Management Science Letters 12 (2022) 165–176

Contents lists available at GrowingScience

Management Science Letters

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Assessment of risk propagation during different stages of new product development process

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C H R O N I C L E

Article history:
Received: November 2, 2021
Received in revised format: December 10 2021
Accepted: February 19, 2022
Available online: February 21, 2022

Keywords:
Risk Assessment
Risk Factors
Markov Process
Quality Function Deployment
New Product Design

A B S T R A C T

New Product Development Process (NPD) is a key aspect of launching new and innovative products in the market. Many products fail in the market because of technical risks, financial risks and product development time risks. It is very important to understand the overall risk factors associated with different stages of product development so that risks can be mitigated effectively. This paper presents a methodology to understand the risk associated with the initial stages of NPD. Design flexibility is higher in initial design stages requiring minimum redesign efforts and costs. It is a great opportunity to deal with risk factors and uncertainties in initial design stages than the later design stages. Product development costs in initial stages are around 5 to 10 percent but impact is 70 to 80 percent so exploration assessment in initial stages of NPD can be hugely beneficial. Stage-wise risk assessment will also provide the details of risk associated with each stage, which will be helpful in implementing appropriate mitigation strategies. Since transition from one stage to another stage of NPD is independent of the previous stage, different NPD stages can be easily expressed by the transition state of the Markov process. In this paper, the Markov process has been used for the risk assessment of initial stages of NPD, keeping mitigation strategies in mind. The three initial stages of NPD considered in this study include the concept design, detailed design and integration & testing stages. This paper also explores a method by integration of quality function deployment (QFD) and Markov process, to understand risk patterns associated with several complete design solutions (CFDs). By using QFD, the mapping between customer requirements can be reflected into risk assessment of complete design solutions (CFDs). This methodology has been demonstrated by a case study on Coffee Maker.

Nomenclature

μ_2= Transition rate from stage 1 to stage 2 by mitigation in case of partial risk

$\mu_{2'}$ = Transition rate from stage 2 to stage 3 by mitigation in case of partial risk

μ_1 = Transition rate from stage 1 to stage 2 by mitigation in case of no risk case

$\mu_{1'}$ = Transition from stage 2 to stage 3 by mitigation in case of no risk case

μ_3 = Transition from stage 1 to stage 2 by mitigation in case of complete risk

$\mu_{3'}$ = Transition from stage 2 to stage 3 by mitigation in case of complete risk

λ_2 = Transition from stage 2 to stage 1 in case of partial risk

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doi: 10.5267/j.msl.2022.2.003

$\lambda_{2'}$ = Transition from stage 3 to stage 2 in case of partial risk

λ_3 = Transition from stage 2 to stage 1 in case of complete risk

$\lambda_{3'}$ = Transition from stage 3 to stage 2 in case of complete risk

λ_1 = Transition from stage 2 to stage 1 in case of no risk

λ_1^2 = Transition from stage 3 to stage 2 in case of no risk

M =Represents the transition probability over one time interval

λ_w = Failure rate of k^{th} stage

μ_w = Repair rate of k^{th} stage.

