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Strengthening Risk Evaluation in Existing Risk Diagnosis Method

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Abstract. An existing risk diagnosing methodology (RDM) diagnoses corporate risk for product-innovation projects. However, it cannot evaluate and compare the risk levels of multiple alternatives in the product development stage. This paper proposes a modified risk diagnosis method to fill the gap of risk evaluation in selections of innovative product alternatives and the application of the method will be also illustrated by a case problem on alternative selections in electrical dimmer designs. With RDM as the foundation, a modified RDM (MRDM) is proposed to deal with the problem of selecting innovative project alternatives during the early stages of product development. The Bayesian network; a probabilistic graphical model, is adopted to support the risk pre-assessment stage in the MRDM. The MRDM is proposed by incorporating the risk pre-assessment stage into the foundation. By evaluating the engineering design risks in two electrical dimmer switches, an application of the MRDM in product innovation development is successfully exemplified. This paper strengthens the existing methodology for RDM in innovative product development projects to accommodate innovative alternatives. It is advantageous for companies to identify and measure the risks associated in product development so as to plan for appropriate risk mitigation strategies.

Keywords: Risk Diagnosis Methodology, Product Innovation, Product Development, Phase of Product Development, Bayesian Network

1. INTRODUCTION

In today's challenging business environment, competitive advantages can be sustained and gained by developing and launching successful innovative products (Lee, 2008). Regardless whether product innovation is incremental or radical, it has been classified as a relatively risky activity in a company (Van de Ven *et al*., 1999) due to its organizational exploration concepts, which require search for new knowledge, application of uncommon technologies or prediction of uncertain customer demands. The explorative nature of product innovation also distinguishes product innovation from ordinary product development which is closely related to existing product knowhow for deployment to other applications (Greve, 2007). With higher expectations on returns, the innovation process usually involves higher financial investment, but often with uncertainties (Caputo *et al*., 2002).

Scholars have pointed out that risks throughout the project development process are often handled subjectively by management perception in many organizations (Griffin, 1997; Calantone *et al*., 1999; Cooper, 2006; Dey *et al*., 2007). Undesirable project outcomes, e.g., delay of delivery, extra life cycle cost incurred, selection of inappropriate projects, etc., are the consequences of such subjective and unsystematic handling styles (Mullins and Sutherland, 1998; Caputo and Pelagagge, 2008).

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The situation will be more severe when it is a case of relatively risky product innovation. Risk diagnosis methods for product innovation were proposed in the past (Halman and Keizer, 1994; Keizer *et al*., 2005; Loch *et al*., 2006), however, the methods do not include risk evaluation of selecting product alternatives. Meanwhile, studies on risk measurement were carried out so that a more enhanced accuracy of the decision-making process in the uncertain product development process can be found (Buyukozkan and Feyzioglu, 2004; Chin *et al*., 2008; Chin *et al*., 2009a).

In light of existing risk management studies in product innovation, a MRDM that covers the pre-assessment of alternatives in innovative product development projects during the early stages of product development, is proposed. It is believed that the proposed method will be advantageous to enterprises for the measurement and evaluation of associated risks in innovative product alternatives so as to aid managerial decisions in developing appropriate strategies and responses in the latter part of product development stages. As a result, companies are able to manage, reduce and avoid risks by evaluation decisions (Smith, 1999; Ozer, 2001).

This paper will be divided into three major parts in the following sections. First, relevant literature on the risks of product innovation, risk factors from innovation, existing RDM, the development of literature and project motivations will be addressed in Sections 2 and 3. Second, the proposed risk analysis techniques will be presented in Section 4. Third, a case study on engineering design decisions on dimmer switches will be used to exemplify and conclude the application of the proposed method in Sections 5 and 6.

2. REVIEW OF LITERATURE

2.1 Risk of Product Innovation

Risk is an inherent part of business as well as public life (Tchankova, 2002). It is due to uncertainty, i.e., a lack of complete data and information, and uncontrollable outcomes. The likelihood of occurrence of an event, the impact on the course of action and the potential consequences are usually considered when risks are evaluated in a project (Halman and Keizer, 1994). Risk management is the process of understanding potential risks and making positive plans to mitigate, eliminate or take advantage of them (CIMA's Fraud and Risk Management Working Group, 2002; Shaw *et al*., 2005). It can be achieved by a three-step process that includes the identification of uncertainties, measurement of uncertainties and optimization (Focardi and Jonas, 1998).

Nowadays, customer demands have become increasingly more challenging. Technological and administrative challenges in product innovation are driven by customer needs for new product features (Ettlie, 2000). Product innovation refers to the implementation of new methods, systems, mechanisms, styles and equipment that change or improve the way that end products are offered (Cooper, 1998). The scope of product innovation does not only focus narrowly on totally new product for the industry; the provision of new product insights to a firm can also be regarded as product innovation (Lee and O'Connor, 2003).

Product innovation is a risky activity in an enterprise (More, 1985; Halman and Keizer, 1994; Keizer and Halman, 2007) due to the possibility of occurrence of unexpected and uncontrollable events (Caputo *et al*., 2002). Usually, the innovation process involves substantial financial investment. Risks in an innovation project may come from any stage in product development which can be categorized into concept development, product planning, detailed design and development, commercial preparation and market introduction (Wheelwright and Clark, 1992). Due to the risky nature of product innovation, scholars have suggested that a systematic risk-assessment should be conducted throughout the product development process in order to enhance the chances of success of breakthrough innovation projects (Keizer *et al*., 2005).

