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Risk Assessment of Product Innovation and Development Using Markov Process Approach

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***Abstract*—Product Innovation is a key aspect of any company and central to the New Product Development (NPD) process. Companies must take risks to launch innovative new products speedily and successfully for its survival and sustainability. Despite meticulous efforts by companies to bring innovations, most of them are failing in the market place and hence the ability to diagnose and manage risk is a very important activity in high risk innovations. This paper presents a new Product Innovation and Development (PID) process and a quantitative methodology for risk assessment. FMEA (Failure Modes and Effects Analysis) and Markov process analysis are combined and presented as the risk assessment method which brings research value to risk assessment in PID process. This methodology also investigates the overall Product innovation and Development process and explores various risks, categorize them according to their sources, assess those risks and explores various risk mitigation techniques. The methodology is demonstrated using a case study on a new innovative home appliance project.**

***Index Terms*—New product development, product innovation, risk assessment, markov process, FMEA.**

I. Introduction

Risk is the potential that a chosen action or activity (including the choice of inaction) or actions from external world will lead to a loss (an undesirable outcome). Risk management is the identification, assessment, and prioritization of risks followed by coordinated and economical application of resources to minimize, monitor, and control the probability and/or impact of unfortunate events or to maximize the realization of opportunities. Risk management and innovations are not opposed. The core competency of the most effective and successful innovator is risk management as per reference [1]. For these innovators the ability to identify, prioritize, and systematically eliminate risks is what drives innovation forward. This paper aims to present new PID process and a risk assessment methodology for product innovation and development system for a new product or service which the company wants to bring into the market. Any innovative products are of little value to a firm that cannot get to market, either on its own and/or through partnership. Find below are some of the essential requirements of a successful organizations.

- Imperative to innovate
- Emphasis on developing the capability and capacity to innovate and taking into market
- Culture of accountability and responsibility for delivering results
- Systematic organizational learning
- Risk management processes in decision making

This view of innovation from a market and institutional perspectives reveals that importance of innovation is related to the overall market delivery system which the organization possess or intend to develop to bring innovative product / service to the market. A risk assessment methodology has been developed for the product innovation and development system to assess risks available in the current product innovation and development system of organization. This helps the organization in making better decisions and to ensure corrective actions are in place to bridge the gap in the PID system and hence to bring innovation successfully to the market. There are several risk analysis techniques available to analyze the risks in a project. Most of the tools and techniques are static in nature and only few of them dynamic in nature suitable for innovation projects.

Two stage approach for risk assessment for NPD was developed by [2]. In the first stage critical risk factors in NPD were analyzed and then Bayesian network is used in dealing with uncertainties of those risk factors. Bayesian network was modelled to facilitate the assessing of the risk involved in an NPD process. The reference [3] divided the innovation process into 6 states: idea generation, idea screening, economic analysis, development, testing, and commercialization. Probability of success or failure of the project, at every stage of innovation, was modeled through the transition matrix and Markov chains, and then a solution was proposed. The AHP, fuzzy model, Markov process, and evolution strategy models were described to predict risk factors that may occur while working on NPD then a systematic framework for risk management was proposed for handling risk factors, risk degrees, integrated risk degree, and responding activities with corresponding data flow diagrams [4]. The reference [5] investigated risk management methodologies applied to Research and Development projects and a risk management framework was proposed in which Project Risk Failure Mode and Effects Analysis (RFMEA) principles were applied to development projects. It is very difficult to find research papers in PID using Markov process methodology for risk assessment (most of the research papers available in Markov process are for reliability applications in complex system). In this paper, method based on Markov chain model is

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proposed to analyze risks in PID projects which considers dynamic response actions.

II. The PID Process Framework

A. Six Phases of PID

Six phases process has been recommended for Product Innovation and Development process. (Fig. 1). It consists of six phases and the details are given below.

Phase 1- Scan

Keep your eyes open for new technologies/innovations that might assist you. It is a series of studies that tracks trends, technologies, competitor activities, substitution products, and innovations could influence or be leveraged as part of next generation products. The scope of this phase is the Innovation/*Technology Watch List*, which includes identified innovation/technologies, their trajectory in terms of performance and potential for adoption, along with major opportunities and limiting factors.