1. Introduction

Product design (Yan & Shang, 2019) involves a high number of risk factors, making its evaluation and controlling a daunting task. Due to the complexities brought in by the presence of varying internal and external conditions and regional specificities, optimization of risk mitigation strategies of new product design and development (NPD) become essential (Kaplan et al., 2012). Risk management is more important for complex, international product design projects that involve a high degree of novel technology (Oehmen et al., 2010) significant efforts have been made to define the various levels of risk factors, as well as to develop mitigation strategies to reduce adverse consequences. Sicotte and Bourgault (2008) identified four relevant types of uncertainty: technical and project uncertainty, market uncertainty, fuzziness, and complexity. Lin et al. (2005) did the risk assessment for complex product design and proposed a new risk model which is based on Multi-Agent Systems. Martinez et al. (2020) reported a development of a failure mode, effects, and criticality analysis by the help of 3D risk assessment approach which was based on a questionnaire performed with three industry firms in medical device product development. Thangamani (2018) investigated the overall product development process and explored various risks, categorized them according to their sources, and assessed those risks by the help of the Markov process. Tsang et al. (2007) used deterministic sensitivity analysis and analysed the effect of variations in the product and feedstock prices, total production cost, fixed capital investment, and discount rate, among others, and its impact on the product design and development. Thangamani (2018) combined FMEA (Failure Modes and Effects Analysis) (Welborn, C2007) and Markov process analysis and presented it as the risk assessment method of the different stages of product design and development. Gargalo et al. (2016) conducted economic risk assessment of early stage designs for glycerol valorization. The focus of the QFD (Gotzamani et al., 2018) is on the early phase of new products/services design or redesign process; most of the input parameters are therefore highly subjective in nature (Kim et al., 2007). Based on the survey results of over 400 companies in the US and Japan, Cristiano et al. (Year) showed that the QFD analysis may only require a simple and practical decision aid based upon the experience and judgment of the team. This is mainly attributed to the fact that the QFD was born out of an industry need for ensuring design quality. Hence, the accuracy level of these subjective experience and judgment will significantly determine the quality of the QFD results (Kim et al., 2007). Raharjo et al. (2007) explained how Quality Function Deployment (QFD), as a customer-driven tool used in the early phase of new products design process. Park et al. (2011) used a fuzzy model, Markov process, and evolution strategy to predict risk factors that may occur while working on new product design and a systematic framework for risk management is proposed for handling risk factors, risk degrees, integrated risk degree, and responding activities. Yang and Chen (2014) used a fuzzy linear programming model to determine the optimal level of engineering characteristics and finally, used a software product design as a numerical example. Lin (2018) identified the features of wearable devices by analyzing the emotional adjectives and functional terms of the data to assist designers to launch appropriate products. Yang et al. (2019), proposed a method to forecast product development time which is based on the combination of kernel-based regression and Gaussian margin machines (GMM). There are several examples of risk assessment of important engineering systems by different methods. Ullah et al. (2021) proposed a method using Game theory for modeling utility functions for the firms, considering uncertain demand, risk attitude, and different options for warranty and maintenance service strategies. For example, Fattahi et al. (2021) conducted the review of risk assessment of transportation of hazardous materials which is one of the most critical issues in transportation planning that involves multiple risks to the physical and social environments. Although the Markov process has been applied in different fields of management and engineering, for example: Zhou et al. (2021) applied the Markov process to analyze the degree of efficiency loss because of interference between operators and machines in Machines. Yahaya et al. (2021) performed the evaluation of various performance measures through Markov chains and also explained how adoption of the optimal charting parameters results in a large deterioration on the actual performance, especially for small shifts, a small number of subgroups, by incorrect assumptions of process parameters. Similarly, the Markov process can also be applied to do the risk assessment of new product development processes.

From our literature survey, we have seen that though the risk assessment of the entire product design and development process as a whole was done by different methods, there is scarcity of methodologies that can handle stage-wise risk assessment of NPD. In this paper, risk assessment of initial stages of NPD has been conducted by integrating Quality Function Deployment (QFD) and Markov process. NPD has several stages and each of these stages consist of many associated risk factors. From concept design to final product development, design realization reduces continuously because of the associated risk factors.

Transition from initial stage to final stage requires much resources and time, so the reliability of transition from one stage to another stage needs to be improved by mitigating risk factors. There is a need for proper understanding of risk factors associated with each stage of product design to mitigate the risk factors.. The risk factors of each stage separately in order to increase the reliability of transition of product from one stage to another stage of product design.. Since approximately 70% of product cost and 80% of product quality are determined during the design phase, concept design is a critical concern for developers. It is important to understand associated risks as early as the initial design stages so that appropriate mitigation strategies can still be applied to reduce the risk associated. Risk assessment in early stages can also be helpful in reducing the number of iterations and reaching the budget limit. Since, the transition from one stage to another stage is independent of the previous stage, they can be expressed as the transition states of the Markov process. Therefore, in this study, the Markov process has been used to analyze the risk factors and mitigation strategies of different initial stages of NPD (Kumar & Tandon, 2017).

2. Different Initial Stages of NPD

New product development process (NPD) is taking a product or service from conception to market. The process sets out a series of stages that new products typically go through, beginning with idea and concept generation, and ending with the product's introduction to the market. The NPD process generally involves six key stages which are Strategic analysis, Concept Design, Detailed Design, Integration & Testing, Product development & testing, Market testing, Commercialization and Product Launch. In this study, we will be focusing on the initial three design stages, for methodology illustration purposes. It is to be noted that the methodology is not limited to initial stages and it can be extended to entire NPD stages.