2.2 Risk Factors of Innovation

The risks of product innovation may come from incomplete information and changes in market and technology throughout the product innovation process (McDer-mott and O'Connor, 2002). For instance, when a product is launched into the market, the project manager may find difficulties in obtaining customer acceptance as market situations may change after the product design is fixed in the early stages of new product development (NPD). As discussed in Gilbert (1996), risk factors of innovation come from the novelty of the product, novelty of the system technology, demand for speedy development, phase-in of the new system, contingency cushions, degree of user-system interface and internal management issues in project commitment. This becomes more complete if the ideas of Halman and Keizer (1994) can be integrated into the discussion who suggested that in product innovation projects, risk factors can be categorized into technological, organizational and commercial aspects. When considering the risk factors of a product innovation project, the technological gaps between existing and expected technology know-how should be evaluated (Halman and Keizer, 1994). Also, the breaks between organizational and commercial issues in terms of skills and experiences on project management, supply chain and sourcing should be considered (Keizer *et al*., 2005). Generally speaking, the variables associated are highly dependent on specific project conditions in an enterprise. Therefore, relevant variables for assessing the risks in a project should be designed based on project requirements and actual company situation.

2.3 Risk Diagnosis Method (RDM) in Product-Innovation Projects

This paper aims to supplement the scope of RDM, which was first introduced in 1994, to identify and evaluate technological, organizational and business risks in innovative product development projects (Halman and Keizer, 1994). RDM was further developed in 2002 and is now a developed methodology in diagnosing innovation projects so as to formulate suitable risk management strategies for the subject area. RDMs highlight risk issues, such as consumer acceptance, manufacturability, etc. Furthermore, RDM is widely applied in various industries worldwide, including Germany, Italy, Belgium, and the USA (Keizer *et al*., 2002). According to the RDM, three major phases will be necessary to conduct a risk diagnosis in business, including risk identification, assessment, and response development and control, as shown in Figure 1. It is found that RDM is helpful in the diagnosis of project risks, stimulation of creative solutions as well as strengthening of project team congruence.

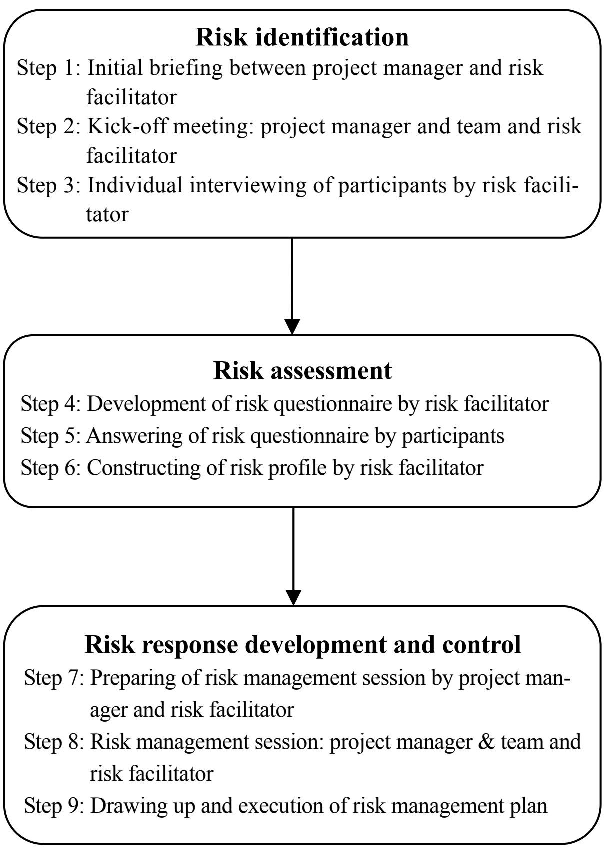


Figure 1. Outline of RDM (Keizer *et al*., 2002).

Existing RDM pinpoints its application into the end of the feasibility phase which does not specify the key milestones of product development that should be achieved. The use of RDM in the feasibility phase is applicable within the stages of conceptual design, and detailed design and development. In a product development environment, design specifications may project different possible product solutions. It is an iterative process to reevaluate possible product solutions when project status becomes more certain. Meanwhile, due to the explorative nature of product innovation, project team members often generate more than one possible solution to tackle the project problem. Although RDM provides a good methodology for overall corporate risk diagnosis, it has not specifically addressed how to compare and measure the risk levels of project alternatives. Hence, there is a need to enhance the RDM in order to quantify alternative priorities in the product development period. A MRDM is thus proposed in this paper to deal with the selection problem of project alternatives in the early stages of product development.

2.4 Recent Development

The risk reference framework (RRF); a structured and systematic scheme, was introduced in 2005 to supplement the risk identification process of the RDM (Keizer *et al*., 2005) as it helps people to integrate information intuitively. RRF not only focuses on potential failures in the technology domain, it also emphasizes the organizational and market-related risks. Aside from that, it is a reliable data gathering procedure which is able to reduce the inter-social influence of individuals than traditional vulnerable brainstorming techniques.

A study conducted by Keizer and Halman in 2007 further reinforces the reasoning of risk identification. The dimensions of risk factors in an innovation project risk diagnosis have been further unveiled. Other than the traditional unambiguous risks that concern product performance to specification, supplier relationships and custommer demands, companies should be aware of the potential ambiguous risks that relate to the coordination of internal organization and project management (Keizer and Halman, 2007). Although a robust foundation of the risk identification process in innovation projects is recommended for risk assessment to be conducted in a more comprehensive manner, the research gap in the risk diagnosis method in alternative selection is not yet addressed and the existing literature still cannot accommodate the needs to evaluate alternative solutions in innovation projects.

2.5 Research Motivations

It is agreed that the accomplishment of product development milestones could be influenced if the associated risks are not managed properly. Current research has addressed the critical factors of NPD, but few have paid much attention to the illustration of risk-based evaluation in the innovative product development process. Risk-based innovative project evaluation remains vague in many areas (Keizer *et al*., 2005). Although the provision of a methodology by RDM for corporate risk diagnosis in product-innovation projects has been addressed, the risk assessment should be conducted when a comprehensive risk situation on the product is found. As well, it cannot evaluate and compare risk levels for multiple alternatives in a project problem within the product development stage. As the existing methodology is lacking, this paper attempts to propose a MRDM to fill the gap of risk evaluation in the selection of product innovation alternatives and the application of the method will also be illustrated by a case problem on alternative selections for electrical dimmer designs.

