.15	0.15	0.12	0.3	0.2	0.25	0.25	0.4	0.35	0.3	0.35	0.45

investment risk = 0.63 for all years

Risk mitigation actions reduce the initial impact of a risk on a factor. If we take a look at the effects of mitigation actions for each risk, we certainly should observe the efficient results for the objectives we take in to consideration (Revenue & customer satisfaction). Since there are, we conduct our analysis based on 3 level variables; revenue, customer satisfaction and inventory in addition to sales, production and quality as other 3 significant variables. For each factor, we compare the four scenarios in order to show the risk effects at once. Based on Figure 12 the sales increase when the move from the reference scenario with high risk levels to the low level risk scenarios. The maximum sales state is for scenario3 in which both risks are mitigated. Comparing with the second scenario, the first scenario in which the investment risk (IR) is decreased and the political risk (PR) remains constant, sales factor has the higher value. This means that taking mitigation actions for the IR is more effective than the PR mitigation. The revenue has also the same procedure as sales have as shown in Figure13. The revenue increases as the risk decreases. The effect of risk mitigation on quality is increasing. As illustrates

in Figure 14 the risks effects on quality is much more less than The same effect can be observed on the customer satisfaction as well, taking Figure 15 into consideration.

The investment risk has the direct effect on sales and revenue. Thus, it is obvious that has the maximum effect on sales and revenue and the minimum effect on quality and customer satisfaction. We can say that the investment risks is the most critical risk for the company of this case study as it highly affects the NPD performance. If we look at Figure 16 for the effect of risks mitigation on the production and similarly on inventory, we can observe the decreasing effect of risks on inventory reduction. This is due to the fact that although according to Figure 17 the production is augmented as the risks are diminished, sales growth is much more than production as the risks are declined. Similarly, the higher effect of IR mitigation is remarkable than the PR reduction effects. From all of the above analysis, we perceive the NPD process procedure under risk for the last 20 years and the four prosperous years. Figure 12: Risk mitigation scenarios for sales.