2.1 Concept Design

In this stage, the core ideas which drive the design of a product are generated by the help of experts using brainstorming or other methods. This stage includes identification of innovation/technologies, their trajectory in terms of performance and potential for adoption, along with major opportunities and limiting factors. This stage plays an important role because all other stages completely depend upon this stage. In this study, this stage has been further divided into following different intra stages:

2.1.1 Customer Requirements to Design Characteristics Mapping

In this stage, after defining the customer requirements (CR), as per their respective weights, it is translated into design characteristics (DC) by the Quality Function deployment method (QFD). Its weight of importance is obtained by how well it satisfies customer needs and requirements. Suppose that engineers have identified k requirements to reflect the needs of customers. Let R = {R1, R2… Ri… Rk} be the set of k customers' high weightage requirements. Let D= {DC1, DC2… DCj… DCl} be the set of design characteristics of the product. Then, a correlation matrix can be created to reflect the mapping between CR and DC. Let RDC = [RDCij] be the correlation matrix between R and DC, where DCij indicates the strength of the jth design characteristics (Dj) towards the satisfaction of the ith customer requirement (Ri). These matrices have three levels of correlation strengths: weak (= 1), medium (= 3) and strong (= 9), and these levels are set based on the traditional practice in QFD. The matrix entries will be left blank for the absence of correlation.

2.1.2 Design Solution Evaluation

In this stage, different sets of design solutions are generated. For each design characteristic of the product, there are certain sets of design solutions. Design solutions with respect to a design characteristic can be obtained from discussions with product domain experts and historical/experiential data. For every customer requirement there is either need to change the design or need to incorporate new design elements, therefore there may be multiple sets of design solutions for each customer requirement.

2.1.3 Selection of Complete Design Solutions

Different complete design solutions (CDS) can be synthesized by combining these possible design solutions. Out of several complete design solutions, there is a need to select the proper complete design solution according to the technical, product development time, product development costs and other risk factors associated. In this study, propagation of risk in the entire NPD has been estimated by the help of the Markov process. Markov-process has also been applied on the CDSs to understand the transition of different risk through the stages of NPD.

2.2 Detailed Design

In this stage, it is ensured that the overall design solution satisfies the project objective. It is performed through analysis of dimensions, tolerance, material choices and other quantitative analysis. Sometimes, a mini-implementation can also help to evaluate innovative and new technologies. In this study, risk analysis of transition from concept design to detail design has been done by help of the Markov process. The risk assessment checks if the risk factors are within the permissible limits, which is shown by the stage gate 2 in the flowchart (refer to Fig. 1).

2.3 Integration & Testing

The purpose of this stage of testing is to expose defects in the interaction between the different components when they are integrated. Sometimes, integration between different components is not easy because of dimensions, tolerances and other engineering specifications. To increase the probability of this stage, risk assessment of transition from detailed design to integration & testing has been done. Here again, the risk assessment checks if the risk factors are within the permissible limits, which is shown by the stage gate 3 in the flowchart (refer to Fig. 1).

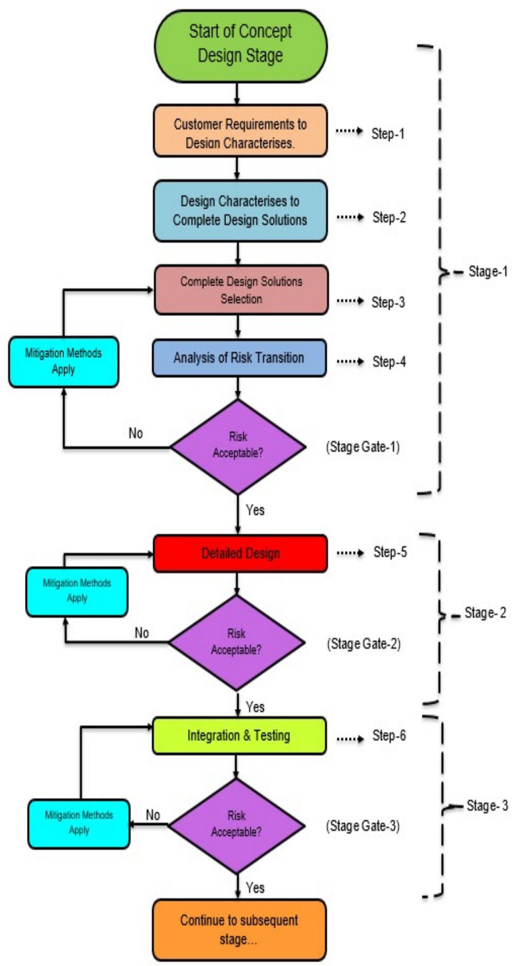

Fig.1. Flowchart of the methodology

3. Methodology

The first three stages of NPD have been selected to focus on in this study. Proper methodology is illustrated in detail and described below in a stepwise fashion.