3. RISK ANALYSIS TECHNIQUES IN PRODUCT INNOVATION

3.1 Risk Analysis Techniques

In a behavioral model, potential problem analysis (PPA), failure mode and effects analysis (FMEA), technique for order preference by similarity to ideal solution (TOPSIS), analytical hierarchy process (AHP), and analytical network process (ANP), are some well developed risk analysis techniques. However, these techniques are not applicable to every practical risk project as each case may have their own situations. One of the arguments on the application of such techniques is that these tools may be either too preliminary or too structured when applied in practical risk-based subjective decision problems.

For instance, behavior models (Mullins and Sutherland, 1998; Leithhead, 2000, Mobey and Parker, 2002) can neither accommodate complex decision making nor analyze uncertainties quantitatively. An FMEA can only indicate the average of performance in a single score and is unable to present the true diverse nature of a complete evaluation (Chin *et al*., 2009b). Fuzzy TOPSIS (Hwang and Yoon, 1981) and AHP (Roger *et al*., 1999; Lam and Chin, 2005; Chen *et al*., 2007) have also been applied in decision making in product development stages. Both approaches have the fundamental assumption that a problem should be constructed in a strict hierarchical structure and elements in the same level are independent of each other. The assumption is often difficult to be met in problems that involve various elements with complicated inter-relationships. Although ANP is able to tackle the underlying problems of AHP, there are other limitations that concern ANP. For instance, ANP cannot quantify and explicitly demonstrate the influences among the defined elements. ANP fails to deal with uncertainties which are often quantified as probability when making decisions. In comparison with the above tools, the Bayesian network is a better approach for handling uncertainty in cognitive based problems in the context of NPD. The method for an industrial application of the Bayesian network into risk evaluation is further illustrated in this paper.

3.2 Bayesian Network: An Overview

● Bayesian Theorem

The Bayesian theorem is the basis of the Bayesian network. It is through the Bayesian theorem that Bayesian networks can update prior knowledge in light of new evidence.

The Bayesian theorem can be expressed as follows:

$$P(h \mid e) = \frac{P(e \mid h)P(h)}{P(e)}$$

where e represents the new evidence, $P(e)$ is the probability of the evidence, h is the hypothesis, $P(h)$ is the prior probability of the hypothesis, $P(e \mid h)$ is the likelihood function, and $P(h \mid e)$ is the posterior probability; the probability of the hypothesis h after the new evidence e comes out. From the above explanation, it is revealed that the original knowledge of the hypothesis, h, which is represented by $P(h)$, is updated to $P(h \mid e)$ when e comes out. This is the central idea on how the Bayesian network updates prior knowledge in accordance to new evidence.

● Definition of Bayesian network

A Bayesian network consists of a set of nodes; each of which stands for a variable, a set of directed edges pointing from a parent node to a child node, and the probabilities of each node. Every variable has a finite set of mutually exclusive states. The variables together with the directed edges form a directed acyclic graph (DAG). For each node X with its parent nodes $Y_1, \cdots, Y_N$, there is attached, a set of probabilities $P(X|Y_1, \cdots, Y_N)$, which forms the conditional probability table (CPT) of X. If X has no parent, then the attached probability is the prior probability of X, i.e., P(X). Figure 2 displays a DAG. The probabilities to specify are P(A), P(B), P(C|A, B), P(E|C), P(D|C), P(F|D), and P(G|D, E, F).

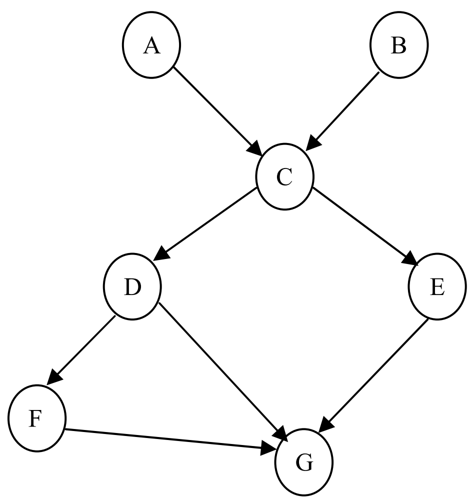


Figure 2. A Directed Acyclic Graph (DAG).

3.3 Bayesian Network in Risk Based Product Innovation Decisions

A Bayesian network which is a probabilistic graphical model that represents a set of variables and their probabilistic dependencies has been applied in different risk-based decision problems to evaluate uncertain factors (Sinharay and Almond, 2007). Although many critical factors of NPD have been identified in the literature, consideration of a risk management perspective and integration of multiple risk factors to portray interpretations has not yet fully been highlighted. Furthermore, only a small number of research has highlighted the Bayesian network approach in the development process of product innovation.

One of the purposes of constructing a Bayesian network model is to provide estimation of the outcomes of uncertain events. It describes the relationships among variables in the domain by a causal network, in which some evidence (i.e., some variable states or events that are certain) should be controlled by the users and such evidence are able to infer the probabilities of other indefinite variables (Khodakarami *et al*., 2007). One of the major advantages of Bayesian networks is that it is intuitively easier for company managers to understand direct dependencies and local distributions by a network. It also provides a means to understand how changes of one factor affect the likelihood of the states of other factors (Cooper, 2000). Furthermore, it deals with the problems which can be modeled in a network structure rather than a fixed hierarchical form. The Bayesian network was applied previously in different areas to support decision making (Mittal and Kassim, 2007), such as information technology (IT) implementation (Lauría and Duchessi, 2007), bankruptcy predication (Rajagopal and Castillo, 2007), knowledge discovery for process control (Li and Shi, 2007), design for six sigma decision making (Rajagopal and Castillo, 2007), and partially in areas of NPD, etc. (Cooper, 2000; Nadkarni and Shenoy, 2001).

