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APPLICATION OVERVIEW OF THE RSM METHODOLOGY IN THE PRODUCT DESIGN SCENARIO

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Abstract. *The dynamic scenario of product design and the growth in design complexity has led to the increase of interrelated risk parameters in order to assist decision-making processes. In this context, this study aims to present an overview about the application of RSM (Risk Structure Matrix) methodology in order to verify its applicability at product design phases. Our goal is to verify possible opportunities of integration, similarity and difference through the review of this existing method of risk management for product design. The literature reviews of RSM show big developments for project management and processes, but only a few theoretical examples can be found for the application of the method for product design. Thus, the purpose of this paper is to highlight the opportunity to use this method for product design. In our future research and development, we shall verify the efficiency of application in order to verify if it can be considered complementary to traditional product design models and tools.*

Keywords: *Product Design, Risk Management, Risk Structure Matrix, Project Management.*

1. INTRODUCTION

Project complexity is the property of a project that makes it hard to understand, foresee and keep under control its progression, even when reasonably complete information about the project system is known. This definition of project complexity proposed by Ludovic (2010), is in agreement with the definitions of Baccarini (1996), Marle (2008) and Vidal et al. (2008). Considering the project definition of the PMI (2013) "A project is a temporary endeavor undertaken to create a unique product, service or result" and extending to the practical project concept of having a defined beginning and end; both definitions meet when the project phases, along with its inter and intra dependencies, need to be identified.

Project complexity involves decisions-making (Earl et al, 2001 and Vidal et al, 2009) which may lead to communication and coordination problems in a complex scenario. The uncertainty and instability intrinsic to projects increase the complexity and reduce the efficiency of decisions, leading to increases in risks.

White and Fortune (2002) have mentioned that that there are lots of arguments that projects fail due to inappropriate risk management and others authors, such as, Grimaldi (2005) and Smith, Merritt (2002) have stated that risk management is the critical factor to guarantee project success.

Raz and Hillson (2005) compare the main available standards of risk management. For example the Project Management Book of Knowledge, PMBoK Guide, PMI and the Project Risk Analysis and Management, PRAM Guide, verified that despite the variation in process quantity between them, they approach the same main processes of planning, risk identification, analysis, monitoring and control.

For this overview, we studied a cluster methodology proposed by Ludovic (2010), called Risk Structure Matrix that helps project risk management under complex scenarios, focusing on the interdependencies of projects risks.

Therefore this study objective is to present an evaluation of the RSM method, considering the advantages of clustering risk interactions and evaluating its applicability for product design.

2. PRODUCT DESIGN

In order to adapt to the actual competitive scenario and achieve the strategic objectives of the organization, industries are concentrating their efforts more intensely on design practices towards the development of their products, helping companies to face the challenges of the market in the globally.

For this environment there are several paths and rules with concepts, methods, techniques and tools; it is only necessary to choose the most appropriate form and develop it with commitment, establishing goals, monitoring the execution and being creative (Cordeiro et al., 2015). Thus, the relationship between project management concepts and product design becomes essential.

The approach to these management and methodology universes needs to be more intense and integrated, because during the development of a project it is necessary to share knowledge. The integration and cooperation of all the team is necessary so that there are no problems of communication and lack of information.

Cordeiro et al. (2015) states that the product development process involves research, planning and constant control. For this process to occur in an orderly manner we should use design methodologies. The design methodologies exist to assist the designer in the product development task, through the customer's need generated by the market. The design methodology can be defined as a collection of procedures, methods and techniques, in order to help designers in the activity of product development. Therefore, product design are methods applied in the project development to help the creation process and its application cannot guarantee the success of the product project, but increases the chances of success of product development.

Pahl et al. (2007) describe the design methodology as a planned procedure that is a joint result of project knowledge with cognitive psychology and know-how of different applications. Roozenburg and Eekels (1995) say that product design consists of a method system, in the other words a set of procedures, which are applied in the project activities. However, Evbuomwan et al. (1996) define product design as one collection of procedures, tools and techniques for designers during the design process. According to Delgado Neto (2005) the methodology used to design a product varies from product and company.