Step 1: Customer requirements will be mapped with design characteristics (DC) using the three levels of correlations as discussed in section 2.1.1.

Step 2: DC will be mapped with different possible complete design solutions using the same three levels of correlations as discussed in section 2.1.1.

Step 3: The complete design solutions (CDS) having high correlation with the relative customer requirements and design characteristics weightage will be selected for the risk assessment.

Step 4: Risk assessment of each CDS will be done by understanding the pattern of transition of different risk through the entire NPD stages. Every NPD stage has its acceptable limit for risk factors. Until the risk factors become acceptable as provided by company management based on prior historical data and/or prior experience, changes or modifications in the design will continue.

Step 5: Risk assessment of the transition from concept design to detailed design has been done by the Markov process. For the risk assessment transition to the subsequent stage has been considered under three risk conditions. Transition under no risk, transition under partial risk and transition under complete risk, are the three conditions which have been considered in this study. If the risk factors are beyond the acceptable limit then mitigation strategies will be applied, which is shown by stage gate 2 in the Fig. 1.

Step 6: Risk assessment of the transition from detailed design to integration & testing has been done by the same method as discussed in step 5. If the risk factors are beyond the acceptable limit then mitigation strategies will be applied, which is shown by stage gate 3 in the Fig. 1.

In this study, risk assessment of the first three stages has been done, which can be further extended for the rest of the NPD stages.

3.1 Mathematical Modeling of Design Concept Selection

The transition of risk factors in NPD depends on many parameters and each transition is independent from its previous stages. That's why the Markov method is the best method to analyze the risk factors associated with the concept design stage. For applying the Markov process, the construction of the state process and determining the state probability matrix is the initial process. The state probability refers to the possibility of emergence of a variety of risk factors. Using the state transition probability, we have the initial probability of failure as the initial state vector. Probability on the j th stage is calculated by P (j) = (j-1) *P; j = 0, 1, 2… The probability of subsequently transitioning to condition state Xj at some point in time depends only on its last observed condition. If, for example, three primary condition states are defined (C_1 –no risk, C_2 – Partial risk, C_3 –Complete risk), then the expected state of the component at the next state depends only on its most recent previously observed state. Thus, if M is the transition matrix that defines the transition probabilities for a single time interval. If So = [0 1 0] represented a risk condition in the and M represents the transition probability over one time interval, then the current condition state which is 2 time intervals from the last state, to be given by

$$[So \times M] \times M = So \times M^2. \tag{1}$$

3.2 Mathematical Modeling of First Three Design Stages

Propagation of risk factors through the NPD stages can be analyzed by the Markov process. If the risk factors are beyond the permissible limit then that can also be controlled by applying different mitigation strategies. Due to different risks, transition probability from one stage to another stage of NPD reduces, which can be further increased by

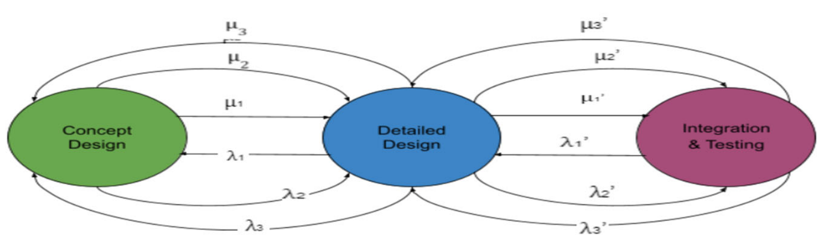

Fig. 2. Transition diagram of initial stages of new product design.

Applying different mitigation strategies. In this study, the effect of mitigation strategies on transition probability has been analysed by the Markov process. For transition from one stage to another stage transition diagram is shown in figure 1. Transition from one stage to another stage has been considered under three cases. Case 1: Transition under no risk. Case 2: Transition under partial risk and Case 3: Transition under complete risks. The stage transitions from time t to ($t + \Delta t$) will then be governed by the following equations.