Phase 2 - Screen

Evaluate the innovation against your strategy. Ask yourself if implementing this innovation/technology will help your company reach its strategic goals better or faster. Does it increase efficiency, reduce cost or act as a product differentiator? It is about detailed understanding about various technologies under consideration and identifying potential options.

Phase 3 - Select

During this phase, we will identify all the necessary requirements including business, functional, and technical. Based on focused stakeholder interviews, requirements technology options are categorized and prioritized. Each requirement is weighted to provide a level of importance to the organization. In addition, this phase will evaluate the organization's current business product /processes potentially affected by the technology change and begin to outline the future state of these product/ processes.

Phase 4 - Develop and Mini-implement

Begin with a limited test of the innovation/technology. A mini-implementation can help to evaluate innovation & new technologies within organization's own products, processes and services. This will serve as a proof of innovation/technology/concept to proceed further with development.

Phase 5 - Recommend

Based on results from phase 4, further development as NPD will be recommended. This should include communications such as status, timetables, phases, issue resolution and cost. It also should include how to communicate with employees, vendors or consultants assisting with the implementation.

Phase 6 – NPD Process

After completion of innovation proving, the NPD process shall be initiated to bring new product into the market. The phase 6 shows the generic new product development model adopted by many organizations. The reference for the same are included in [6]-[12].

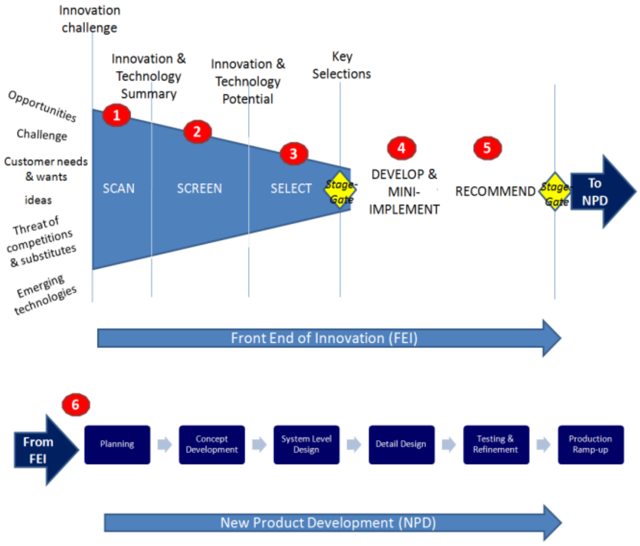

Fig. 1. The proposed innovation & product development framework.

III. PID Case Study: Infrared Technology Based Clothe Dryer

From late 1990s onwards, developments in home appliances focused on energy efficiency and environmental friendliness. Environmental awareness is at an all-time high and studies had found that home appliances were a major source of electricity consumption and greenhouse gas emissions. Many governments introduced a product labelling program, whereby the energy efficiency of an appliance was clearly displayed. These encouraged consumers to buy the most environmentally-friendly option available. Because of these, the strength of competitiveness of appliances industry is determined by their good technology innovation capability and technology development process meeting these energy/environmental requirements. In the international market and competitiveness of products or industry is directly proportional to its scientific and technological content meeting these needs [7].

Clothes dryer is the second most energy consuming household appliance after refrigerator. This paper is to evaluate risk associated with infrared heating (IR) based heating for the clothe dryer since these are believed to have lower power consumption, reduced drying time, flexibility in drying temperature compared to the existing technology which is based on filament heating element. This new technology option may also have some limitations with respect to their ability to handle different type of clothes and safety in usage etc. Most risk assessment framework addresses only the financial aspects and does not include other issues related to technology/innovations. In this paper, FMEA method combined with Markov analysis are used to assess risk in this new product development.

A. The Proposed Risk Assessment Methodology Sources of Risks and Failure Modes

The proposed Risk assessment method for innovation helps to identify risks associating in delivering innovation value through all the six phases of PID. This will help the companies to focus their effort in important delivery system aspects, so that the innovation value has been delivered as intended. To start with, the product FMEA has been used for assessing the risks in delivering innovation value. The IRPN (Innovation Risk Priority Number) for different innovation values of the product or service under consideration will help the organization in recommending corrective actions for overall delivery of innovation values. The various sources of innovation risks and their failure modes for infrared technology-based clothes dryer are given in Table I.