At the beginning of the project many aspects are not clearly defined, resulting in the need for tools which support project development; the methodologies. To facilitate organizing information, data generation, data analysis and choice of solutions, most of these methods are applied to product design, however it is necessary to follow some sequence of development steps.

According to Dedini (2002), the process of development of industrial products, is divided into three sequential phases: Planning, Product Design and Implementation. After the completed steps, the designer receives a report with the fundamental concepts for the development of the project. In Figure 2, the steps of the three phases of operation are shown: feasibility study, preliminary design and detailed design in flowchart form.

The design of a component or system provides in each case, a chronological and methodological development that allows the creation of a model common to almost all projects. In the figures below, we may verify that risk management in figure 1 and design methodology at figure 2 have a link with the planning phase of the project management and feasibility study for design methodology. They complement each other and both are necessary considering the risk features.

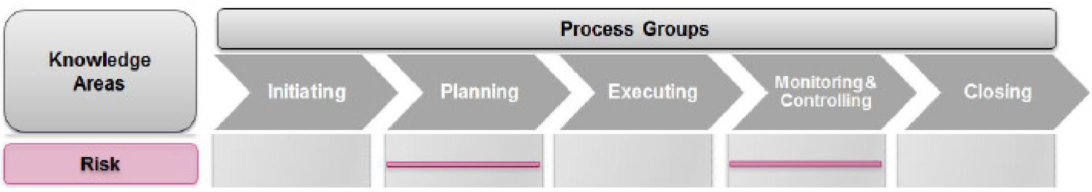

Figure 1. Project Management flow for risk knowledge area
Source: adapted of PMBOK (2013)

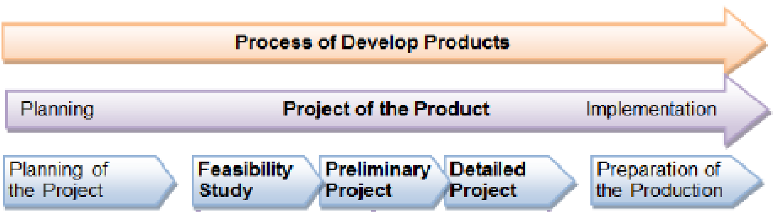

Figure 2. Basics steps of the product design, LabSin
Source: adapted of Delgado Neto (2010)

1-Feasibility study: identify the problem and clearly define input data, even as main observations and constraints are decided for the project. The understanding of market and customers allows the raise of designer sense about the problem, these characteristics and disposal of customers can be converted in engineering parameters through tools of products design. The creative process should be scanned widely to generate as large a number of alternative solutions as possible. The result of this phase is a set of creative solutions with technical and economic viability.

2- Preliminary project: the main objective is to analyze the solutions presented in the feasibility study. In this phase, mathematical modeling, simulation and optimization are done, in order to transform this into a decisive step in the project design process. All the calculations and dimensioning supports finding the optimal option through the numerical simulations and eventually, it is possible to reevaluate some or all of the project steps. One of the key points at this phase is to consider properly the necessary parameters and their functions ensuring nothing was forgotten. The focus in this step is dimensioning and optimization of the functions.

3-Detailed project: involves a set of complete drawings and specifications of components, assembly, installation drawings, prototypes, layout and definitions of assembly parameters. In this step the solution chosen in the preliminary project will be detailed and tested, therefore the focus of this phase is detailing, definition of tolerances and constructive adaptation.

According to Cordeiro et. al. (2015) for each step can be applied different methodological tools such as QFD, Functional analysis, Brainstorming, TRIZ, Matrix morphology, FMEA and others. These are some of the possible tools to be use for the design process and can be used in any kind of project according to the necessity and profile of each company.