$$P_0(t+\Delta t) = P_0(t)[1-\lambda_0 \Delta t] \quad + p_1(t)\mu_1 \Delta t \tag{2}$$

$$P_k(t+\Delta t) = P_k(t)[1-(\lambda_k+\mu_k)\Delta t] + P_{k-1}(t)\lambda_{k-1}\Delta t + P_{k+1}(t)\mu_{k+1}\Delta t \tag{3}$$

$$\sum_{k=0}^{\infty} \quad P_k(t) = 1, \Delta t \to 0 \tag{4}$$

$$\frac{dp_0(t)}{dt} = \lambda_0 P_0(t) + \mu_1 P_1(t)$$
$$\frac{dp_k(t)}{dt} = -(\lambda_k + \mu_k)P_k(t) + \lambda_{k-1}P_{k-1}(t) + \mu_{k+1}P_{k+1}(t) \quad (5)$$
$$\sum_{k=0}^{\infty} P_K(t) = 1 \quad (6)$$

Obtaining the equilibrium solutions by setting $\frac{dp_i(t)}{dt} = 0 \ \ \forall i$ and obtaining the state distribution $p_i \ \ \forall i$ such that the normalization condition

$$\sum_{i=0}^{\infty} p_i = 1 \quad (7)$$

is satisfied. This yields the following equations to be solved for the state probabilities under equilibrium conditions

$$\lambda_0 P_0 = \mu_1 P_1 \quad (8)$$
$$\lambda_{k-1}p_{k-1} + \mu_{k+1}P_{k+1} = (\lambda_k + \mu_k)P_k \quad (\ k = 1,2,3,\dots\dots\dots\dots,) \quad (9)$$
$$\sum_{i=0}^{\infty} p_i = 1 \quad (10)$$

Product from Solution is

$$p_k = p_0\left[\prod_{i=0}^{k-1} \frac{\lambda_i}{\mu_{i+1}}\right] \quad (11)$$
$$p_0 = \frac{1}{1 + \sum_{k=1}^{\infty} \prod_{i=0}^{k-1} \frac{\lambda_i}{\mu_{i+1}}} \quad (12)$$

Let the probability of stage 1 is$S1$. Then the transition probabilities due to risk factors can be found by the above equations under the assumption that transition from any stage is possible only to the next higher stage or next lower stage. Based on the above Chapman-Kolmogorov equation if the probability of stage '1' is P_1, then probably of other stages under partial risk, no risk and complete risk are as follows:

Probably of stage 2 under partial risk= $\left(\frac{\mu_2}{\lambda_2}\right)P_1$ (12)

Probably of stage 3 under partial risk = $\left(\frac{\mu_2}{\lambda_2}\right)\left(\frac{\mu_{2\prime}}{\lambda_{2\prime}}\right)P_1$ (13)

Probably of stage 2 under no risk = $\left(\frac{\mu_1}{\lambda_1}\right) P_1$ (14)

Probably of stage 3 under no risk =$\left(\frac{\mu_1}{\lambda_1}\right) \left(\frac{\mu_{1\prime}}{\lambda_{1\prime}}\right) P_1$ (15)

Probably of stage 2 under complete risk = $\left(\frac{\mu_3}{\lambda_3}\right) P_1$ (16)

Probably of stage 3 under complete risk= $\left(\frac{\mu_3}{\lambda_3}\right) \left(\frac{\mu_{3\prime}}{\lambda_{3\prime}}\right) P1$ (17)

4. Case Study of New Product Design of Coffee Maker

To illustrate the implementation of this study, a new product design of coffee maker has been used as a case study. Jinjuan at el. (2009), Rooden at el. (1999) and Wang et al. (2018) have illustrated customer requirements, design characteristics and design functions in their studies, which have been liberally used in this paper. Customer requirements have been also illustrated from customer feedback on Amazon, Flipkart and other online selling platforms. In this study, the customer requirements are mapped to the design characteristics as shown in Table 1. Next, the design characteristics (DC) are mapped to a set of design solutions in Table 2. For example, DC1 (Add Heat effectively) is possible by the design solutions which can be helpful in adding heat with minimum loss to the surroundings. Each DC has certain design functions which can be achieved by multiple solutions. For example, to reduce maintenance, there are three or more options (disposable filter, removable permanent filet and removable cap.) Out of these options, disposable filters are cost effective but it requires comparatively more development time. For each DC, there are different possible sets of design solutions. Different complete design solutions can be synthesized by combining these possible design solutions, which are also shown in Table 2. Designers can select several sets of complete design solutions as per the customer requirements. In Table 3, all DC has been mapped with several complete design solutions. To understand the propagation of risk factors in complete design solutions, the Markov process has been applied. In this study, three risk factors are taken into consideration for analyzing the propagation through different