By nature, product development problems that fulfill the needs of the Bayesian network as the theoretical foundation of NPD are mature (Keizer *et al*., 2005). It is sufficient enough to model the risk situation into a Bayesian network. Furthermore, research has found that risk handling in product development projects in many organizations is often done by informal and unsystematic methods and largely based on management perceptions (Griffin, 1997; Calantone *et al*., 1999; Cooper, 2006). It may be due to the failure in incorporating systematic risk diagnosis methods into practical applications in NPD problems. A Bayesian network can be seen as a systematic and effective method to more accurately assess product development risks. Although Nadkarni and Shenoy (2001) applied the Bayesian network approach to making inferences in product development decisions, this study focuses more on the Bayesian network methodology than the application of the approach in evaluating decisions on risk based innovation projects.

This paper attempts to illustrate the application of MRDM for selecting product alternatives in innovative product development. Therefore, it does not intend to solve the underlying problems of Bayesian networks, such as: the difficulties in generating consistent prior probabilities and conditional probabilities for the nodes in a Bayesian network based on expert opinions, and the inability of the Bayesian network to deal with incomplete information, which is prevalent in the early stages of a project innovation process. A more objective and reliable approach to reduce biases during the process of initial probability generation and an approach to deal with incomplete information were developed in other papers (Chin *et al*., 2009; Tang *et al*., 2009).

In this paper, we demonstrate a simple application as one of the possible techniques for risk analysis in the risk pre-assessment phase by the Bayesian theorem. The model created can be represented by a set of variables and their probabilistic dependencies. The Bayesian network can provide support to tackle intuitive problems which involve uncertainty and probability reasoning in causal relations (Khodakarami *et al*., 2007).

4. PROPOSED MRDM (MODIFIED RISK DIAGNOSIS METHOD) FOR PROJECT ALTERNATIVES

As the foundation, RDM is modified. In this paper, the MRDM aims to entertain product innovation projects with multiple solutions. As the scope of risk identification stage is to spot the possible risk factors. It neither models the relationship of risk factors nor conducts appraisal on the risk levels of the alternatives. Therefore, the risk pre-assessment methodology is supplemented between risk identification and risk assessment stages to conduct appraisal on the risk levels of the alternatives. To deal with the selection problem of innovative project solutions with alternatives, a reliable, comparable and systematic risk analysis technique should be integrated in order to obtain a comprehensive view in the risk levels of the alternatives. Four major steps are further developed in the risk pre-assessment stage; namely, the design of the risk model, confirmation of risk measures, obtaining of expert judgments, and development of risk profiles for the alternatives. The successive milestones are discussed in the last chapter and the flow of the MRDM is displayed in Figure 3.

4.1 Risk Model in MRDM

Following the roadmap of the RDM, interview sessions are conducted with all of the project participants in the risk identification phase to collect risk factors with an integral overview in terms of technological, business, and organizational risks (Keizer *et al*., 2005).

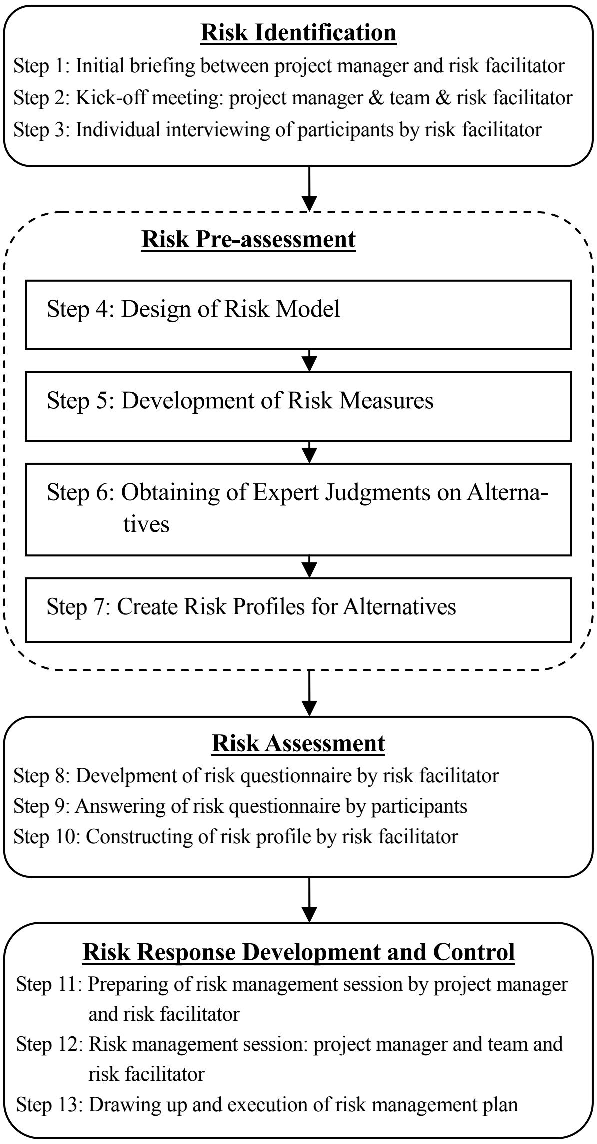


Figure 3. MRDM for project alternatives.

The identified factors are collected and the interrelationships are then analyzed by the risk facilitator. A risk model that depicts the entire overall network of the risk situation is suggested to display the interrelationships among the risk factors. Sometimes, a fixed hierarchical model is not able to entertain intuitive problems which involve uncertainty and probability reasoning in causal relations (Khodakarami *et al.*, 2007), especially in a complex product innovation environment. Instead, a causal network with interrelated risk factors is usually more practical to present the risk situation under a product innovation project.