In this paper, considering the risk subject, one tool of design methodology needs to be focused on. Failure Mode and Effects Analysis (FMEA) is a well-established method in product development. In some parts of the industry, e.g. automotive suppliers, the application of FMEA is even compulsory. The method comprises the systematic linking of components, functions and failures in a comprehensible and target-oriented way. By application of FMEA, failure chains shall be derived, rated and optimization measures implemented. The amount of possible failure chains can be very high.

Despite of the existence of one tool for identifying failures at the product development flow, a matrix-based method for dependency modeling shall improve the generation of functions and failure networks and consequently increase efficiency as showed by Maurer (2011). “The matrix-based method shall not replace the established procedure and tool application. In fact, it shall be integrated into the existing approach “, as will be presented in the next sections.

3. DESIGN STRUCTURE MATRIX - DSM

Before detailing the existing risk methodology to evaluate the application for product design, it is mandatory to understand the concept of Design Structure Matrix (DSM), because it is the basis for understanding possible interactions between interfaces.

DSM is a compact matrix representation of a design system or a design engineering project. This approach is widely used to model complex systems in systems engineering or systems analysis; as described by Steward (1981), Eppinger (1991), Browning (2001), Sosa et al. (2004); particularly in the contexts of project planning and project management; (Eppinger et al. 1992, Carrascosa et al. 1998).

Hellenbrand (2008) proposed an approach that combines different component alternatives in order to list consistent concepts. The clustering is done through the filling in of a DSM by engineers. The only information available is the existence or not of the compatibility between two components. This is presented by an “X” square in the matrix.

Depending on the type of system being modeled, DSM can represent various types of architectures. Wyatt et al. (2008) define an “Architecture Schema” based on an ontology where “components are linked to component types and to connection types”. For example, to model a product's architecture, the DSM elements would be the components of the product, and the interactions would be the interfaces between the components. Thus, DSM is a generic tool for modeling any type of system architecture.

A DSM consists of a square matrix. The cells along the diagonal represent the system elements. The sources and destinations of these input and output interactions are identified by marks in the off-diagonal cells analogous to the directional arcs in the digraph model. Reading across a row reveals what other elements the element in that row receives inputs from, and scanning a column reveals what other elements the element in that column provides outputs to.

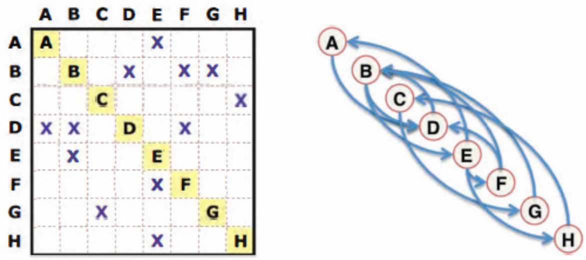

Figure 3. 8 Elements DSM and its Graph
Source: Eppinger (2012)

Steward (1981) proposed the simple DSM as a binary DSM because of the off-diagonal marks indicating presence or absence of interaction. The binary representation can be extended showing data as the number of interactions and/or the importance, impact, or strength of each, represented by using one or more numerical values, symbols, shadings, or colors. The rows and columns are identically labeled and ordered, and the off-diagonal elements indicate the link between the on-diagonal elements.

Eppinger (2012) defined a five-step approach to architectural modeling and analysis, adapted below:

1. Decompose: Break the system down hierarchically into its constituent elements.
2. Identify: Document the relationships among the system's elements.
3. Analyze: Rearrange the elements and relationships to understand structural patterns and implications for system behavior.
4. Display: Create a representation of the DSM model, highlighting features of particular importance
5. Improve: Most DSM applications result not only in better understanding of the system but also improvement of the system through actions taken as a result of the DSM analysis and interpretation of its display.

DSM can be partitioned or rearranged using a variety of analytical methods, the most common of which are clustering and sequencing. Clustering analysis applies primarily to the kinds of interaction networks found in product and organization architecture DSM models, where interaction marks are largely symmetric about the diagonal.