NPD stages. The stage transition probability of different risk factors has been calculated in Table 4, by the previous studies on the similar type of design products and calculating the average value of risk factors associated. The probability of different risk factors in initial NPD stages, associated with selected complete design solutions are tabulated in Table 5. There are few risk factors which may be difficult to predict in the concept design stage, therefore those risk factors should be mitigated during transition from one stage to another stage. In this study, mitigation has been applied to only technical risk, product development cost. Risk and product development time risk. Same method can be applied for other risk factors as well. It will further increase the transition probability from one stage to another stage. The Markov process has been again applied between the initial three stages in case of NPD of coffee maker to mitigate the risks between different stages.. Unmitigated risk has been calculated by the help of the product of probability rating of and its severity impact in Table 6. Mitigation rate for each risk factor is assumed to be 5 for the risk assessment. For each case, the probability of transition from stage 1 to stage 2 and stage 2 to stage 3 has been calculated in Table 6 using Eq. (1) to Eq. (9). From Table, the probability of transition from one stage to another design stage in all three cases has been calculated. Probability of stage 1 has been assumed to be 0.5.

Table 1
Customer Requirements to Design Characteristics Mapping

Customer Requirements (CR_i)	Relative Weight of Importance of CR(C_i)	Design Characteristics (DC)					
		Add Heat Effectively ($DC1$)	Easy to control ($DC2$)	Reduce Maintenance ($DC3$)	Seal Components ($DC4$)	Disperse Water ($DC5$)	Simplify Housing ($DC6$)
Safe operation	5	9	9	9	1	1	
Durability	5		3	1	9	9	
Simplify Use	3		9	3	1	3	1
Less Noise	5	3	9		3		
Reduced Brew	3		1			9	
Less Maintenance	5			1	1	1	
Sealed Components	3	3				1	
Appearance	3					1	9
Transportability	5	1	3	1	3		
Relative Weight % of DC		20	40.7	20.9	26.7	25.5	8.15

Table 2
Different set of design solutions and complete design solutions for concept design stage

