Proceedings of DET2011
7th International Conference on Digital Enterprise Technology
Athens, Greece
28-30 September 2011

RISK MANAGEMENT IN EARLY STAGE OF PRODUCT LIFE CYCLE BY RELYING ON RISK IN EARLY DESIGN (RED) METHODOLOGY AND USING MULTI-AGENT SYSTEM (MAS)

Leyla Sadeghi
Cemagref - Unité TSAN 1, rue Pierre-Gilles de Gennes - CS 10030 - 92761 Antony cedex
leyla.sadeghi@cemagref.fr

Mohsen Sadeghi
Graduate School of Management and Economics
Sharif University of Technology
sadeghi@gsme.sharif.edu

ABSTRACT

Risk assessment and management play a very critical role in design phase of product process. The aim of this article is sustain risk assessment and management during early design phase of product. Indeed the results presented in this work contributes to managing risk during product design phase by development of a computerized system by utilizing the concepts of Multi-Agent System , RED (risk in early design) methodology and rule based intelligent techniques. The suitable decision for design selected according to the acceptable risk. In fact Multi-Agent System helps to facilitate applying RED methodology for risk assessment and management. This paper firstly, describes motivation of this research, context and environment related to this topic. Secondly, a brief state of the art of failure analysis methods is introduced. In the third part, a structured model is proposed for applying RED metrology by utilizing Multi-Agent System. In fact this model is introduced that applies feature-based and parameters design concepts and also Multi-Agent System to handling Risk in Early Design (RED) Method. Then, the results are presented by RMD_MAS_RED tool. Finally, the perspective of this work is presented.

KEYWORDS

Design Phase, Risk in Early Design, Risk Assessment, Risk Management, Multi Agent System

1. INTRODUCTION

Risk assessment and management play a very critical role in design phase of product process. Early assessment and management of risks is necessary to anticipate and prevent failure from occurring or repeating. In fact the impact of risk assessment on the product is more in design phase especially conceptual design phase. So to increase the product safety, performance and reliability risk assessment need to be moved forward to the conceptual design phase [1]. Because the product has not assumed a physical form in conceptual design stage thus risk assessment is difficult in this phase. In an effort to perform risk assessments, based on function rather than physical components, the risk in early design (RED) method was developed [1].

It is known that formal risk analysis is considered by designers as time consuming, tedious and often useless activities (in mechanical and semiconductor industries).

This paper presents RMD_ MAS_RED (Risk Management in Design by using Multi Agent System and Risk in Early Design method) tool which is developed to capture, assess, organize, store, share and update knowledge and information in order to support RED method by using multi-agent systems.

2. LITTERATURE REVIEW

Risk in the early design stages is concerned by designers too much. One of first steps for risk assessment and management is failure identification and analysis. Several failure analysis methods exist and they are used in industry but Failure Mode and Effect Analysis (FMEA) is widely used [2].This method examines components of system and their failure mode characteristics to assess risk and reliability [3]. To assure a systematic and thorough coverage of all failure modes, the information is usually arranged in a tabular format. The table consists of at least three columns, one for the component name and its reference number, the second for the failure modes and the third for the effects. Other columns might include failure detection method, corrective action and criticality [4]. Some examples of FMEA shortcomings are:

1. FMEA is tedious and time consuming because it relies on experts to examine each component of a system to identify its potential failure modes [5]. FMEA often leads to very poor quality in the designed artifact that it is not very economical.
2. FMEA is applied too late so it does not effect on important design and decision [9].If FMEA is performed earlier in design stage then it will have to be repeated whenever the design is changed [7, 8].
3. The analysis FMEA requires a detailed level of system design, and thus is not optimal to be used during conceptual design [10, 11].
4. FMEA does not capture component interactions explicitly, and it relies heavily on expert knowledge to assess failure consequences and their criticality [11].

Another method is Fault Tree Analysis (FTA). FTA is an event-oriented analysis which starts with identification of a high-level failure event [11]. This tool provides a logical framework for analyzing the failure behavior of a system by identifying sequences of events that have negative impacts. The FTA history is now about 50 years, and has become a tool for the reorganization and translation of the failure behavior of a physical system into a visual diagram and logic model [12].