Advantages of DSM for system architectures, adapted from Eppinger (2012):

• Conciseness: The structured arrangement of elements and interactions provides a compact representation format for complex system compared to other modeling approaches.
• Visualization: Highlights relationship patterns of particular interest to a system designer. Provides a system-level view that can support globally optimal decision making and help orient particular elements.
• Intuitive Understanding: Once introduced, people find that they are able to understand the basic structure of a complex system quickly once the DSM model is properly displayed. Hierarchy and complexity become apparent in a review of the tool.
• Analysis: The matrix-based nature allows to apply a number of powerful analyses in graph theory and matrix mathematics as well as specialized DSM analysis methods. Can also illuminate indirect links, change propagation, process iterations, convergence, modularity, and other important patterns and effects.
• Flexibility: highly flexible system modeling tool. Since its initial development more than three decades ago, many researchers and practitioners have modified and extended the basic DSM with helpful graphics, colors, and additional data.

The Design Structure Matrix method has proven to be a practical tool for representing and analyzing relations and dependencies among components in system design. Fang et al. (2010), proposed to extend the concept of DSM to risks in project management.

4. RISK STRUCTURE MATRIX (RSM)

Fang (2012), Marle (2013) and Ludovic (2010) state that the interrelations between project objects, such as activities, actors and product components, can facilitate the identification of interrelations between the risks related to these objects. The objective of the Risk Structure Matrix (RSM) is to group risks in clusters, in order to achieve a better number of interactions inside the project, facilitating the coordination of subjects involved in the process of project risk management.

Considering a process evaluation, the project schedule may provide information about activity-activity sequence relationships which enable the link between two risks and allows delay identification between them. For a component-component relationship, whether functional, structural or physical, risks which may be related to product functions, quality, delay or cost can be linked, since a problem about one component may have an influence on another. In a similar way, the Domain Mapping Matrix - DMM (non-square matrix mapping the domain of one DSM to the domain of another DSM) and Multiple-Domain Matrix – MDM (represent more than one type of DSM in a single matrix) are helpful in identifying risk interactions across different domains of the project.

There are many risks of different natures, making identification an exhaustive task. Thus, to cluster the group in smaller groups is necessary and therefore easier to manage. These risks are interconnected, meaning that they are not independent events, and this dependency causes some problems in decision-making at risk management when decisions are being made about risk prioritization and risk mitigation actions.

Risk Structure Matrix is a binary and square matrix in which $RSM_{ij} = 1$ when there is a link of potential causality from R_j to R_i, as described in Marle & Vidal (2008). RSM is the DSM with project risks as system elements. It represents causal interactions in the complex project risk network. RSM can also be regarded as a multiple-domain matrix (MDM) because risks reside in and could interact across different domains in project, as explored by Biedermann & Lindemann (2008).

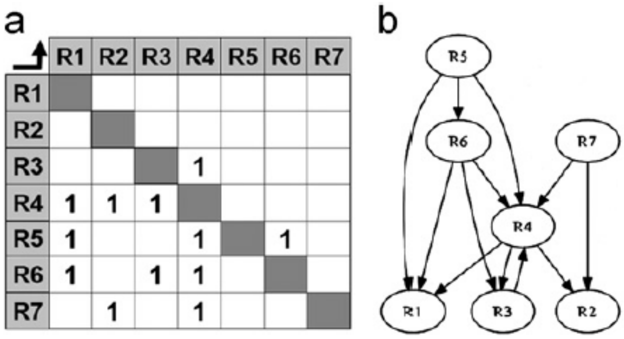

Figure 4. Illustration of (a) RSM and (b) project risk network
Source: Fang (2012)

The binary matrix RSM needs to be transformed into a numerical one to assess the strength of interdependencies, Risk Numerical Matrix (RNM). It is important to highlight that the method already exists and we are presenting an overview about the efficiency of this application.

Similarly to Chen and Lin (2003), Ludovic (2010) proposed a five-step approach to capture the strength of risk interactions, which enables the numerical matrix to be built. They are also detailed at the figure 5.

Step 1: Decomposing the problem into two sub-problems for each Xi. The elements which have a potential interaction with Xi either in column (possible effects) or in row (possible causes) are isolated by the extraction of each row and column as separate vectors.