TABLE I: PID PROCESS RISK CATEGORIES AND ITS FAILURE MODES

Id.	Sources of Risks	Sources' Failure Modes
a.	Market and Competition	Lack of market understanding (Customer needs and wants)
		Difficulty in building relationship with key customer
		Delay in developing new market
		Issue in product positioning
		Lack of proper portfolio
		Unrealistic sales forecasts
		Growing internal competition
		Growing international competition
b.	Strategy, Managerial and Oraganizational	Difficulty in clarifying and agreeing on innovation objectives
		Unscientific feasibility study
		Lack of coordination between functions / departments
		Late / delay in making decisions
		Frequent decision changes
		Lack of internal competencies
		Retention of key employees
		Internal organizational change
		Lack of commitment to innovation and product development
c.	Financial	Over running budget
		Incorrect pricing
		Inadequate sales expectation
		High initial costs
		Unpredictability of suppliers costs
		Cash flows issues
		High BoM cost
		Low IRR and NPV
d.	Innovation	Inadequate idea evaluation
		Confusing priorities
		Issue in linking technology with customer / business needs
e.	Technology	High technology development time
		Unanticipated technology complexities
		Lack of competencies in technology development
		Not viable in price/performance
		High cost to acquire technology
		Huge funds to be invested in R&D
f.	Design / manufacturing related	Many iterations
		Too much waiting time for ID, prototypes
		Performance is not proven
		Quality issues
		Issue in manufacture
		Too much material handling and transport
		Very short time available to market
g.	Suppliers	Too much dependance on components / services from suppliers
		Supplier component quality issues
		Inadequate capacity
h.	IP	Research not sufficient to validate claims
		Delay in developing and protecting IP
i	Legal and Compliance	Test compliance with standards issues
		Safety issues
		Compliance with any new requirements
		Legal issues with competitors

The implementation of Innovation FMEA for the case study is provided in the Table II. Innovation risk priority numbers were developed for the clothes dryer. As per the methodology, IRPN indicates *"Innovation Risk Priority Number"* which guides the organization to better understand their product innovation and development system risk and providing scope for corrective action to deliver innovation without scarifying its value to market place. There are nine sources of risk are identified using FMEA study. These inputs are used for Markov modelling and analysis.

TABLE II: INNOVATION FMEA FOR IR CLOTHES DRYER

Risk Category	Failure Mode(s)	Possible Cause(s)	Effect(s)	Severity	Occur	Current Control	Detectability	IRPN	Recommended Action(s)
a) Market and Competition	Lack of Customer Understnding (needs and wants)	Not so good market understanding / research	Risk of business survival	8	6	Target market study with pilot	4	192	Collect / analyse customer data, QFD
	Difficulty in building relationship with key customer								
	Delay in developing new market								
	Issue in product positioning								
	Lack of proper portfolio								
	Changes in sales forecasts	Lack of market potential understanding and competition	Loosing competitive advantage	6	7	Competitor analysis / monitoring	5	210	Collect / analyse competitor data
	Growing local competition								
	Growing international competition								
	Unscientific feasibility study								
b) Strategy, Managerial and Organizational	Difficulty in clarifying and agreeing on innovation objectives	Lack of leadership and organizational culture	Risk of business survival	8	5	Innovation Roll-out	7	280	Leadership coomunication & comitment plan on innovation
	Lack of coordination between functions / departments								
	Late / delay in making decisions								
	Frequent decision changes								
	Lack of internal competencies	Inability to attract talent	Mistrust and poor organizational culture	6	4	Training on innovation topics	5	120	Hiring and retension policy to meet innovation requirements
	Retention of key employees								
	Internal organizational change								
	Lack of commitment to innovation and product development								
c) Financial	Over running budget	Lack of awareness in overall cost	Hampered growth and return	7	4	Learnings on innovation costing	5	140	Training on cost control
	Incorrect pricing								
	Inadequate sales expectation								
	High initial costs								
	Unpredictability of suppliers costs								
	Cash flows issues								
	High BoM cost	Additional parts to ensure safety	Low profit margin	8	5	Elaborate design review	2	80	Detailed design review
	Low IRR and NPV								
d) Innovation	Poor in opportunity identifaction/analysis	Lack of structured "Front End for Innovation" Process	Less flow of innovations and hence hapered economic sustainability	6	8	Seed funding available for idea prooving	8	384	FEI process development and its integration with NPD
	Not many ideas								
	Inadequate idea evaluation / short-listing								
	Poor idea/concept development and prooving								
	Confusing priorities								
e) Technology	High technology development time	Lack of understanding on technical difficulty and uncertainty	Less flow of innovations and hence hampered economic sustainability	6	7	Collecting more info about technology and tracking trends	8	336	Expert identification and consultancy
	Issue in linking technology with customer/business needs								
	Unanticipated technology complexities								
	Lack of competencies in technology development								
	Not viable in price/performance								
	High cost to acquire technology								
	Huge funds to be invested in R&D								
f) Design/manufacturing related	Quality issues	Poor execution of NPD	Missing product launch & decline in market share	7	6	NPD process is available	4	168	Strict adherence of NPD process
	Many iterations								
	Too much waiting time for ID, prototypes								
	Performance is not proven								
	Issue in manufacture								
	Too much material handling and transport								
	Current design maturity level								
	Materials issues								
	Process capability issue								
	Manufacturing and fabrication								
	Very short time available to market								
g) Suppliers	Too much dependance on components / services from suppliers	Missing ESI in FEI	Not meeting sales targets and revenue reduction	6	4	Supplier involvement in NPD	5	120	ESI in innovation activities
	Supplier component quality issues								
	Inadequate capacity								
h) IP	Research not sufficient to validate claims	Lack of understanding and structure in handling IP	Loosing market leadership	7	6	Has some previous experience	5	210	Training of key people
	Delay in developing and protecting IP								
	Legal issues with competitors								
i) Legal and Compliance	Test compliance with standards issues	Lack of understanidng on countries policies, laws and regulations	Not meeting sales targets and revenue reduction	6	4	Similar activities on existing products	4	96	Training of key people
	Safety issues								
	Compliance with any new requirements								