By employing this technique, we can generate qualitative descriptions and quantitative estimation (when sufficient data are available) of the risk elements [13]. FTA is a well accepted technique and it is very suitable for finding failure relationship but difficult to understand and the complex logic is involved so that it cannot be perform by novice designers. It is useful both in designing new products and in dealing with identified problems in existing products.

Like FMEA, FTA is a well-accepted, standard technique. It is likely to identify more possible failure causes than FMEA. However, FTA also relies greatly on expert input and it shares similar criticism that FMEA is subject to that [11]. Formally capturing of component interactions and system dynamics is crucial for supporting design decisions during early conceptual development. So FTA is not appropriate for risk analyzing in early design phase.

An attempt toward the identification of failure modes during conceptual design was made possible through the function-failure design method (FFDM).The FFDM is a mathematical relationship between product function and failure modes that was developed by Tumer and Stone (Stone et al. 2005; Stone et al. 2004; Tumer and Stone 2003) [14,15]. This method uses a functional model in combination with historical failure information to map functionality to potential failure modes [14].Functional Basis is a standard taxonomy to describe functionality and it was used to model systems and components at the highest (functional) level. Then the method collected failure data from historical databases and designer elicitation and it mapped these failures onto function, hence building a knowledge base, related to failure modes, directly onto functionality needs to know the details of the design form or solutions [14].

FFDM produces the type and number of failures that occurred for a particular product. A bill of material that is a list of the components, making up the product and functional model, are used to document functional data. In other words FFDM involves formation of a function failure matrix that can be used as a knowledge base to identify and analyze potential failures for design [15].

In FFDM, function-component matrix (EC matrix) is created with the help of the bill of materials and the functional model. This matrix has m columns (component) and n rows (functions) [16]. For creating component-failure matrix (CF matrix), the bill of material and documentation of failure are used. Finally, the function-failure matrix (EF matrix) is obtained by multiplication of the function-component matrix (EC) and the component-failure mode matrix (CF).

$$EC \times CF = EF \qquad (1)$$

By use of matrix EF; designers can design out identified failure modes during the conceptual design stage.

FFDM provides a starting point for determining the likelihood of system failure based on a set of functions [11]. Designers can analyze potential functional failures before any component selection is made by using this method. Several methods have been developed based on the FFDM method, for example:

-A methodology to enable the design of health monitoring modules, concurrently with system conceptual design in order to reveal, model, and eliminate associated risks and failures (Hutcheson et al., 2006) and;
-A formulation for a functional failure likelihood and impact-based risk assessment approach which classifies high-risk to low-risk function failure combinations to provide designers (Lough et al. 2006; Krus and Lough 2007) [14].
In this research we used the second method. This method is Risk in Early Design (RED) method which formulates a functional-failure likelihood and impact risk assessment. This approach classifies high-risk to low-risk function failure combinations and provides designers a tool that can be used to qualitatively rank/order functional failures and their consequences during conceptual design [11].
In other words RED method is an engineering design tool for identifying and assessing risks in early design. This method produces risk assessment based on catalogued historical failure data. This method translates recorded information about function and failure into categorized risk likelihood and impact for a product [6]. Indeed this method is a necessary extension of the FFDM that creates a relationship between function and the risk in early design by use of a mathematical mapping from product function to likelihood and impact risk assessment [17]. It uses a database including historical failure event information to present specific areas that are at risk of failure in a product. RED's aim is to identify risks and communicating of those risks [1].
Therefore, the RED method attempts that based risk, related to product function, promotes the identification historically. A 2-D Fever Chart with axes of likelihood and impact of failure is used for communication of those risks [1]. In the following, we will describe this method. RED method consists of 1+4 steps (Figure 1). This method focuses on the relationship between function and risk by representing a mapping from function to risk likelihood and impact [1].