Step 2: Comparing relatively the strength of interactions. For each Xi, the non-null elements of the two associated vectors are ranked using pairwise comparison principle. For every pair of elements Xj and Xk interacting with Xi, the user assesses which one is more important to Xi. This importance is expressed as an influence on an attribute of the element. Numerical values express these assessments thanks to the use of the traditional Analytic Hierarchy Process (AHP) scales. The same principle is applied to the other vector related to Xi, with the relative comparison of the probability that Xi influences more or less the elements it is connected to. The 2 NX vectors are assessed using the same principle.

Step 3: Extracting the eigenvectors. The AHP implies to concatenate previous vectors into two NX * NX square matrices, since we have 2 NX vectors of size NX which their principal eigenvectors are calculated using the maximal eigenvalue.

Step 4: Aggregating the results. The principal eigenvectors are respectively aggregated into cause/effect matrices (CM and EM). The ith row of EM corresponds to the principal eigenvector of the matrix relative to outputs of Xi presented in Step 3. The ith column of CM corresponds to the principal eigenvector of the matrix relative to causes of Xi.

Step 5: Compiling the results. The previous two matrices are aggregated into the final numerical matrix, the values of which assess the strength of interdependencies.

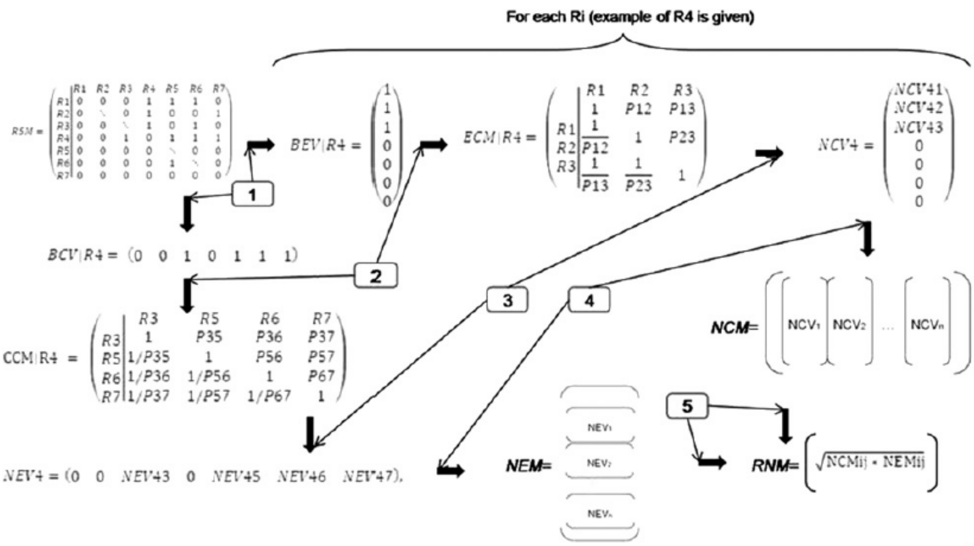

Figure 5. How to build the Risk Numerical Matrix (RNM)
Source: Ludovic (2010)

5. RESULTS AND DISCUSSION

Ludovic (2010) proved that the application of RSM allows the evaluation of risk interactions, because information can be checked and refined since the interaction needs to be listed twice, which causes an increase in the reliability of identification of risks and risks interactions. Clustering risks in order to maximize intra-cluster interaction values allows us to facilitate the coordination of risk monitoring and controlling activities which gives the project the cooperation and transversal communication within the project team since communication has already been facilitated.

Fang (2011), showed that risk networks enable re-evaluation of risks with their characteristics, such as risk probability and risk criticality and the results provide project managers a new insight into risks and their relationships, helping the planning of effective mitigation actions. Figure 7 shows a visual RSM with risk classification in colors and it´s respective clusters.