1)Markov modelling

We begin with the Markov formulation by designating all the possible states of the Product Innovation and Development process.

G: PID process operating without any risk events

R: PID process is under partial risk environment, working at reduced efficiency / effectiveness and is being under risk response actions.

F: PID process is under complete risk environment and is being under risk response actions.

2)Assumptions

- All sources transition rates are constant over time.
- All sources states except those arising due to multiple sources risks are mutually independent.
- A response actions will result in process without risks.
- All response actions begin immediately upon appearance of risks

3)Notations

The various risk sources are mentioned in Table I; "a" represents risk events from source "Market and Competition"; "b" represents risk events from source "Strategy, Managerial and Organizational" and so on. The other notations are given below.

λ_{x1}	transition rate from state *G* to state *R* because of risk source `*x*' where *x* stands for any of the source *a, b, ..., i.* The subscript *1* indicates the partial risk state of PID process because of source *x*.
λ_{x2}	transition rate from state *R* to state *F* because of risk source `*x*'. The subscript *2* indicates the complete risk state of PID process because of source *x*.
μ_{x1}	transition rate from state *R* to state *G* because of the source `*x*'.
μ_{x2}	transition rate from state *F* to state *R* because of the source `*x*'.
φ	common-cause event rate from state *R* to state *F* due to the events of sources `*a*',`*b*' *and* `*c*'.
ω	response rate from state *F* to state *G* due to response completion of sources `*a*',`*b*' *and* `*c*'.
τ	common-cause event rate from state *G* to state *F* due to the events of sources `*a*',`*b*' *and* `*c*'.
η	response rate from state *F* to state *G* due to response completion of sources `*a*',`*b*' *and* `*c*' collectively.
P	Pr {PID process is in a state of risk free}
P_{x1}	Pr {PID process is in a state of partial risk due to risk events of *x*}
P_{x2}	Pr {PID process is in a state of complete risk due to complete risk events of *x*}
$P_{(a2bc)com}$	Pr {PID process is in a state of failure due to common-cause failure of *a* (after reaching a_1), *b* and *c*}
$P_{(ab2c)com}$	Pr {PID process is in a state of failure due to common-cause failure of *b* (after reaching b_1), *a* and *c*}
$P_{(a2b2c2)com}$	Pr {PID process is in a state of failure due to common-cause failure of *a, b and c* (together)}

4)Mathematical analysis

Fig. 2 represents the state-transition diagrams for the PID process. Since the transition from any state is possible only to the next higher state or to the next lower state, based on Chapman-Kolmogorov equations, one can identify the evolution of the system with a birth and death process. The derivation of the differential equations and state probabilities of the events of the sources, though complex, can be obtained from Fig. 2. The steady state probabilities are given by the following expressions.