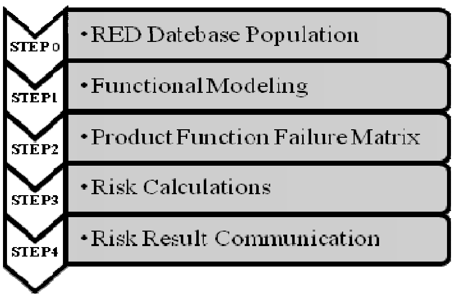

Figure 1 - Steps of RED Method

The starting point is RED Database Population. A database of historical and corresponding failure information is necessary for RED method. It has to gather failure reports from various features. This database should provide enough information to be able for identifying specific component and failure.
In first step functional model is created for generating a function failure matrix as part of RED. Because in this step, it has to describe what the product will do, so functional modeling will be useful for this work [1]. In other words by using this functional information about what the product does, designers can begin to perform analysis and studies about how the product can perform these functions [5].
In next step function failure matrix for product is produced by use of Equation 1. This matrix provides the number of failures for each particular function according to the historical database. This step provides a starting point for determining the likelihood and impact of product failure by a particular function.
In step 3, the information as a yield of function, failure mode, impact and likelihood is provided. The aim of this step is risk calculation. The risk likelihood and impact calculation are extension of the FFDM and appropriate mapping should be selected for applying this extension. A key assumption for applying these mappings is that a fully populated database of related historical failures has been established. Without a strong foundation, the risk assessments are not likely to produce relevant and adequate risk data [1].
In the final step of RED, these risk elements must be communicated to it, being easy to understand [1]. So after selecting the appropriate combination of mappings, the data is summarized through the use of a 2-D Risk Fever Chart.
A Fever Chart is a 5-by-5 matrix that shows impact on the horizontal axis and likelihood on the vertical axis. Each cell of the matrix displays the number of elements falling into impact-likelihood combination [18].
When all the risks for a product are plotted on the Fever Chart, designers can quickly get a visually feel of the risk level from the entire of system. If most of the risk elements are in the green or low risk areas, then the product is considered in low risk and if a large number of the risk elements are plotted in the red or high risk areas, then the designers can identify that there is a significant amount of areas of concern [1] (Figure 2).

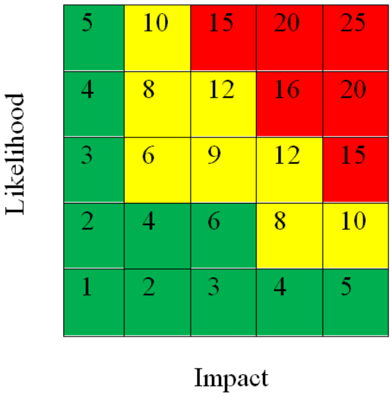

Figure 2 - Risk Fever Chart

All information of RED can be achieved before the product has assumed a physical form, where the potential for positive impacts on product performance, costs and reliability are the greatest. Our proposed method relies on RED methodology and it can be progressed by using multi agent system

3. THE MODEL

At the first it is necessary to note, that in this research we use features instead of components in FFDM and RED methods. So in FFDM Method, EC matrix shows relationship between function and feature and CF matrix shows relationship between feature and failure.

As a result EF matrix is relationship between failure and function. In other words we analyze the definition and expression of function and also we build the function model of product. Furthermore, we take apart the functions and achieve function-feature mapping.

The feature has some functions and geometries, and it can be combined with other features to create new parts, then these new parts form products and are related to product designing and product manufacturing. Based on the definition of feature, feature consists of some information for example functional information and geometric information [19].So we defined feature agent and feature risk management agent.

And also according to risk assessment which is based on function instead of physical form, function agent and function risk management agent are defined. A design database is defined to hold all the data, needed for reasoning, to save records of the interactions and updating the agent. The main structure of the Multi-Agent system for our approach is given in Figure3. Knowledge sharing and exchange is particularly important to determine.