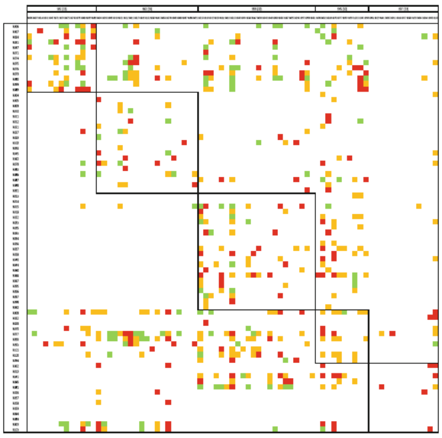

Figure 7. Clusters of a RSM
Source: Ludovic (2016)

As a consequence of these applications of RSM in a project management scenario, the expected result for the use of the methodology for products development is a clear way to visualize the risks at the beginning of product design.

From the literature review, the tool permits greater communication on project risks as well as better confidence in risk management activities making possible a new approach for the product design in comparison to FMEA, changing the point analysis from the end to the beginning of the project/product/process cycle.

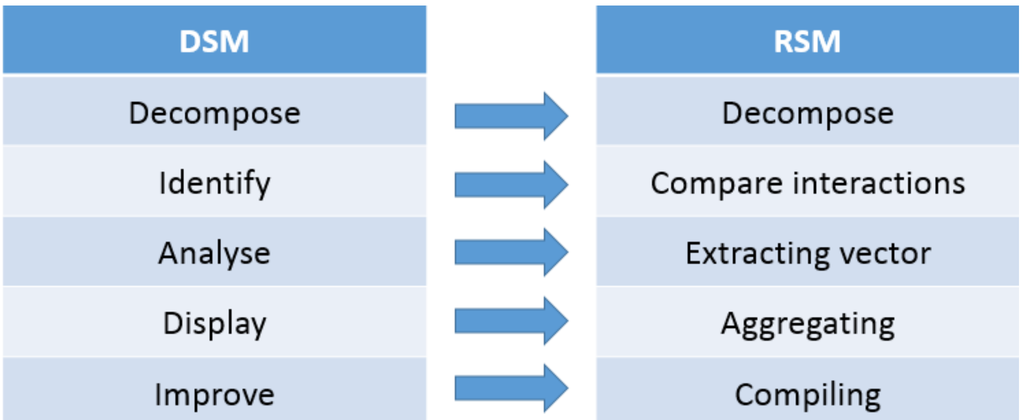

Figure 8. Approach of DSM and RSM construction
Source: adapted of Eppinger (2012) and Ludovic (2016)

The phases of the DSM and RSM described by Eppinger (2012) and Ludovic (2016) were detailed previously. When we take a closer look at the phases, as in the summary in figure 8, we may verify that they are very similar due to the matrix method. The DSM is already well known as helpful for design methodology, with this comparison we may confirm that the risk matrix although mostly used for project management is adequate for the use at product design methodology. In future studies we intend to use the RSM method for cases studies at design methodology.

The RSM methodology applied to product design may guarantee high efficiency of risk management activities and also allows better communication on project's risks. The Cluster grouping methodology changes how decisions are made broadcasting the risks detection from a local approach to an integrated system.