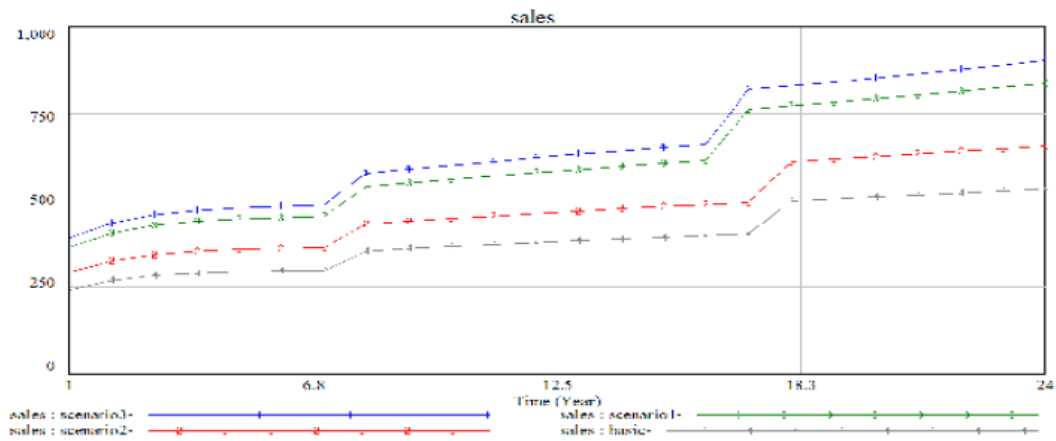


Fig. 12. Risk mitigation scenarios for sales

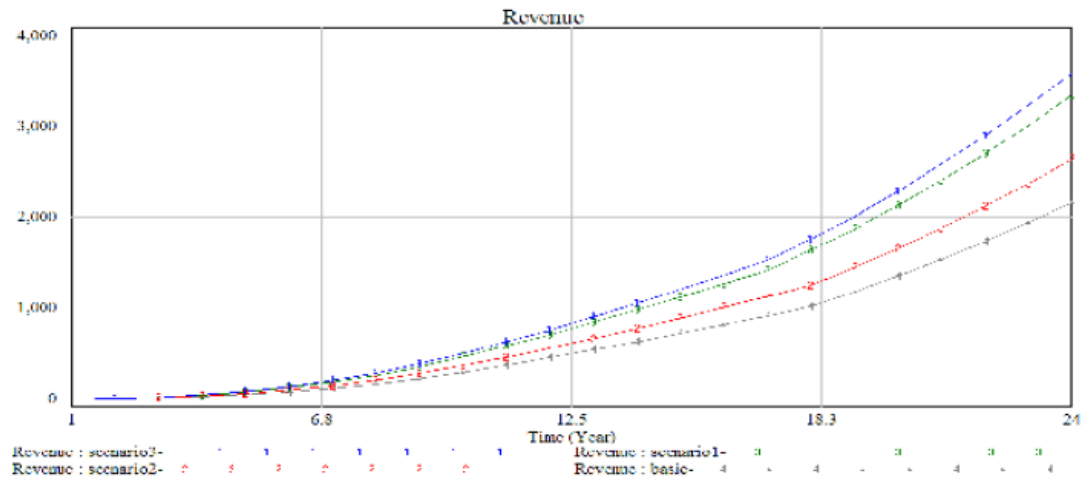


Fig. 13. Risk mitigation scenarios for revenue

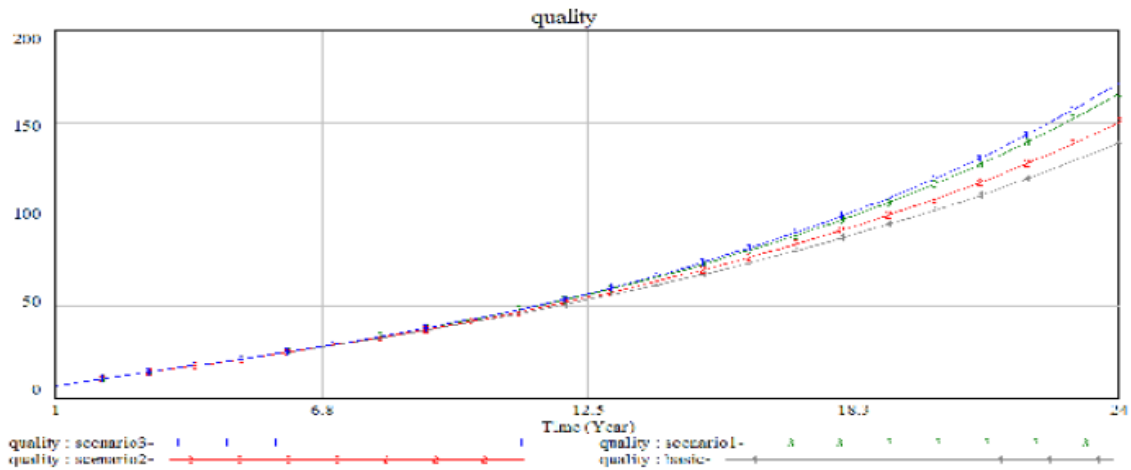


Fig. 14. Risk mitigation scenarios for quality

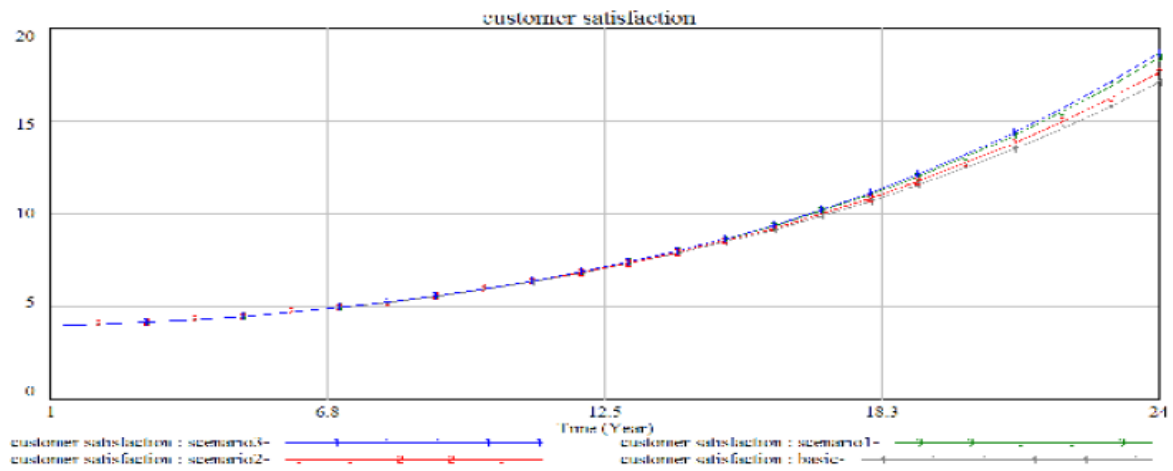


Fig. 15. Risk mitigation scenarios for customer satisfaction

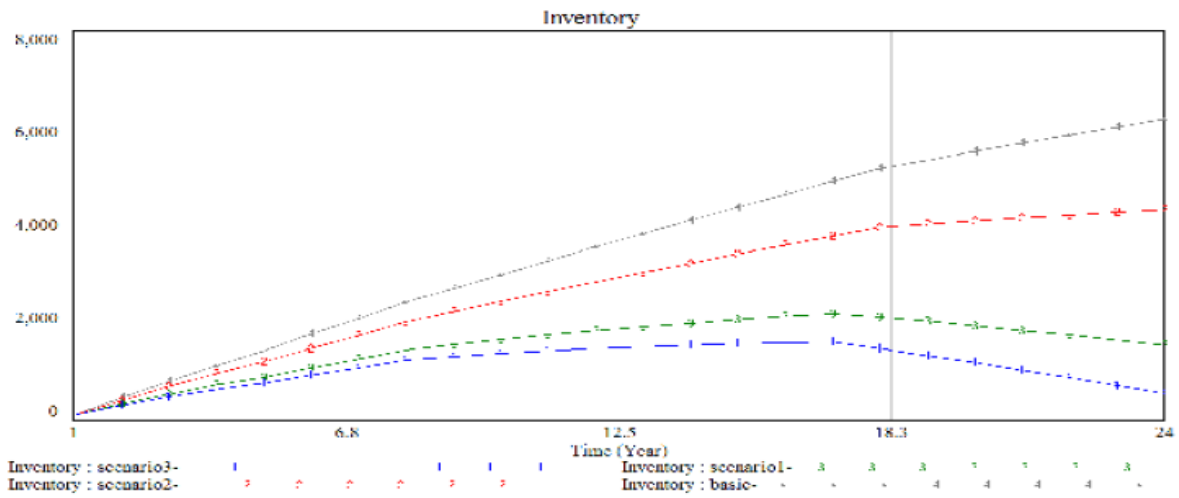


Fig. 16. Risk mitigation scenarios for Inventory

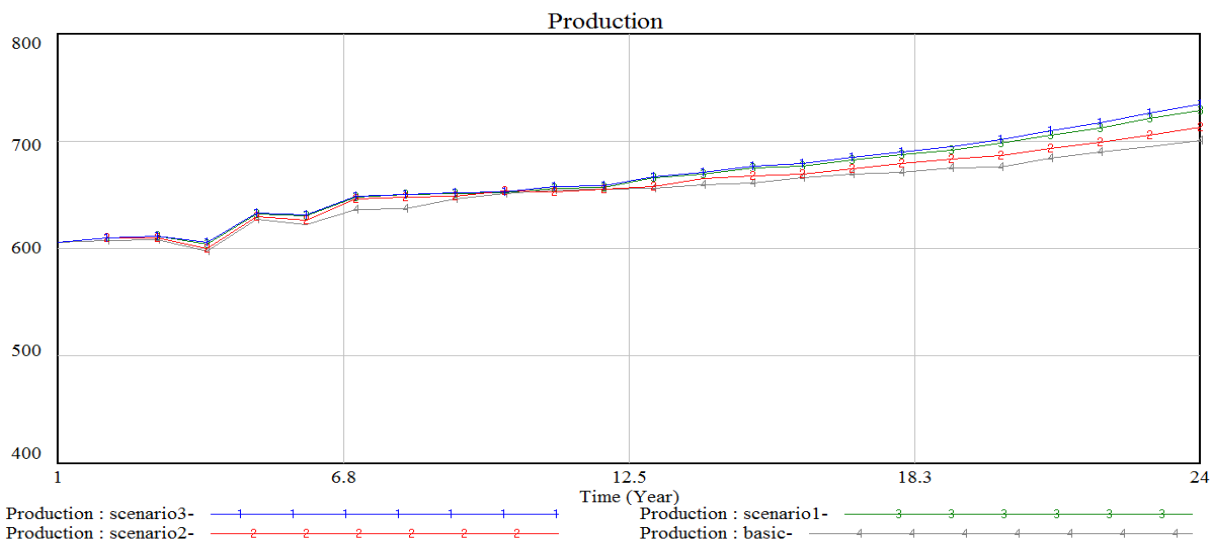


Fig17. Risk mitigation scenarios for Production

5. Conclusions and Further Work

In this study, we present the main factors affected in NPD process. It has presented NPD risk analysis procedure using FMEA and system dynamics approach after reviewing on other studies of the related field since there has not been a thorough research for the NPD process risks. In order to depict the criticality of some risks, the analysis is applied and examined in a safety clothing manufacturer in Iran. Twenty three risk factors were identified among which some are more critical.