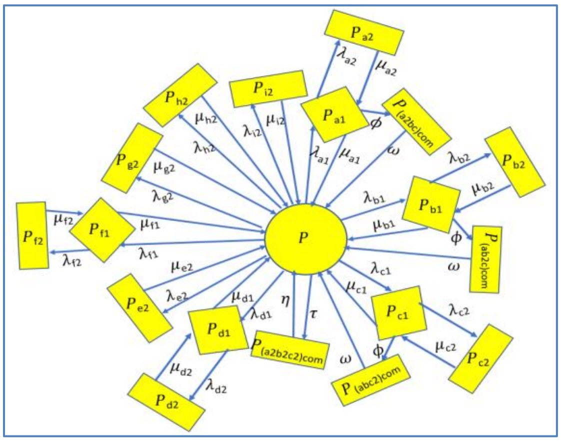

Fig. 2. State transition diagram for PID process.

$$P_{a_1} = \frac{\lambda_{a_1}}{(\mu_{a_1} + \phi)} P \tag{1}$$

$$P_{a_2} = \frac{\lambda_{a_1} \cdot \lambda_{a_2}}{\mu_{a_2} .(\mu_{a_1} + \phi)} P \tag{2}$$

$$P_{(a_2bc)com} = \frac{\phi \cdot \lambda_{a_1}}{\omega .(\mu_{a_1} + \phi)} P \tag{3}$$

$$P_{b_1} = \frac{\lambda_{b_1}}{(\mu_{b_1} + \phi)} P \tag{4}$$

$$P_{b_2} = \frac{\lambda_{b_1} \cdot \lambda_{b_2}}{\mu_{b_2} .(\mu_{b_1} + \phi)} P \tag{5}$$

$$P_{(ab_2c)com} = \frac{\phi \, . \, \lambda_{b_1}}{\omega \, .(\mu_{b_1} + \phi)} P \quad (6)$$

$$P_{c_1} = \frac{\lambda_{c_1}}{(\mu_{c_1} + \phi)} P \quad (7)$$

$$P_{c_2} = \frac{\lambda_{c_1} \, . \, \lambda_{c_2}}{\mu_{c_2} .(\mu_{c_1} + \phi)} P \quad (8)$$

$$P_{(abc_2)com} = \frac{\phi \, . \, \lambda_{c_1}}{\omega \, .(\mu_{c_1} + \phi)} P \quad (9)$$

$$P_{(a_2b_2c_2)com} = \frac{\tau}{\eta} P \quad (10)$$

$$P_{d_1} = \frac{\lambda_{d_1}}{\mu_{d_1}} P \quad (11)$$

$$P_{d_2} = \frac{\lambda_{d_1} \, . \, \lambda_{d_2}}{\mu_{d_1} \, . \, \mu d_2} P \quad (12)$$

$$P_{e_2} = \frac{\lambda_{e_2}}{\mu_{e_2}} P \quad (13)$$

$$P_{f_1} = \frac{\lambda_{f_1}}{\mu_{f_1}} P \quad (14)$$

$$P_{f_2} = \frac{\lambda_{f_1} \, . \, \lambda_{f_2}}{\mu_{f_1} \, . \, \mu_{f_2}} P \quad (15)$$