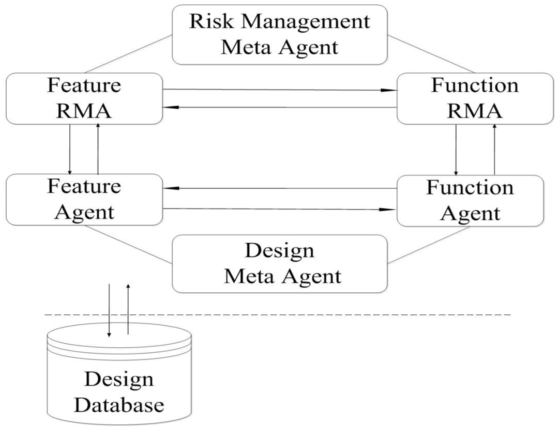

Figure 3 - Structure of Multi- Agent System

The design Meta agent provides support to the design activities and initiates queries to the other agents on Multi agent System. Design Meta Agent consists of two agents: Feature Agent and Function Agent. Feature Agent involves list of feature parameters and indeed a database is need for data representation of function and feature. This database plays a significant role in making decision at the early design stage.

Risk Management Meta Agent is defined for determining and calculating the risk and consists of Function Risk Management agent and Feature Risk Management agent. According to historical data, Feature Risk Management agent calculates risk, related to each feature and a database represents historical product and corresponding failure information. To construct a database for performing RED, failure reports from various products should be gathered. The failures recorded in the database provide a part of the context for which the product risk is considered. Function Risk Management determines risk related to functions. Communication and messages between these agents must be defined to sustain RED in design phase. Figure 4 shows the proposed communication architecture of Multi agent system. For a successful communication in such environments, the agents have to share knowledge with each other.

Messages:

1. Which feature can realize function?
2. List of alternative features that can realize function.

What is the risk related to function according to select feature?

4. What is existing failure for features?
5. Existing failure for features (relationship between failure and feature).
6. Relationship between function and feature.
7. Risk related to function according select feature.

Here, the methodology is introduced applying feature-based, parametric design concepts and a Multi-Agent System to apply Risk in Early Design (RED) method. We discuss agent communication and knowledge sharing based on RED method for achieving this purpose. The Figure 4 illustrates the interactions between function, feature, function risk management and feature risk management agents and their communication by exchanging messages. These messages express information which a transmitting agent desires that the other agents take into account.

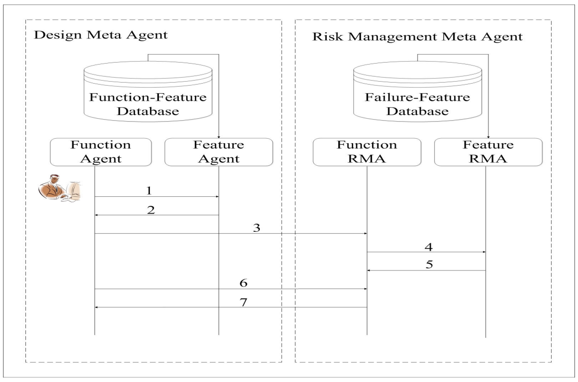

Figure 4 - Multi-Agent System for sustain RED

According to the analysis of customers needs and requirements, the designer determines which function is able to acquire customers needs and requirements. Indeed Functional modeling describes what the product will do. So function entity is created by the function agent. After that risk will be calculate based on this entity. At the first function has to realize by features, so initially, the request *"Which feature can realize function?"* is made in function agent in order to send to feature agent.

Feature Agent creates list of feature that can be realize by function, by help of Function-Feature Database. This "*list of feature*" is sent to Function Agent by Feature Agent. Indeed, the relationship between function and feature is created in this step. The Function-Feature Database is populated with a 1 entry if the feature, in the corresponding column, solves the function, otherwise a 0 is entered.

In next step, the aim is calculating of risk. Risk Management Meta Agent is defined for determining and calculating of risk. This Meta agent includes Function Risk Management and Feature Risk Management Agents. So message «*what is the risk related to function according to select feature?*" from function agent is sent to Function Risk Management Agent. For answering this message, the relationship between function and failure is needed.

Feature Risk Management Agent demonstrates the relationship between Feature and Failure. This message calculates risk related to each feature according to historical failure Feature Risk Management agent. Feature-Failure Database contains these historical failures and it helps to Feature Risk Management agent for risk calculation. Therefore message "*what existing failure for feature?*" is sent from Function Risk Management Agent to Feature Risk Management Agent. For answering this question, Feature Risk Management agent uses the Feature-Failure Database. Feature Risk Management Agent demonstrates failures of feature and then sends it in form of a massage to Risk Management Meta Agent.