The results showed 9 critical and 5 more critical risks by considering the RPN (risk priority number) and risk scores through scatter plot. In order to illustrate the effects of main risks on NPD process factors, we applied model building of system dynamics due to the dynamic and complex behavior of NPD. Using such a system could help us find the ways for some risks to be taken, some other risks to be mitigated or reduced for which some mitigation strategies are also presented in section 3.1. Based on the results achieved, the risk mitigation action on the main NPD risks can critically influence on the process. The investment risk was the main risk affects highly on Revenue and consequently on profit as the objective of the factory and less on customer satisfaction as the customer objective. For further work, we propose to enter the mitigation strategies to the model to show how it may reduce risks and to what level.

This article makes a significant contribution to the product development study due to the fact that it shows how FMEA can be used to calculate some risk factors and how we can relate them to the system dynamics in new product development. We analyzed the risks firstly through a case study by FMEA then by system dynamics for process modeling and risk effects on the process.

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Appendix I. Vensim Modeling Equations

- (01) Advertisement= 0.05*Revenue
(02) Creativity= f (management support)
(03) Customer needs prediction= DELAYII (0.01*project planning, 1, 0.009)
(04) Customer satisfaction= INTEG (Satisfaction Rate, 4)
(05) Delay=IF THEN ELSE (Inventory>=650, 0, (650-Inventory)/ (3*365))
(06) Demand=IF THEN ELSE ((market share*1600)>=650, (market share*1600),650)
(07) Design=10*technical know how+100*customer needs prediction
(08) Education=0.03*"R&D investment"
(09) External communication=INTEGER (IF THEN ELSE (government support<=200, government support/4, IF THEN ELSE (government support>200: AND: government support<=1000, government support/2, government support)))
(10) f([(0,0)-(200,20)],(1,2),(50,5),(100,7),(150,10))
(11) FINAL TIME = 24
Units: Year (The final time for the simulation.)
(12) Government support=Revenue-political risk * Revenue
(13) Income=price*sales
(14) Inflation = WITH LOOKUP (Time,([(1,0)-(24,1)],(1,0.15),(5,0.27),(10,0.25),(13,0.18),(14,0.15),(16,0.12),(17,0.13),(20,0.25),(24,0.4)))
(15) INITIAL TIME = 1
Units: Year (The initial time for the simulation.)
(16) Inventory= INTEG (Production-out sales,100)
(17) Investment risk=0.75
[0, 1, 0.2]
(18) Knowledge transfer= technical know how
(19) Management support= DELAYII (0.01*Revenue, 2, 0.6)
(20) Market share= IF THEN ELSE (5>=customer satisfaction, DELAYII (0.5, 2, 0.4), IF THEN ELSE (5< customer satisfaction: AND: 10>=customer satisfaction, DELAYII (0.7, 12, 0.5), DELAYII (0.9, 22, 0.7)))
(21) New technology availability=DELAYII (knowledge transfer, 1, 0.015)
(22) Out sales= sales
(23) political risk = WITH LOOKUP (Time, [(1,0)-(24,0.6)],(1,0.07),(3,0.07),(4,0.12),(5,0.06),(7,0.06),(8,0.1),(9,0.08),(11,0.08),(12,0.1),(13,0.05),(15,0.05),(16,0.1),(17,0.2),(19,0.2), (21,0.17),(23,0.14),(24,0.1)))
(24) Price= (Production*0.007+1+RAMP (15, 1, 24))/Production+((Production*0.007+1+RAMP (15, 1, 24))/Production)*Inflation
(25) Product attractiveness= (quality*0.01+product newness*0.001)-(Delay*(0.01))-0.02*(price)
(26) Product newness= creativity
(27) Production= (IF THEN ELSE (demand<=Production Speed, demand, Production Speed)-IF THEN ELSE (Demand<=Production Speed, demand, Production Speed)*supplier risk)
(28) Production Speed= 650+new technology availability*100
(29) Project planning= 0.01*Revenue
(30) Quality= INTEG (Quality Rate,7)
(31) Quality Rate= 0.5*raw material +0.3*design + 0.2*new technology availability
(32) "R&D investment"= 0.01*Revenue
(33) Raw material= 7-9*supplier risk
(34) Revenue= INTEG (Income-advertisement-project planning-"R&D investment",100)
(35) Sales= (advertisement+ demand)-(advertisement+ demand)*investment risk
(36) Satisfaction Rate= product attractiveness
(37) SAVEPER = TIME STEP
Units: Year (The frequency with which output is stored.)
(38) Supplier risk= IF THEN ELSE (external communication<=200, RANDOM UNIFORM (1, 2, 1)/external communication, RANDOM UNIFORM (2, 4, 2)/external communication)
(39) Technical know-how=DELAYII (education, 1, 0.02)
(40) TIME STEP = 1
Units: Year (The time step for the simulation.)

