Workflow-Based Decision Support for Failure Mode and Effects Analysis

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Abstract: To achieve high quality designs, processes, and services that meet or exceed industry standards, it is crucial to identify all potential failures throughout a system and work to minimize or prevent their occurrence or effects. This paper presents an innovative approach to Failure Mode and Effects Analysis (FMEA) that uses a Decision Support System (DSS) for supporting the FMEA processes. The DSS is powered by a workflow engine that guides the users through the processes by considering standard work templates or previous similar cases. It is also built as a framework for decision support tools so, beside its default one, different FMEA work instruments can be plugged-in and used throughout a workflow instance by exchanging results in a common data format. Collaboration is assured by the systems web-based interface that supports multiple users from anywhere, at any time.

Keywords: Failure Mode and Effects Analysis (FMEA), Decision Support Systems (DSS), Collaborative Work, Workflow Engine, Case Based Reasoning (CBR).

1. INTRODUCTION

Preventing process and production problems before they occur is the purpose of Failure Mode and Effect Analysis (FMEA). Used in both the design and manufacturing processes, they substantially reduce costs by identifying product and process improvements early in the develop process when changes are relatively easy and inexpensive to make. The result is a more robust process because the need for after-the-fact corrective action and late change crises are reduced and eliminated (McDermott, Mikulak and Beauregard, 2008). The paper presents an innovative approach to FMEA that uses a Decision Support System (DSS) developed by Ropardo S.R.L. for supporting the processes. At a higher level this takes place inside an integrated system called *iPortal*, which is actually a software suite for different business related activities like project management, document management, decision support systems or other forms of collaboration.

This endeavor is carried out within the *iDDesign Research Project (Intelligent Decision Support System for Advanced Product and Process Planning and Design)*. The innovation lays in the way that the FMEA worksheets are managed; in the grading method/procedure. The proposed architecture mixes the use of the wiki technology with the flexibility of the DSS tools. FMEA worksheets are displayed as wiki pages inside iPortal in order to manage the entries, while the actual grading process is done by launching a DSS tool inside a virtual meeting (session) that has all the required participants invited. At this point, depending on the nature of the graded item, different tools are selected. For example, if a consensus for the severity of an item must be reached, then a 10-point scale voting meeting is started where each participant grades the item's severity on a scale from 1 to 10. Multiple worksheet items are handled in the same DSS meeting if necessary and of course, for simplicity, in case of trivial items this whole collaboration process is replaced with simple Skype conferences. Also, a *workflow* engine that resides inside the system automates routine operations in order for the FMEA process to run as smooth and efficient as possible. This is based on a Case-based Reasoning implementation, called *Experience Database* which is also integrated into iPortal.

The DSS system is called *iDecisionSupport* and was developed in the last years at Ropardo S.R.L. It was developed within the CEEX (Research of Excellence) project as a software framework for group decision support systems (Georgescu, Cândea and Zamfirescu, 2007). The original name was *iGDSS* and served as a placeholder for DSS (GDSS) tools allowing them to run and interchange results. It will be referred to as *iDecisionSupport* or *the DSS*.

Access to the entire system is provided via web interfaces with SSO (Single Sign-On) features so that attending the FMEA work sessions is done via web-browsers and is not restricted to localization.

Section 2 reviews briefly the existing FMEA software, the DSS and iPortal systems. *Section 3* describes the FMEA worksheet approach and is followed by the presentation of the (DSS) grading process in *Section 4*. The workflow concept and the Experience Database are described in *Section 5* while the conclusions are presented in *Section 6*.

2. SOFTWARE FOR FMEA

2.1. The Trend

Software FMEA has been referred to in the technical literature for more than fifteen years (Goddard, 2000) and software packages for Failure Mode and Effect Analysis appeared on the market in the last two decades, especially after the year 2000 when the lack of collaboration support of the existing tools yielded for some web based tools (Huang, Shi and Mak, 2000).

There are many different types of failure mode and effects analysis (FMEA) software. Choices include process, design, concept, equipment, service, system, and software. Process applications are used to analyze various manufacturing and assembly processes. Design applications are used to examine products prior to their production. Concept-oriented FMEA software enables businesses to analyze systems or sub-systems in the early-design or conceptual stage. Equipment applications enable procurement personnel and operators to analyze machine designs before purchasing expensive capital equipment. Service-oriented FMEA programs can help service industries analyze processes before their release to the customer or end-user. The impact upon the customer is an important part of this analysis. Finally, some types of failure mode and effects analysis (FMEA) software are used to analyze the functions in other software systems.