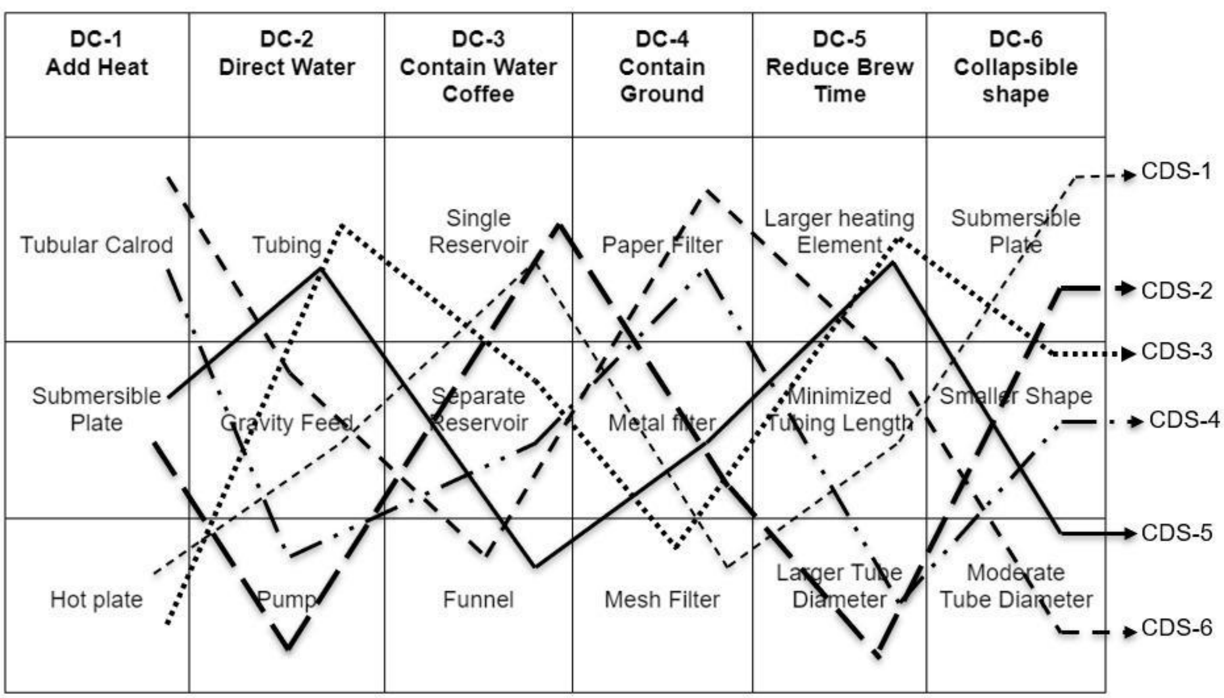

Table 3
Design characteristics to complete design solutions mapping

	Relative weight %	CDS1	CDS2	CDS3	CDS4	CDS5	CDS6
DC1	20	9	3	3			3
DC2	40.7	1	9	1	9		
DC3	20.9	1	3	9	3	9	9
DC4	26.7	3	3	9	9	3	9
DC5	25.5	1	`1	1	1	3	1
DC6	8.15	9	9	3		3	1
Relative Weight of importance of DC		12.7	19.1	17.4	21	11	15.7

Table 4
Initial stage transition probability Matrix (P) of risks factors during NPD concept design stage

		No risk	Partial Risk	Complete Risk
Technical Risk	No risk	0	0.56	0.44
	Partial Risk	0.25	0.46	0.28
	Complete Risk	0.20	0.54	0.26
Product development Time	No risk	0.18	0.5	0.32
	Partial Risk	0.15	0.62	0.23
	Complete Risk	0.25	0.35	0.4
Product Development Cost	No risk	0.5	0.2	0.3
	Partial Risk	0.65	0	0.35
	Complete Risk	0.6	0.2	0.2

5. Results and Discussion

The first and very important stage of the NPD is the concept design stage which is discussed in section 3.1. In the case of Coffee Maker, NPD starts with mapping customer requirements with design characteristics. In Table 1, the mapping of customer requirements to different design characteristics was performed. From Table 1, design characteristics can be arranged from high priority to low priority as per the customer requirements. DC 2 has the highest relative weightage of 40.7. For each design characteristic, various possible solutions have been proposed in Table 2. From Table 2, the designers can select any one option with respect to each DC. Thus, the designers can choose from multiple options for a complete design solution (CDS). To synthesize a complete design solution, one possible solution is picked for each DC. For example, DC1 (add heat effectively) has three solutions, out of which any one can be selected for each complete design solution. To synthesize a complete design solution, we need one solution for each DC. By this way total six complete design solutions have been generated, which is shown in Table 2. Relative weightage of CDS1, CDS2, CDS3, CDS4, CDS5 and CDS6 are respectively 12.7, 19.1, 17.4, 21, 11 and 15.7 respectively from Table 3. CDS 4 has relative weightage of 21, which is highest, whereas, CDS 5 has the relative weightage of 11, which is lowest. Out of multiple complete design solutions, the top three or four as per their relative weightage can be selected (set-based design) for risk assessment because they have relatively high correlation with customer requirements. Risk factors in subsequent stages at different intervals of time are independent from the previous stage. Therefore, to analyze the trend of risks associated with these CDSs, the Markov process has been applied. In this study, the investigation of risk trends has been conducted for only one complete design solution. A similar method can be applied for the other complete design solutions. The Markov process has three elements: a set of states, the transition probability matrix (TPM), and the initial state probability. The determination of the state transition probability matrix is the initial process for applying the Markov process as discussed in section 3.1. Transition probability can be determined by the help of historical data and project experts. The initial state probability is obtained in Table 4. The set of states is defined as a range of frequencies for a given risk factor recognized in past projects. Transition probability between states is computed in a Markov chain, therefore the number of transitions between states must be normalized to convert the total sum of probabilities in each row to 1. By the help of the Markov process, multiplying transition probabilities with state probability, the transition trends of three different risks associated with these CDSs has been calculated in Table 5. In this study, transition of risk has been investigated only in CDS4, because it has the highest relative weightage of customer requirements and design characteristics. Similarly, this method can be applied for the investigation of other completed design solutions. For CDS4, there is a 52% chance that technical risk will be in partial condition in stage 2 and stage 3 of NPD. Similarly, there is an approximately 55% chance that product development time risk will be in partial condition in stage 2 and stage 3 for CDS4. Similarly, for CSD2 and CDS3, the probability of risk factors in different stages can be determined by this method. Every NPD stage has an acceptable value of risk factors, which is determined by the management as per their requirement of the project. Using the method proposed in this paper, the best design solution and permissible risk factors according to the requirement can be selected. Any changes in the process steps can also easily be incorporated in the model and their effects can be analyzed.