● A BN-based causal network

While product development problems fulfill the needs of the Bayesian network as the theoretical foundation of NPD are mature (Keizer *et al.*, 2005), it is appropriate to model the risk situation by Bayesian network. A causal network comprises a set of variables, which are represented by nodes in the network and a set of directed links between the nodes. If there are two nodes; A and B, which are connected by a unidirectional arrow from A to B, then B is the child of A and A is the parent of B. The nodes without parents are root nodes. The tail of the arrow is regarded as the cause of its head, i.e. the node at the tail can be considered as the cause of the node at the head. The variables are events which are presented by a number of states, for instance, sex (male, female), and color of metal cases (white, black, golden, silver). An arc represents the casual and dependent relationship between the nodes on each end of it.

One should be aware that causal relations between risk factors are not always obvious. When modeling a casual relationship, a distinction of direct and indirect causes is necessary. The redundant relationships may increase the complexity of the network, whereas failure in identifying important relationships may neglect the authentic linkages between variables. Devising causal relations should be based on the underlying cause and effect relationship of the domain rather than the language description of the causal statement as it may involve misrepresentation from effect to cause (Nadkarni and Shenoy, 2001).

The development of a causal network can be explained by the following simple example. For instance, pregnancy is the cause of a positive pregnancy test. After checking the report of the pregnancy test of a woman, the doctor concludes that this woman is pregnant. In this situation, the doctor is using inductive reasoning. It is obvious that a pregnancy test is not the cause of pregnancy. From this example, it is revealed that reasoning can contradict causation. Making a deductive judgment is essential to truly present the domain in a causal network.

After having transformed the potential risk factors into a risk model, the model will be examined by the project manager in order to assure that the risk issues are well presented and their interrelationships are well addressed.

4.2 Risk Measures in MRDM

Once the risk model of a product innovation project is generated, a set of risk measures should be developed to assess the risk level of alternatives. In a Bayesian network environment, a set of conditional probabilities should be assigned with regards to the historical and current situations of the non-root nodes so as to develop the measure. By taking the following example, the basic concept for determining conditional probabilities can be illustrated. To check one's pregnancy, a pregnancy test is conducted. This test typically detects the presence of human chorionic gonadotropin and will either show a positive or negative result. There are two hypothetical events: (1) pregnancy and (2) no pregnancy, which are mutually exclusive and can be grouped into the variable

"Pregnancy?" with the states "yes" and "no". To reveal the situation of pregnancy, information from the test result is obtained which can either be positive or negative.

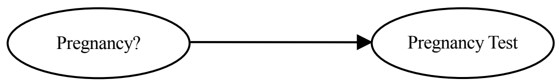


Figure 4. A model for pregnancy with a pregnancy test.

However, no test in this world is absolutely perfect. A positive result may be given to a non-pregnant woman, whereas a negative result may be found in a pregnant case. Based on the history of the pregnancy test, the conditional probabilities can be drawn on the accuracy of the test. The probability of observing a positive result when no pregnancy occurs; P (Pregnancy = No|Pregnancy Test = Positive), is assumed to be 0.003 and the probability of observing a negative result when pregnant; P (Pregnancy = Yes|Pregnancy Test = Negative), is 0.002. Therefore, the conditional probability table can be developed as follows.

Table 1. Conditional probability table.

Pregnancy Test	P (Pregnancy? = Yes)	P (Pregnancy? = No)
Positive	0.997	0.003
Negative	0.002	0.998

4.3 Expert Judgments on Alternatives

Expert judgments should be obtained after the risk measure is developed. Those experts could be the company top managers or external consultants, who possess solid experience in similar types of product innovation and have good knowledge in company operations. Product development experts evaluate the chances of occurrence and the impacts of the failure and controllability of all root nodes (Halman and Keizer, 1994) in order to assess the risk levels of the alternatives.

Furthermore, the Bayesian network approach can reflect expert knowledge in the decision context where such knowledge may involve uncertainty.

Also, validation exercises can be conducted from time to time during the construction of the Bayesian network and performance of the evaluation. The causal network should be communicated with the project team members and experts to confirm the factual interpretation of variables with the decision context. In some circumstances, modifications of the network can be made to enhance reliability in the mapping process. If several experts are involved in the evaluation decision, and there are expert disagreements on the network, prior probabilities may be found as different points of view exist. It is suggested that there should be better communication of the ideas among experts. If a consensus on ideas cannot be made, a possible resolution is to calculate a weighted average (Nadkarni and Shenoy, 2001).

4.4 Risk profile for alternatives

The risk facilitator should create a risk profile for each alternative. The profiles contain all of the relevant risk factor information with respective expert judgments. With the support of Bayesian network software, e.g., Hugin (Hugin software, 2007), Netica, Bayes Net Toolbox for Matlab, etc. and also sensitivity analysis, etc., the risk levels and how the factors influence the subject area for each alternative can be ascertained. Taking the previous example on pregnancy, if a woman suspects that she is pregnant and believes that she has a 70% chance of pregnancy, the probability of getting a positive pregnancy result is 0.6985 and the risk result can be recorded.

In some circumstances, the reasoning process may be carried out to update prior judgments when new evidence comes out or the situation has changed. A subsequent evaluation can also be conducted by utilizing the reasoning ability of a Bayesian network to assess the effects of preventative actions after an initial evaluation. These on-and-off risk records should also be filed with the risk profiles so as to act as a future reference for taking risk response actions in accepting, reducing, transferring or rejecting decisions.

Once the decision of selecting the best alternative is made by this pre-assessment stage, a detailed risk assessment for the selected choice can be conducted by using the developed roadmap of the RDM. Once further information in the project is revealed, the risk facilitator can develop a risk questionnaire for the selected alternative by referring to the appropriate risk issues encountered in the innovation process. With the results of the risk assessment, the corresponding risk response development and control can be executed (Keizer *et al.*, 2002).