The approach presented in this paper is compatible with all of the types presented above. Some similar DSS approaches to FMEA were attempted by implementing a methodology based on a decision system supported by qualitative rules which provides a ranking of the risks of potential causes of production system failures. (Puente, Pino, Priore, Fuente, 2002)

2.2. History of iDecisionSupport

The DSS system was developed at Ropardo S.R.L starting from 2006 (although the idea was from way back) within the CEEX project and was continued separately afterwards. iDecisionSupport is a web based framework for decision support tools that provides a collaborative environment where different software tools for decision making can be easily integrated while the users can access them remotely and asynchronously (Georgescu, Cândea and Zamfirescu, 2007). Its use and development is continued now within the *iDDesign* project where we will create a FMEA software package for an automotive enterprise in Sibiu based on the tools that it provides so far and also to develop new ones if necessary.

2.3 iPortal

iPortal was also developed by Ropardo S.R.L within the *m-Business Research Project* and is a software suite for project management, document management, decision support systems, collaborative work and other business related activities, unifying them all in a single web-interfaced access

point. The solution is in the form of a web-portal that plays an active role for SMEs employees, partners and customers by managing business content, unifying work teams and providing access to essential documentation, functionality and services with the help of well structured wiki (Cândea, Georgescu, Cândea, 2009). Figure 1 shows the most important integrated components that are also the basis for the FMEA implementation. Beside the DSS and the wiki, iPortal integrates the *Experience Database* component. This is a Case-based Reasoning implementation that is used to provide support for detecting potential failure modes from different past (occurrences) experiences.
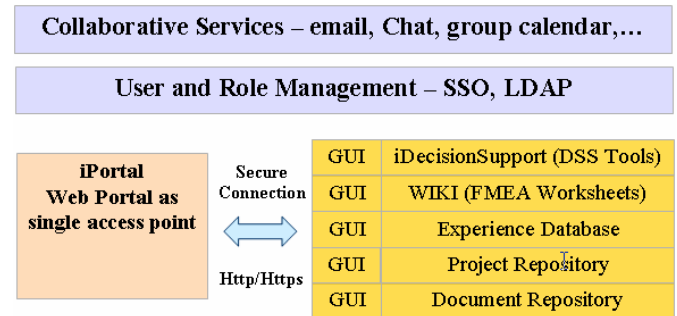

Fig. 1. iPortal components.

iPortal introduces the concept of "project-based" activities which focuses collaboration around projects. This enhances managing data and capturing knowledge on specific topics, and also determines a better organization of tasks and solutions. Project content stored in the repository can be easily referenced and accessed from the existing applications. There is no need to create duplicates of the documents or go through additional authentication procedures (Cândea, Ciovică, Radu, 2008).

3. THE FMEA WORKSHEET

This section starts with a brief description of the FMEA process (use of FMEA worksheets during this process) and then it describes the way that these worksheets are handled.

3.1. FMEA worksheets

FMEA processes are based on worksheets that contain important information about the system, such as the revision date or the names of the components. On these worksheets all the items or functions of the subject should be listed in a logical manner, based on the block diagram. For each item or function, the possible *failure modes*, *effect* and *causes* are listed and each of them are graded for their *severity (S), frequency of occurrence (F), and detection rating (D)*. Afterwards, the *Risk Priority Number* (*RPN*) is calculated by multiplying S, F and D. Once this is done it is easy to determine the areas of greatest concern. This has to be done for the entire process and/or design and the items that have the highest RPN should be given the highest priority for corrective action. After these values are allocated, recommended actions with targets, responsibility and dates of implementation are noted on the worksheets.

During the FMEA process it is important to confirm that robustness and past history are included in the analysis. This means that when listing failure mode, effects or causes for different items this information should be taken mostly from previews cases (experiences) due to the fact that products do not change drastically during the development process so a lot of their possible problems are similar. When new failure mode appears in the picture they are recorded and taken into consideration in future analysis.