$$P_{g_2} = \frac{\lambda_{g_2}}{\mu_{g_2}} P \quad (16)$$

$$P_{h_2} = \frac{\lambda_{h_2}}{\mu_{h_2}} P \quad (17)$$

$$P_{i_2} = \frac{\lambda_{i_2}}{\mu_{i_2}} P \quad (18)$$

$$\text{where,} \quad P = \left[1 + \frac{\lambda_{a_1}}{\mu_{a_1} + \phi} + \frac{\lambda_{a_1}\lambda_{a_2}}{\mu_{a_2}(\mu_{a_1} + \phi)} + \frac{\phi\lambda_{a_1}}{\omega(\mu_{a_1} + \phi)} + \frac{\lambda_{b_1}}{\mu_{b_1} + \phi} + \frac{\lambda_{b_1}\lambda_{b_2}}{\mu_{b_2}(\mu_{b_1} + \phi)} + \frac{\phi\lambda_{b_1}}{\omega(\mu_{b_1} + \phi)} + \frac{\lambda_{c_1}}{\mu_{c_1} + \phi} + \frac{\lambda_{c_1}\lambda_{c_2}}{\mu_{c_2}(\mu_{c_1} + \phi)} + \frac{\phi\lambda_{c_1}}{\omega(\mu_{c_1} + \phi)} + \frac{\tau}{\eta} + \frac{\lambda_{d_1}}{\mu_{d_1}} + \frac{\lambda_{d_1}\lambda_{d_2}}{\mu_{d_1}\mu_{d_2}} + \frac{\lambda_{e_2}}{\mu_{e_2}} + \frac{\lambda_{f_1}}{\mu_{f_1}} + \frac{\lambda_{f_1}\lambda_{f_2}}{\mu_{f_1}\mu_{f_2}} + \frac{\lambda_{g_2}}{\mu_{g_2}} + \frac{\lambda_{h_2}}{\mu_{h_2}} + \frac{\lambda_{i_2}}{\mu_{i_2}} \right]^{-1} \quad (19)$$

$$\textit{PID process in State G or R} = P + P_{a1} + P_{b1} + P_{c1} + P_{d1} + P_{f1} \quad (20)$$

Eq. (19) gives the steady state probability that the PID process is in state *G*, whereas Eq. (1), (4), (7), (11) and (14) constitute the steady state probability that the PID process is in state *R*. The various common-cause risk probabilities are given by Eq. (3), (6), (9) and (10). The complete risk probabilities of PID process are given by Eq. (2), (5), (8), (12), (13) and (15) to (18) and its steady state probability (PID process is in state G or R) is determined by Eq. (20).

TABLE III: RISK EVENT OCCURRENCE RATES OF VARIOUS RISK CATEGORIES OF PID PROCESS

	Components	Partial risk event occurrence rate (f/year)	Full risk event occurrence rate (f/year)	Partial risk event response rate (f/year)	Full risk event response rate (f/year)
a.	Market and Competition	1	1	52	52
b.	Strategy, Managerial and Organizational	0.5	1	52	34.67
c.	Financial	2	3	52	80
d.	Innovation	1	0.5	17.3	17.3
e.	Technology		1		13
f.	Design / Manuf. Related	2	3	17.3	17.3
g.	Supplier		2		26
h.	IP		0.5		26
i.	Legal and Compliance		0.5		26

IV. RESULTS AND DISCUSSION

Table III gives the risk event data for all the risk sources used in the assessment. Substituting these in the above equations (Eq. 1 to 20), the probability of PID process is risk free state can be estimated. The estimated probability of the PID process risk free is 0.6591; which means 65.91% of time that the PID process will operate without any risk. This innovative IR based clothe dryer would generate 55 million US dollars as new revenue for the organization (one dryer can be sold to customer at the price of $550 and the marketing function assured to sell 100000 units of dryer if the product is launched as per plan). Considering the estimated PID process failure probability of 0.3409, the estimated risk in revenue is equal to US$ 18,749,500.

Now the Markov model is used to study the effects of the risk event occurrence rates of various risk categories on the success of the PID process. Tables IV to VI and Fig. 3 to 5 show these effects. From Fig. 3, it follows that the Market and Competition risk event occurrence rate do not have considerable effect on PID process failure. From Fig. 4, it follows that the Financial do not have influence on PID process failure. This is due that response actions are very fast if that event occurs. From Fig. 5, it is apparent that the variations in the risk event occurrence rate of Technology has considerable influence on the PID process success. It is very clear that if any technology related risk event happens, it may take considerable time to implement any response actions which is drastically affecting the probability of success of PID process. Hence, it is necessary to prove the technology at the earlier stages of PID process to avoid those risks. This paper has demonstrated Markov model successfully for the estimation of the success probability of PID process. Any changes in the process steps can also easily be incorporated in the model and their effects can be analyzed. It is also possible to analyze the process when different development strategies and response policies are adopted.