Table 5
Probability of different risk factors in initial NPD stages

	Initial vector S (0)	Stage 1 Vector M (1)=S(0)*P [Concept Design]	Stage 2 Vector M (2)=M(1)*P [Detailed Design]	Stage 3 Vector M (3)=M(2)*P [Integration & Testing]
Technical Risk	[0,1,0]	[0.25, 0.46, 0.28]	[0.18, 0.52, 0.32]	[0.18, 0.52, 0.32]
Product development Time	[0,0,1]	[0.16, 0.64, 0.20]	[0.17, 0.55, 0.27]	[0.18, 0.56, 0.28]
Product Development Cost	[1,0,0]	[0.58, 0.09, 0.26]	[0.55, 0.08, 0.38]	[0.58, 0.08, 0.34]

Many complete design solutions have the highest correlation with customer requirements and relatively high risk factors. In the case of many NPD projects, customer requirements play a very crucial role. In such cases, stage-wise mitigation strategies can be applied to reduce the risk factors. In this study, the Markov model is again applied to study the probability of transition from one stage to another stage keeping mitigation strategies in mind. Table 5 shows the effect of mitigation and transition probability in three different cases (no risk, partial risk and complete risk). Considering the initial probability in stage 1 as 0.5, the probability of transition from one stage to another stage is calculated in Table 6. For calculating the transition probabilities, first unmitigated risk has been calculated by multiplying probability rating of risks with its severity impact. Probability rating is ranked on a five point scale: Frequent - 5: Likely to occur often in the life of an item, Probable - 4: Will occur several times in the life of an item, Occasional - 3: Likely to occur sometime in the life of an item. Remote - 2: Unlikely but possible to occur in the life of an item. Improbable - 1: So unlikely, it can be assumed an occurrence may not be experienced. Similarly, the severity impact has been calculated by the average of all possible magnitude of impacts of risks. The unmitigated risk has been calculated in Table 6 by multiplying the probability rating and severity impact. Transition from one stage to another is considered through three different cases. In this study, the rate of mitigation is assumed to be 5 for all the three cases. From Table 6, the probability of transition from stage 1 to stage 2 in case of product development time risk is lowest, which is 0.437 and the same is highest for financial risk, which is 0.907. Transition probability under technical risk factor can be increased further by increasing the mitigation rate. By this way, this paper has demonstrated the Markov model successfully for the estimation of success probability of stages of NPD process keeping mitigation strategies in mind.

Table 6
Risk associated with transition in initial stages

Risk	Probability Rating	Severity Impact	Unmitigated Risk	Mitigation Rate	Transition Probability from Stage 1 to Stage 2	Transition Probability from Stage 2 to Stage 3
Technical	2.9	1.83	5.307	5	0.471	0.438
Product development Time	3.3	1.73	5.709	5	0.437	0.383
Product Development Cost	1.8	1.53	2.754	5	0.907	1

7. Conclusions and Future Work

In this study, risk assessment of initial stages of product design has been done by the help of the Markov process and it has been proved that different risk factors have different effects on the transition from one stage to another stage of NPD. It has been demostrated in this paper that designers can deal with different risk factors and uncertainties, by selecting appropriate complete design solutions in the concept design stage (first stage) of NPD. This will be very helpful in using several new innovations in the concept design stage and understanding its effect during the entire stages of NPD. Designers will be able to select proper complete design solutions as per the available resources and permissible risk, so that NPD can be completed successfully. Sometimes the priority on product development time is high but there may be more allowances on funds. So accordingly, design solutions with lower product development time can be selected even thoght they may result in slightly higher product development cost. Thus, in the concept design stage, design concepts with unacceptable risk factors can either be rejected or modification in design can be made so that the associated risk factors can be reduced further. For each stage, the optimum mitigation strategies can be estimated so that all the risks can be reduced if it crosses the permissible thresholds. In this study, the mitigation rate has been assumed to be 5. In future research, response rate for each kind of risk can be estimated and represented as a quantitative form so that more realistic calculations regarding transition of risk factors can be done for each stage of NPD. In this study only the first three stages have been taken into consideration for risk assessment. There are several risks which are dependent on each other so mitigation strategies of one risk factor can create a negative or positive impact on the other dependent risk factors. To make this assessment more effective, interdependencies among different risk factors should be explored in future, so that its effect on the overall product design can be analyzed by decision makers. There are many risks which can affect product design of multiple organizations simultaneously so the risk variation recognition can be further extended to develop a conceptual framework that can deal with product design at inter-organizational level so that they can handle diverse risk by collaboration.

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