3.2. FMEA worksheet inside the system

In order to provide the FMEA worksheet features in a flexible way, the proposed architecture handles the worksheets as wiki pages inside the iPortal system. Each FMEA worksheet is accessible via web browser and it can be manipulated in a flexible manner while still respecting the FMEA worksheet standard template. Figure 2 shows the layout of a worksheet inside the system. It consists of two sections:

- Worksheet metadata header containing the product / piece / sub assembles name, FMEA coordinator, team, page number, and other information that is used to identify the worksheet among the many other that make up the FMEA process

- FMEA block diagram (table) which contains the worksheet items (along with their possible failure modes, causes and effects) and their grades (Risk Priority Number–RPN, Severity–S, Frequency of Occurrence–F and Detection Rating-D).

Fig. 2. FMEA Worksheet inside the system.

The worksheet table is the most important part because it communicates with the Experience Database component in order to provide support for detecting failure modes, causes and effects based on previous experiences (similar cases). When an item or function is selected (e.g. "Fill Tub") the table provides all the known potential failure modes in the order that they were usually found or alphabetically, and the user selects the necessary one. If a new failure mode comes up then it is introduced in the table and from there it goes

automatically in the Experience Database component which records also the context that it appears for future support. Experience DB (in combination with the worksheet table) can be seen also as an auto completing nomenclature of failure modes, causes, effects of different other information that can speed up the FMEA process.

New items are automatically created by the system if they are part of routine steps along with all their corresponding DSS meetings prepared for work. Items are also created as results of brainstorming meetings where all the ideas that were generated are interpreted as causes or effects depending on the initial question (issue).

Each item has links for accessing directly the grading DSS meetings. Because of the SSO (Single Sing-On) implementation the user will enter the DSS system without any further authentication. Also, a tree view of the worksheet items can be used for a clearer picture of the whole process (for each potential failure mode there can be multiple causes of effects so it's a bit difficult to track them down in the block diagram).

Another important aspect of the wiki architecture is *security*. The access rights on each page (worksheet) are configured by the FMEA coordinator so the page can be viewed or edited only by the team members that should. Security is based on user and role management system of iPortal which is present in all the integrated components. This means that the restrictions that are imposed to a worksheet are automatically reflected into the DSS part.

The underside of the worksheet (footer in Figure 3) shows other features of the worksheet:

- The Attachments section allows uploading different files that are relevant to the worksheet so they can easily be accessed by the team members.

- The *Comments* section allows commenting on the current work in free text.

- The *History* is the most important of these because it provides worksheet versioning capabilities. All the changes are tracked in this section and can be viewed compared and restored if necessary.

Fig. 3. Worksheet footer

4. TOOLS

The grading for the *severity*, *occurrence or detection* of each worksheet item is done throughout DSS meetings using the tools that it provides. This section describes the grading process, the DSS architecture, and the tools that are used in the grading process.

4.1. Grading process

When an item must be graded the system starts a new DSS meeting with all the requested users invited (all the iPortal project members by default). Of course this happens in the case of non-trivial items which are resolved simply through Skype calls. So, the system uses the DSS API to initiate a new meeting. This means setting a time period, selecting the type of meeting (voting, brainstorming, etc), adding the participants and the worksheet items that have to be handled. To avoid generating an enormous number of meetings (one for each item graded), multiple items are grouped and the participants work on all of them as it would happen in a real face to face FMEA meeting.

Until the work on the item(s) is finished (the meeting reaches its end) the process is managed entirely by the DSS system and all its features are available. All the required participants are notified by e-mails that contain links to access directly the meeting(s) that they have to attend. The e-mail contains also short briefings which are also found in the actual meetings. The results (e.g. the average grade for each item from a 10-point scale voting meeting) are uploaded automatically into the worksheet where are processed further. Figure 4 describes the integration between FMEA components inside iPortal showing the connection between worksheets and DSS meetings, the dataflow between components, the notification procedure and the way the users access the system. Following there are the most important aspects of this integration:
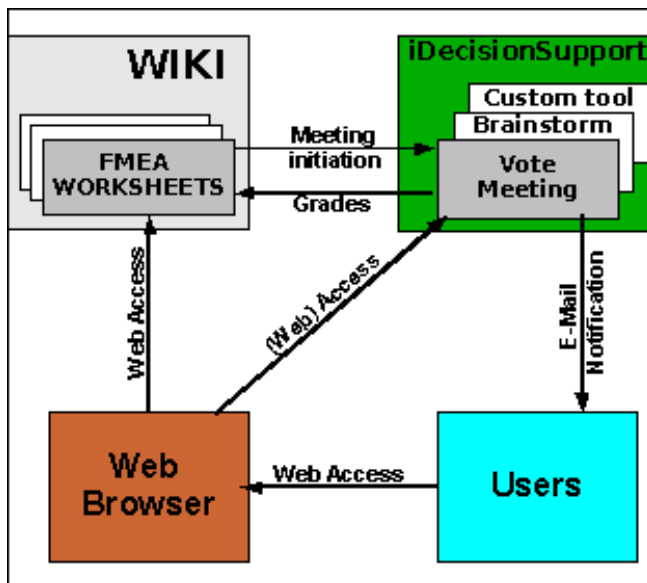