4.5 Summary

The proposed MRDM has an enhanced risk pre-assessment module, which includes designing the risk model, developing risk measures, obtaining expert judgments on alternatives and developing risk profiles for alternatives. The module provides a foundation for systematic evaluation on the risk levels of multiple solutions in an innovative project. Through this pre-assessment phase, related risk factors on the subject area will first be organized to formulate a risk model for the innovative project problem. Then, the risk measures of the model will be established with respect to current situations of the root nodes. Afterwards, company experts will provide their judgments on risk factors in order to assess the risk levels of the alternatives. The risk profile will then be generated which contain all of the relevant risk statements and judgments. The forthcoming on-and-off records from changing situations and alternative modifications should also be filed in the risk profile. A case study is addressed in the next section to illustrate the proposed steps of a risk pre-assessment in MRDM for alternative approaches to assess the engineering design risks of two electrical dimmer switch designs.

5. A CASE STUDY: ENGINEERING DESIGN DECISION

This section demonstrates the application of an MRDM in a NPD decision. A case study that evaluates two alternative engineering designs in dimmer switches is described in this section. First, case descriptions; the design specifications of two alternative dimmer designs and the definition of the decision context, are elaborated. Secondly, in the model design part, a network of causal relationships in determining engineering design risks is developed based on the situation of the dimmer designs. Thirdly, conditional probabilities will be developed to confirm the risk measure. Fourthly, prior probabilities are generated by evaluating the network with experts. Finally, all information obtained and future actions among two alternatives will be documented and the risk profiles for the alternatives can be created for the forthcoming risk response development and control.

5.1 Case Descriptions

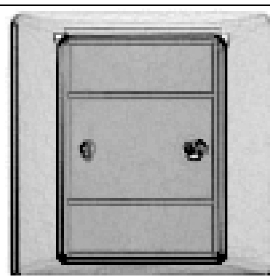
The case example is obtained from a designer and manufacturer of electrical wiring devices and installation system products for electrical appliances. The company product profile places integrated switches in IC devices with more than 100 different products. Their product line covers a great variety of and advanced IC integrated control switches, connection units, fan control systems, junction boxes, mounting enclosures, plugs, and adaptors.

The case company originally had a long history in the design and manufacturing of one way wiring electrical switches. Based on their experiences in electrical switches, their recent intentions are to introduce some innovative features into their switch products. Market research has been done to reveal the potential demands of dimmers in the electrical switch market. Dimmers, which are a type of IC integrated electrical switch, are able to control the light intensity of incandescent lamps. Fundamentally, it should provide basic on-off functions and offer various output signals to adjust the brightness of a lamp to control the light intensity of a room. The panel material is PC (polycarbonate) in white color. Two designs are created based on the product function requirements.

The major difference between the two designs is the adjustment mechanism. Both switches control the light intensity from low to high and are able to restore previous light levels through built-in memory devices. Design A is a dimmer switch with an on-off button plus a rotary controller. This design has a simple button design principle to control the on-off switch on a lamp. To adjust the light intensity, the rotary button is adjusted at different degrees. A potentiometer, which is a three-terminal resistor, is integrated to act as a variable vol-tage divider. Then, the signals will trigger the triac by the control device and the dimmer function works.

Design B adopts a design principle with a push-in on-off button to control the on-off function of the light bulb. Users press and hold the button to adjust the light intensity of the bulb. This function is done by an IC sensor device which is smaller in size than the potentiometer. With different press modes, different signals will be transmitted to the control devices to obtain different levels of brightness. The characteristics and control mechanisms of the designs are displayed in Table 2 and Figure 5 respectively.

Table 2. Characteristics of dimmer designs.

	
Design A: Rotary dimming switch Specifications: Control: On-off button with rotary button for adjustment Voltage: 200-250 V Standby current: < 13mA Power: 500W Dimension: 87×87×55mm Mounting Wall Box: 35mm deep or above Load type: Incandescent lamps Color: White Compliance: BS5518	Design B: Press dimming switch Specifications: Control: Push-In on-off with press and hold mechanism for adjustment Voltage: 200-250 V Standby current: <13mA Power: 400W Dimension: 87×87×40mm Mounting Wall Box: 25mm deep or above Load type: Incandescent lamps Color: White Compliance: BS5518

While two alternative dimmer designs are generated, the case company would select one single design to further develop and manufacture. Both of these two alternatives are able to satisfy the basic product requirements and compatible with existing modularity. Assuming customers have no preference among the two alternatives and the designs have the same impact on the company product profile, the decision context of the selection of the two alternatives goes to the evaluation of their engineering design risk. In engineering design risks, the probability of an unsuccessful development of a final product is attributed to engineering design problems. It is expected that the selected design would be more likely to provide a desirable technical function. In the following paragraph, the application of the proposed RDM in terms of the risk assessment phase will be illustrated by using this example.

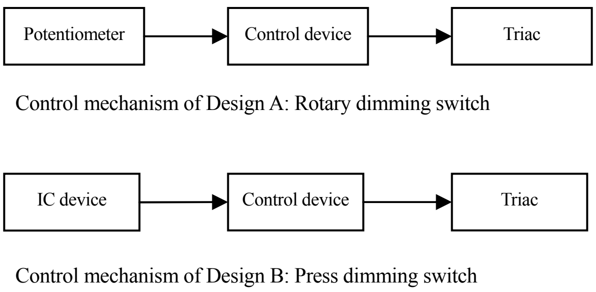


Figure 5. Control mechanisms of dimmer designs.

● Risk Identification

The development of a risk evaluation model is dependent on the actual situation of the problem area and may be subject to change based on the company situation. In this case example, there are two main considerations for the engineering design risk (EDRI) of dimmers; namely, product performance (PPE) and product manufacturability (PMA). The risk facilitator, product designers and the project manager have gone through the risk identification phase, including the provision of an initial briefing, kick-off project meetings and interviewing individual participants in the company, to identify context-specific risk factors. Then, the potential risk factors for an engineering design decision can be obtained, such as concerns in functional performance, research and development capability, process complexity, etc.