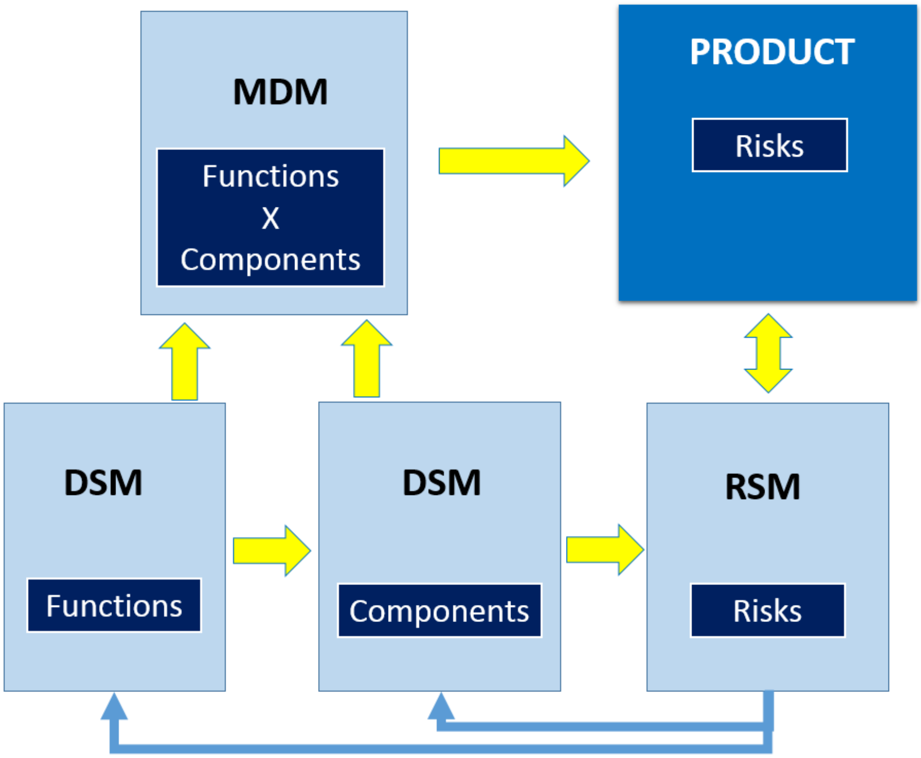

Figure 9. Model of risk, components and function interactions at product design

Figure 9 represents our model for the interactions between functions, components and risks, in the DSM and RSM scenario. The link between functions and components occurs at the feasibility study phase of the product design, and the risk analysis usually occurs after the viability study at the preliminary phase as shown before. Along with the application of the RSM, we intend to verify the risks and its interactions at the feasibility study phase as soon as the risk parameters are identified by the designers. This application may provide better accuracy in the choice of a solution amongst the other options because the risky results may be excluded or modified before the viability study.

It is important to highlight that our purpose is not to substitute the FMEA and the different approach of the RSM. As described before, FMEA is filled out after the viability study at the preliminary phase and doesn´t show in a clear way the interactions between risks. RSM at the design of product application may contribute to the FMEA as complementary information because this may improve the visual management as long as the clusters are identified, but the main difference is the application of the RSM at the feasibility phase.

The greatest benefits of the use of RSM for product design are related to visual management, phase of development and risk interactions as verified before. At the beginning of this study we checked the advantages of DSM too. After evaluation of the bibliography and compound our model we suggest that the expected advantages of the use of RSM for product design are:

- Complementary approach to the classical risk management method and for FMEA.
- Understanding of the inter-relations of the product in a “local-Cluster” way or for the whole product.
- Cluster isolation of the products risks, making them not propagate to others clusters, and avoiding failure propagation.
- Chance to take corrective actions considering the interactions between risks and not just the isolated risk. Sometimes, to break the connection between risks may be more effective then to mitigate the risk itself.
- RSM tool permit greater communication on project risks as well as a better confidence in risk management activities along with visual management.
- The method can provide to the decision maker complementary classifications that along with the existing ones give powerful early-warning signs about the reality of complex phenomena.
- The application at the feasibility study phase facilitates the identification of solutions that are too risky to be considered for the viability study at the preliminary phase.

6. CONCLUSION

This research provides a theoretical basis to better understand interrelated scenarios of products design and risk management. By the basic approach it is possible to highlight that these concepts apply techniques which may support the product design process.

Although this paper is an initial understanding about RSM applied to product design, it can be considered a starting point to discuss more about applications of this technique, aiming to encourage future studies and developments which follow the complexity and market increase demand.

In this paper it is possible to observe that risk structure matrix may provide several benefits to product design, both for the phases of product development itself and for the improvement of the specific existing risk methodologies such as FMEA. In future researches, case studies will be detailed in order to check the efficiency of the expected results.

7. ACKNOWLEDGEMENTS

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