TABLE IV: EFFECT OF MARKET AND COMPETITION RISK EVENT OCCURRENCE RATE ON PID PROCESS SUCCESS

Full risk event occurrence rate (f/year)	Success Prob. Of PID Process
1	0.6591
2	0.6589
3	0.6588
4	0.6587
5	0.6585
6	0.6583

TABLE V: EFFECT OF FINANCIAL RISK EVENT OCCURRENCE RATE ON PID PROCESS SUCCESS

Full risk event occurrence rate (f/year)	Success Prob. Of PID Process
3	0.6591
4	0.6589
5	0.6587
6	0.6585
7	0.6583
8	0.6581

TABLE VI: EFFECT OF TECHNOLOGY RISK EVENT OCCURRENCE RATE ON PID PROCESS SUCCESS

Full risk event occurrence rate (f/year)	Success Prob. Of PID Process
1	0.6591
2	0.6273
3	0.5984
4	0.5721
5	0.548
6	0.5258

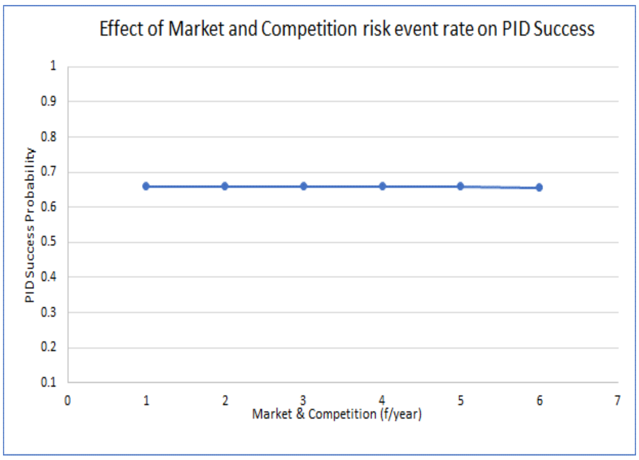

Fig. 3. Effect of market and competition event rate on PID success.

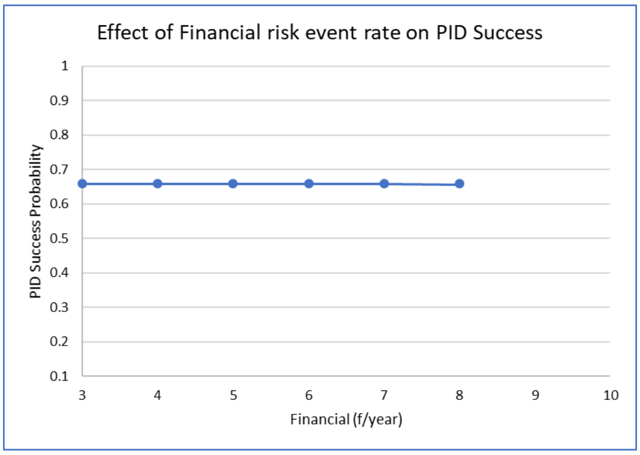

Fig. 4. Effect of financial event rate on PID success.

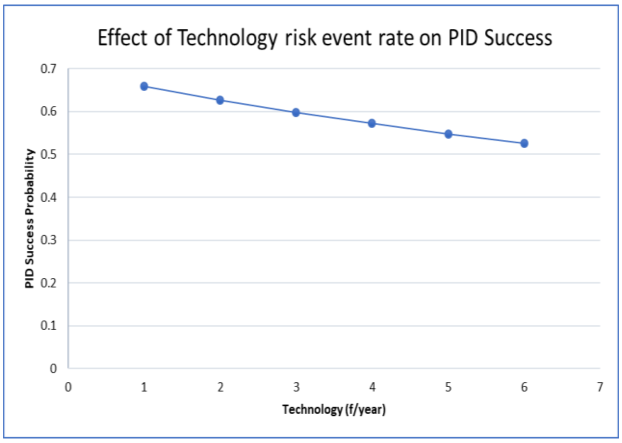

Fig. 5. Effect of technology event rate on PID success.

V. CONCLUSION

The Innovation FMEA combined with Markov process method for the IR clothes dryer generates proactive solutions for managing different sources of risks associated with product innovation and development effectively. Any company can also use these methodologies to find out their weaknesses in their PID process. This will help organizations to develop necessary learning and increase their innovation capabilities, which lead to innovation success. As the direction for further studies, one can explore the same methodology with other product development process and response strategies. The methods like Petri Net shall also be useful to bring modelling close to reality.

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