5.3 Design Risk Model for Engineering Design Decisions

The identified risk factors are then organized and the interrelationships of the risk factors are considered and examined. Then, a network of engineering design risks is created and displayed in Figure 6. PPE is the likelihood that the product requirements can be satisfied in the specific time frame. Achievement of functional performance and fulfillment of product reliability requirements are regarded as the causes of this attribute.

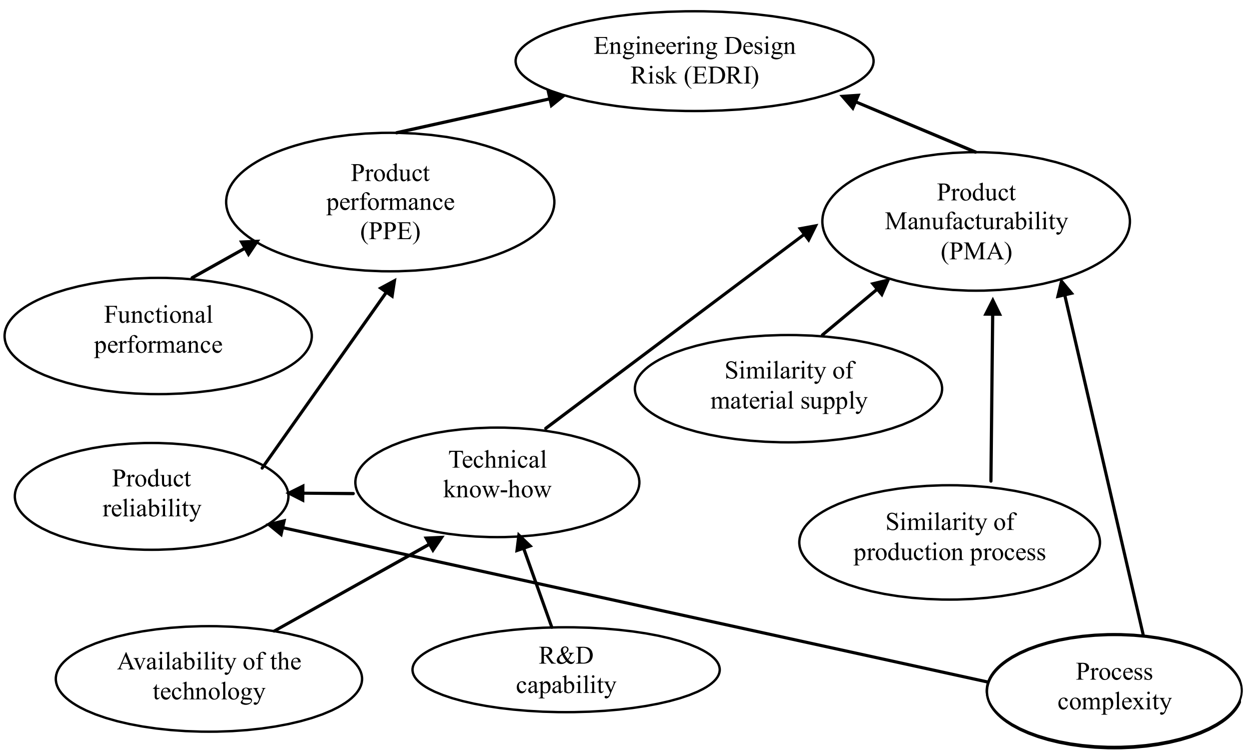


Figure 6. Network relationship of engineering design risks.

On the one hand, product reliability for a switch product mainly depends on the company's technical know-how of the required technologies, and on the other, the complexity of the production process will affect the level of achievement. Technology know-how depends on the availability of the technology, and company research and development capability.

Furthermore, product manufacturability is the likelihood that the targeted design can be successfully produced with regard to the existing production capability in the specific time frame. As a manufacturer, there should be awareness for the successful incorporation of the design specification into mass production. To better integrate the specific design into production, the process complexity and technology know-how of the required technology are important contributors. The causal network is discussed thoroughly with the participants so as to confirm the factual interpretation of variables with the decision context.

5.3 Develop Risk Measures

In consideration of the situations of the referential engineering design situation, the conditional probabilities of each non-root node is obtained. From similar types of engineering design products, it is found that if the required technologies are not available in the existing market, the technology know-how of the product is relatively difficult to guarantee. Aside from that, if a company has higher capability in development R & D, it is more likely to implement the targeted technologies into a specified application. Furthermore, the stability and quality of the material supply, which contributes to stable production, is more likely to be maintained if higher similarity of the material supply is sought. As well, higher similarity of the production process is more likely to assure stable production workflows. The situation is translated to a set of conditional probability values.

Table 3. The probability of EDRI conditional on PPE and PMA.

P(EDRI|PPE, PMA)	PPE = H		PPE = L	
	PMA = H	PMA = L	PMA = H	PMA = L
H	0.15	0.5	0.55	0.9
L	0.85	0.5	0.45	0.1

Two states are categorized into each node; namely, high (H) and low (L). For instance, in the node of similarity of the material supply, H implies that the use of material in the specific design has high similarity with the existing similarity of the material supply in the company, whereas L denotes low similarity between the required material and the similarity of material supply. H in R&D capability indicates that the in-house capability specializes in the required technology in the design, and L refers to incapability in the use of technology. An example of the probability of EDRI conditional on PPE and PMA is displayed in Table 3. With the support of the Bayesian network software; Hugin Lite 6.7 (Hugin software, 2007), the network and probabilities obtained are incorporated into a Bayesian network. The software interface is displayed in Figure 7.