In addition, another message from Function Agent that consists of the "*relationship between function and feature*" is sent to Function Risk Management Agent. In previous steps this relationship is found.

So the "*relationship between failure and feature*" and "*relationship between function and feature*" exist in Function Risk Management Agent. By calculating these relationships with together the "*relationship between function and failure*" is created. This relationship shows type and number of failures that have occurred for a particular function and it can be used as a knowledge base to identify and analyze potential failures for design of a product. Indeed we provide a starting point for risk calculation by exchange of requests, knowledge and information between function, feature, function risk management and feature risk management agents by use of 1,2,3,4 and 5 messages.

The next step is risk calculation. This information about relationship between function and failure in function risk management agent translates into risk likelihood and impact elements for product by applying risk likelihood and impact mappings.

These risk likelihood and impact elements must be communicated to it, for being easy to understand. So after selecting the appropriate combination of mappings, the data is summarized through Risk Fever Chart. Each cell of the Risk Fever Chart displays the number of elements falling into that impact-likelihood combination. So designers can quickly get a visually feel of the risk level of product. So Risk Fever Chart represents a clear communication risk.

So "*risk related to function according select feature*" is analyzed. This result is sent to function agent in form of message.

4. THE IMPLEMENTED SOFTWARE

In this section, results present the managing risk during product design phase by development of a computerized system by utilizing the concepts of Multi agent system, RED methodology and rule-based intelligent techniques. The suitable decision for design is selected according to the acceptable risk. This approach is validated through a RMD_ MAS_RED (Risk Management in Design by using Multi Agent System and Risk in Early Design method) tool development and the application of a case study.

This approach is implemented with Visual Basic (VB) but the concept of Multi-Agent system is used for writing this program. In this tool, agents communicate with each other by exchanging messages through a communication language. For a successful communication in such environments, the agents have to share knowledge with each other. For each Meta Agent, we defined an interface for the creation of agents and the environment of their operation as the platform of agents. These matters show query of messages between agents. According to previous section, seven messages communicate and share knowledge and information between these agents.

Figures 5 and 6 show Design Meta Agent interface. This Meta Agent includes Function Agent and Feature Agent and it provides support to the design activities and initiates queries to the other agents on Multi agent System.

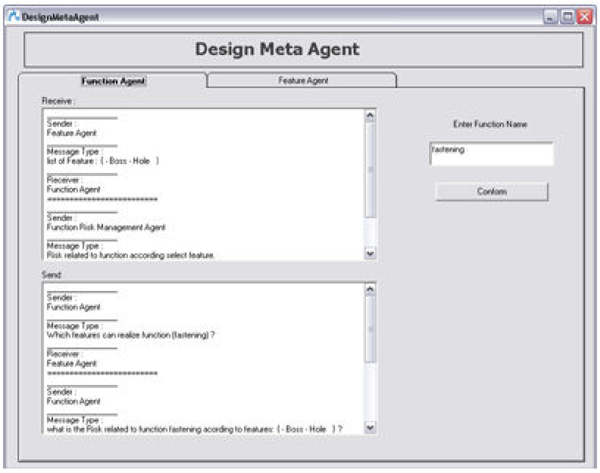

Figure 5 - Design Meta Agent interface (Function Agent).

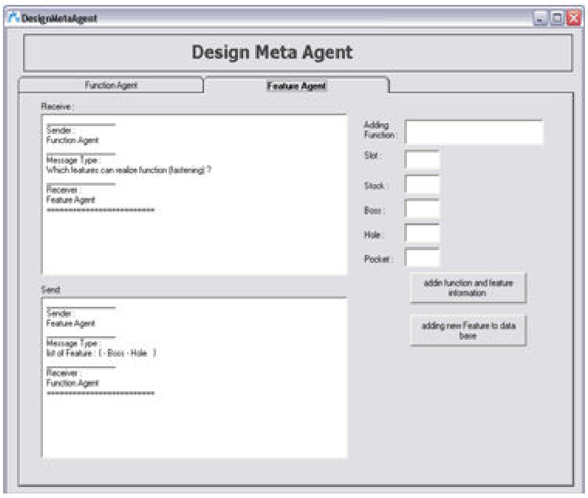

Figure 6 - Design Meta Agent interface (Feature Agent).