Fig. 4. FMEA components.

- The wiki component and iDecisionSupport can reside on two completely different machines; they communicate through web service API's to exchange information or result grades. This approach adds scalability to the system which is a necessity in large scale and complex system

- User access to all the components are done via web browsers through a strong SSO (Single Sign-On) implementation inside the system so once a user enters it using the e-mail link or a normal login he/she can "move around" freely from one component to another without having to re-authenticate.

- Although the tools are represented inside the DSS system this is because they are considered as a whole but the tools can reside anywhere on the internet. This also contributes to system scalability.

4.2 DSS architecture

The iDecisionSupport framework is built of two main components: the DSS server and the DSS web client (interface). Beside these, there are of course the tools (Section 4.3) that can reside anywhere, integrate directly with the server using the server API and are accessed through the web-client.

The *DSS server* handles all the business logic by separating meetings in projects and plans (sub plans) and by providing a web-service API for the tools. It uses a relational database (PostgreSQL, MySql or other) to store all the meeting information (metadata, duration, participants, etc) and the meeting results that are transferred from the actual tools (which can stay on different machines). This way, if at some point a tool becomes unavailable, the work that has been done with it is saved. The server also manages the data transfer from one tool to another. This information is stored in XML format and different XSLTs for data transformation can be applied if a tool has a different internal data format.

The server has a build in workflow engine which can create the session chains presented in Section 5.2. The workflows respect the WfMC/Wf-XML standard and can be developed with any compliant workflow editor and uploaded in the system. In addition, the server also provides an internal agents environment for software agents that perform very specific FMEA (or any other type of) actions which cannot be generalized.

The *DSS web-client* is the access point to all the described features. It has a tree view of all the meetings (grouped by projects and plans) and manages the access to the meeting tools. Beside this it has different entry points and views for accessing the system from the notification links.

Both components are build using the Java language and Java related technologies (spring, struts, axis for web-services, JSP/JSTL, JADE (Java Agents Development Framework), jBPM for the workflow engine).

4.3. DSS tools

iDecisionSupport provides a default set of tools that can be combined to efficiently perform the grading process of a certain set of items. Other custom tools can be developed and integrated in the system if necessary. Most of them are web-based but desktop applications are also integrated.

Vote is a decision support tool for voting (polling) activities. Different items (described in free text) are graded by the users using different methods like 10 point scale grading (Figure 5) or expressing the agreement level (agree, disagree, strongly disagree, etc) or by selecting a subset of the initial issues.
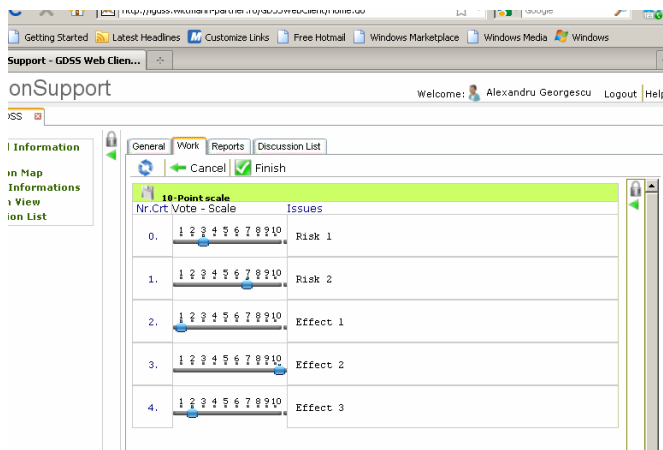

Fig. 5. Voting tool inside a vote meeting

Brainstorming is another decision support tool that allows for electronic brainstorming meetings (sessions). The activity starts with an initial aspect (problem or question) that is the subject for ideas coming for the users. Each of these ideas is commented with positive or negative arguments which are be the source of new questions that continue the cycle. Throughout this procedure lots of ideas are generated and their positive and negative aspects are emphasised.