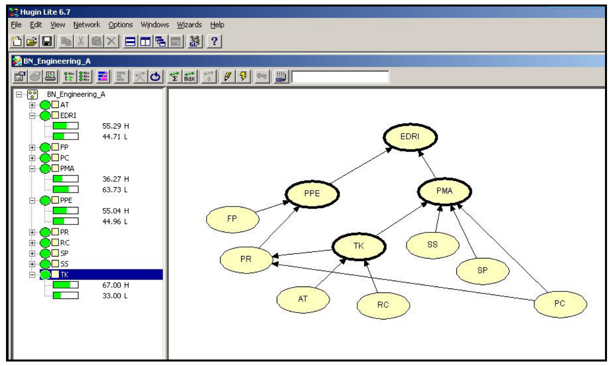


Figure 7. Software interface.

5.4 Obtain Expert Judgment for Alternatives

The interviewees, who are selected to provide judgment, possess strong and solid experience in product design and development across different electrical products and components. The probabilities are given in accordance to experience and judgments. Based on the situation of designing a dimmer switch and the strength and weaknesses of the dimmer alternatives, the prior probabilities of each root nodes are estimated by the respondent during the interview.

Both of the product design alternatives achieve product functional requirements and therefore their functional performances are reasonably well attended. Both designs have some strong and weak points in each node. For design A, a similar control mechanism in the rotary switch was applied previously in this company for a fan control system. The experiences in the fan control system are applicable to this dimmer design and the required technology is accessible. Furthermore, some components that are common in this design, such as the control button, potentiometer and supply of key materials, can be ensured with the existing suppliers.

The component size of design B is similar to the ordinary switches in this company. The in-house R&D capability has an excellent track record in integrating IC devices into switch products. The production plant has also trained people well to manufacture IC types of products. Therefore, there is great confidence in the PC for design B due to its higher similarity to existing production. As well, the manufacturing process of design A with IC sensors is relatively less complicated than design B with a potentiometer which should be connected by different voltage contact points. The experts provided probabilities and the data were put into Hugin Lite 6.7 to calculate the risk levels of the two dimmer designs.

5.5 Create Risk Profile for Alternatives

From the risk analysis results, the probability of obtaining a high engineering design risk for design A (0.55) is greater than design B (0.40). After obtaining this result, further discussion with the respondent was conducted in order to evaluate the reasonableness of the result obtained and the expected risks in the designs. It is realized that even if the company has better technology know-how of design A than design B, the advantage cannot compensate for the uncertainties incurred by PPE and PMA and hence, design B is less risky.

Table 4. The risk analysis results for dimmer designs.

	Design A	Design B
EDRI		
H	0.55	0.40
L	0.45	0.60
PPE		
H	0.55	0.69
L	0.45	0.31
PMA		
H	0.36	0.65
L	0.64	0.35
Technology know-how		
H	0.67	0.69
L	0.33	0.32

In addition to the selection decision, risks associated can be filed based on the Bayesian network evaluation results while companies may apply different risk response strategies for the future, such as risk retention, avoidance, reduction and transfer to reduce the risk levels of the designs.

There is one issue that is related to the reduction of the risk level of designs. It is found that the risk of design B in PMA can be reduced if prior probabilities of similarity of material supply, production process, process complexity and technology know-how are more favorable. Based on the company current situation, the first three factors are already optimized and hard to change afterwards. Extra efforts could be put forth in the latter part of the detailed design and development stage to understand the technology know-how of the required technologies. A company could boom it by enhancing their ability to access and develop the required technologies, i.e., availability of the technology and R&D capability. Consultation with professional bodies and communication with suppliers and competitors are some possible methods to enhance their ability to accessing the required technologies, whereas collaboration with universities could provide external help in enhancing its technology development ability. Once the situation of technology know-how has improved, the intermediate results of design B in PPE will also be reinforced as a linkage between them exist. A second set of evaluation may also be conducted after these enhancements so as to re-evaluate the impact of the improvement.

● Risk assessment

Once the product alternative is selected, more comprehensive risk issues can be found in the latter part of detailed design and development due to the further development of the product idea. Then, the risk facilitator develops a corresponding risk questionnaire to assess the detailed risk issues of every risk factor. In this stage, a collaborative idea can be obtained by answering the risk questionnaire by participants and any further information can be added into the risk profile for the product.

● Risk response development and control

A risk management session is to be conducted by the project manager, project team members and risk facilitators once the complete risk profile is created with the supplement of risk assessment results. During the meeting, a risk management plan will be drawn up and corresponding strategies will be formulated to avoid, reduce and transfer the risk issues.

6. CONCLUSION, LIMITATIONS AND FUTURE WORK

It is important to evaluate risks associated with the early stages of the product innovation process, as this reduces unnecessary expenditures at the beginning and the company can further control and mitigate the potential risks. An MRDM which is able to deal with problems of product alternative selection is proposed and the application is illustrated in this paper. By employing a Bayesian network approach into the risk pre-assessment stage, the selection of risk-based alternatives during the product innovation process is exemplified in this paper. The risk pre-assessment is not limited to decisions in making alternative selections only. It is suggested that the result obtained can be further analyzed to evaluate the future risk response strategies of companies to reduce and mitigate risks. Then, the effect of preventative actions can be re-evaluated and monitored in the forthcoming risk assessment phase.

Since the focus of this paper attempts to demonstrate the applicability of MRDM for selecting product alternatives in innovative product development, we have only illustrated a basic application of the Bayesian network as a modeling and reasoning tool. It is understood that such a simple application of the Bayesian network may induce some problems in reality, e.g., how to reduce the biases involved in the process of generating prior probabilities and conditional probabilities of different nodes in the Bayesian network; how to ensure the consistency of expert opinions, and deal with incomplete information that exists in the risk evaluation process at the early stage of product innovation. The problems mentioned above can be accommodated by advancing Bayesian network algorithms in different application scenarios. Currently, research on completing Bayesian network algorithms have been proposed by the authors (Chin *et al*., 2009; Tang *et al*., 2009).

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