By entering function name in function agent of interface, one can calculate risk related to this function according to select feature. Feature agent of this interface has ability of adding new feature to database and also adding function and feature information. This work helps to update function-feature database. This database plays a significant role in making decision at the early design stage.

Additionally Figures 7 and 8 show Risk Management Meta Agent interface. This Meta Agent includes Function Risk Management Meta Agent and Feature Risk Management Meta Agent and it is defined for determining and calculating of risk.

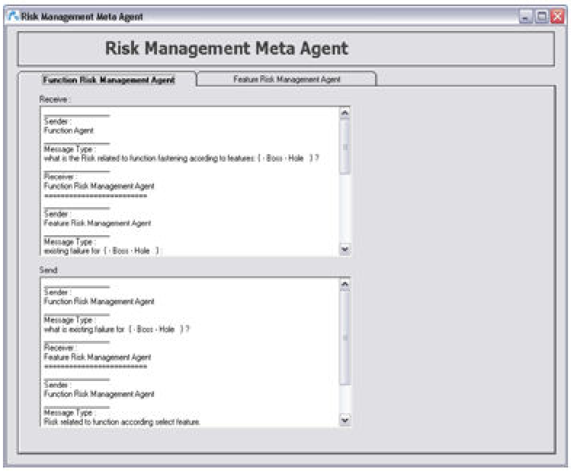

Figure 7 - Risk Management Meta Agent interface (Function Risk Management Agent).

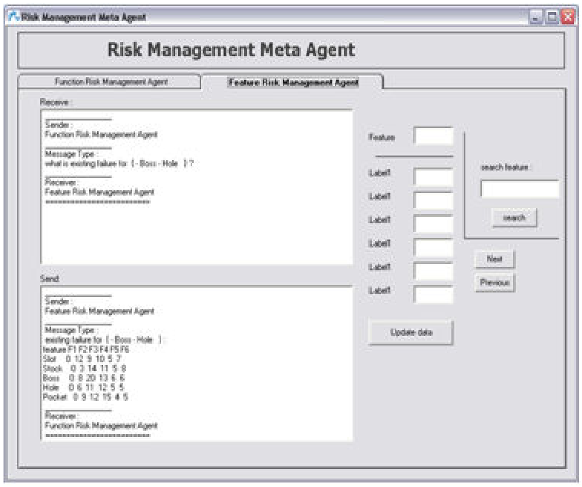

Figure 8 - Risk Management Meta Agent interface (Feature Risk Management Agent).

According to function-feature, database represents historical product and corresponding failure information and also failure reports from various products, gathered in this database. This database has to update during process. So Risk Management Meta Agent interface has ability of updating feature-failure database by use of next button and pervious button.

5. THE PERSPECTIVES

The perspective of future work is determining detail of this work. In Risk in Early Design (RED) method the relationship between function and failure by multiplication of the function-component matrix (EC) and the component-failure mode matrix (CF) is found by help of Function-Failure Design Method (FFDM) and the failure for each feature is considered by use of the Function-Feature Database that it is populated with a 1 entry if the feature, in the corresponding column, solves the function, otherwise a 0 is entered. So relationship and condition of features with each other are not determined. So this approach does not cover this aspect of risk.

We can generate similar approach by some modification for risk calculation and management in detail design. For example, to determine the parameters of feature and in fact the amount of these parameters can affect on risk (angle of slot, diameter of hole and etc).

And also during detailed design phase, designers can specify some property for each function for example tolerance, roughness and etc that these conditions also affect on risk of product. Indeed risk calculation and management can be realized by defining appropriate knowledge base and database. By use of these knowledge base and database we can modify this approach for detailed design.

REFERENCES

[1] Grantham Lough K. Stone R. and Tumer I. , "PRESCRIBING AND IMPLEMENTING THE RISK IN EARLY DESIGN (RED) METHOD", Proceedings of DETC'06:ASME 2005 International Design Engineering Technical Conferences And Computers and Information in Engineering Conference,pp.1-9

[2] Stone R Tumer I.and Stock, Michael E., "Linking product functionality to historic failures to improve failure analysis in design", Research in Engineering Design (2005) 16: 96–108.