Discussion List is the tool that provides forum like discussion threads for different aspects that need to be discussed. It inherits all the forum features for thread management and also adds new ones like *maximum replies per user.*

Multi-criteria analysis (or voting) is a tool that allows for grading different items relative to different reference points. For example, the severity of a potential failure can be graded depending on multiple possible effects.

MindMap is a tool for creating mind map diagrams for generating, classifying and visualising ideas. This is an example of a desktop application tool which is still accessible from the DSS system. It communicates with the other components in the same way that the web-based tools do, the only difference is that it has to be downloaded locally to run.

Custom (Third Party) Tools can be developed by or for any company that would like to implement this FMEA software approach.

5. WORKFLOWS AND EXPERIENCES

In order for the processes to run as smooth as possible and the collaboration to be efficient the system tries to automate as much as possible the repeating or routine actions. This section presents the actions autoamated actions within the worksheets, the DSS workflow engine and the Experience Database component.

5.1. Workflows inside the worksheets

The worksheet handles the ontology for items so it knows their meaning or details and can automatically configure the DSS meetings that handle each item. This auto configuration consists of setting the correct meeting type (voting, brainstorming, etc), writing down the item (or multiple items) as the initial data of the meeting and setting its duration. Also, this information is captured from past experiences by remembering manual meeting configurations that were done by the users. New items may also be automatically created by the worksheet if they are part of routine steps along with all their corresponding DSS meetings prepared for work. Also new items may appear as results of brainstorming meetings. For example, as described in Section 4.3, all the ideas that result from this type of meeting are interpreted as causes of effects depending on the initial question (issue).

5.2. DSS workflow engine

The DSS system has its internal workflow engine which allows for creating chains of meetings of different types where the output data of one is the input data for another. This allows for having multiple meetings for grading more complex worksheet items. For example, some items may exist that need to be discussed before they can be graded or they simply need some details collected form each participant. In this case, a *discussion list* meeting will precede the voting (grading) one. After the first one is finished the workflow system automatically starts the second one and imports the items and details into it. Of course this can continue with a third meeting of a different kind including the ones that are based on custom tools.

5.3. Experience Database

The *Experience Database* component is a Case-based Reasoning implementation that is designed to provide user support for faster worksheet completion. It acts like an auto completing nomenclature for failure modes, causes, effects or other information. This means that these items can be searched in the database by *standard invocation* or added in case they are newly discovered. The component implements the Black Box (BB) concept.

The standard invocation process starts a search in databases – search that is done after similarity functions that are defined on the component level. Search is done separate for each BB and each BB can define separate spaces (case space) in its database for a better case management. To start a new search an XML containing the case pattern data is sent to

Experience Database and, as response, an XML with the best n cases is returned. For the feedback phase the BB will send an XML with feedback data for the specific case pattern based on algorithms that Experience Database "learns".

6. CONCLUSIONS

The paper presented a new approach to Failure Mode and Effects Analysis (FMEA) that is undertaken within the *iDDesign Research Project*. The approach is based on a suite of components that are integrated by the *iPortal* system. This manages the FMEA worksheets using the *wiki component* and allows for their easy access and manipulation. The worksheet items can be displayed as a standard table (block diagram) or in a tree form for a clearer view of the whole process while a CBR implementation (the Experience Database component) helps managing the items (causes, effects, etc) faster based on previews similar cases.

iDecisionSupport is the component that handles the grading process through different types of DSS meetings which allow for better collaboration between team members. Multiple meetings may be performed for a worksheet item (or a set of items) within workflows that are based on standard actions or previous experiences.

Access to the entire system is provided via web-browsers using SSO (Single Sign-On) features, so that attending the FMEA work sessions is not restricted geographically and collaboration takes place easily.

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