[3] Kurtoglu, Tolga, Tumer, Irem Y., "A RISK-INFORMED DECISION MAKING METHODOLOGY FOR EVALUATING FAILURE IMPACT OF EARLY SYSTEM DESIGNS" ,Proceedings of the ASME 2008 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference - IDETC/CIE 2008 August 3-6, Brooklyn, New York, USA.

[4] Book Chapter, "Hazard Analysis", 2007, Process Automation Handbook, Part I, Section 7, Pages 407-423.

[5] Grantham Lough, Katie, Stone, Robert B., Tumer, Irem Y., "Implementation Procedures for the Risk in Early Design (RED) Method", Journal of Industrial and Systems Engineering, Vol. 2, No. 2, pp 126-143, summer 2008.

[6] Grantham Lough, Katie, Stone, Robert B., Tumer, Irem Y., "Failure Prevention in Design through Effective Catalogue Utilization of Historical Failure Events", J Fail. Anal. and Preven. (2008) 8:469–481.

[7] Arunajadai, Srikesh G., Stone, Robert B., Tumer, Irem Y., "A FRAMEWORK FOR CREATING A FUNCTION-BASED DESIGN TOOL FOR FAILURE MODE IDENTIFICATION", Proceedings of DETC'02 ASME 2002 Design Engineering Technical Conference and Computers and Information in Engineering Conference, Montreal, Canada, September 29 – October 2, 2002.

[8] Price, J.P, "Effortless incremental design FMEA", In Proceedings of the Annual Reliability and Maintainability Symposium. 1996.

[9] B., McKinney, 1991, "FMECA, The Right Way», Proceedings of the 1991 IEEE Annual Reliability and Maintainability Symposium, Orlando, FL, pp. 253–259.

[10] Bell, D., Cox, L., Jackson, S., and Shaefer, P., "Using Causal Reasoning for Automated Failure Modes & Effects Analysis (FMEA)", Proceedings of the 1992 IEEE Annual Reliability and Maintainability Symposium, pp. 343–353

[11] Kurtoglu, Tolga, Tumer, Irem Y.,"A Graph-Based Framework for Early Assessment of Functional Failures in Complex Systems" ,Proceedings of DETC '07 ASME 2007 International Design Engineering and Technical Conference and Computers and Information in Engineering Conferences, September 4 – 7, 2007, Las Vegas, NV.

[12] Clifton A., EricsonII., "Fault Tree Analysis-A History", A History from the Proceedings of the 17 International System Safety Conference-1999.

[13] Arben Mullai , "RISK MANAGEMENT SYSTEM – RISK ASSESSMENT FRAMEWORKS AND TECHNIQUES", Publication series 5:200.

[14] Kurtoglu, Tolga, Tumer, Irem Y., Jensen, David C., "A functional failure reasoning methodology for evaluation of conceptual system architectures", Research in Engineering Design ,DOI: 10.1007/s00163-010-0086-1.

[15] Tumer, Irem Y., Stone, Robert B., Bell, David G., "REQUIREMENTS FOR A FAILURE MODE TAXONOMY FOR USE IN CONCEPTUAL DESIGN", INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED 03 STOCKHOLM, AUGUST 19-21, 2003.

[16] jun, Zhang xiang, lin, Gui chan, "Gene Models in Intelligent Computer—Aided Design ", Chinese Journal of Mechanical Engineering, 2001, 37(2):8-11.

[17] Muller Guillaume, Vercouter, Laurent, "Decentralized Monitoring of Agent Communications with a Reputation Model",Lecture Notes in Computer Science, 2005, Volume 3577/2005, 144-161.

[18] Tumer, Irem Y., Stone, Robert B., "MAPPING FUNCTION TO FAILURE DURING HIGH-RISKCOMPONENT DEVELOPMENT", Corresponding Author. Accepted to Research in Engineering Design. Conference version published in ASME/DETC 2001.

[19] Yongtao, Hao, Qin, "Feature-Function Expression Model and Gene Coding for Products", Fifth International Conference on Natural Computation.