Quality and Reliability Process Characterisation, Evaluation and Improvement in Product Design

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Abstract – The product quality and reliability (Q&R) are critical for business success in today's increasingly competitive market. Thus it is of value to have systematic approaches and software tools for deploying the Q&R throughout the design, development and delivery of new products. This research investigates how the key Q&R process variables function and interact with each other in the rapid product development processes, specifically in the product design process of consumer electronics; how to measure and control the Q&R performance in design process; and how the product Q&R and the performance of the design process are correlated. It also seeks potential Q&R improvement through IT solutions to integrate, coordinate, and share the Q&R information in the design process of the consumer electronic products.

Keywords: Quality and reliability, *Product design process, Failure mode and effect analysis, Reliability and quality matrix, Q&R process model*

1 BACKGROUND

The product quality and reliability (Q&R) is not only designed in the product, but also built in the product development processes, and delivered with the product to the customer in order to achieve a competitive advantage in today's marketplace. To do so, it is required that all the product lifecycle development activities and interactions should be carried out based on the consistent Q&R assurance methodologies, procedures, and systems from the product definition stage through the design, prototype, evaluation, mass production, to shipping, market, and service stages.

Product quality can be defined as the totality of features and characteristics of a product that bear in its ability to satisfy given needs [1], while product reliability defined as the probability that a product will perform its intended function for a specified period of time under a given set of conditions [1]. Over years, many studies [2-4] on product quality and reliability have been conducted and methods/tools [5-6] generated for specifying, implementing, analyzing, optimizing, and controlling the product Q&R performance characteristics in the product development processes. However, in a fast change world, the customer requirements on product Q&R are becoming far more critical and demanding, and the ways products are designed, developed, delivered, and used have been changed considerably. Many of the existing Q&R methods/tools are no longer providing effective solutions to the Q&R problems of the fast product development processes which are characterized by the following features:

- Short product development lifetime;
- Dynamic process relation with business partners and customers; and
- Quick process performance evaluation and prediction using approximate data and models at the early design stages, but eventually using more detailed data and analytical models when they are available.

The current research investigates how the key Q&R process variables function and interact with each other in the rapid product development processes, specifically in the fast product design process of consumer electronics; how to measure and control the Q&R performance in a design process which is under strong time pressure; how the product Q&R and the performance of the design process are correlated; and the methodologies and software tools to create, integrate, coordinate, and share the faster and more accurate information for the improvement of product quality and reliability.

2 OBJECTIVE

The objective of this collaborative research project (CRP) is to develop a product Q&R framework for providing methodologies, techniques and software tools to maximise the product quality and reliability, as well as the performance of the fast product design process, specifically:

- To provide methodologies for representation, acquisition, processing and correlation of both design process data and Q&R information;
- To define the Q&R process models and the Q&R information flow diagrams for analyzing and characterising the product Q&R process;

- To develop techniques and software tools to deploy these models for monitoring, evaluation and improvement of both design process performance and product Q&R performance.

3 METHODOLOGY

3.1 Characterisation of Q&R process

Characterisation refers to the process of identifying the specific parameters, activities and components responsible for the product Q&R performance in the fast product development processes. In order to understand the nature of the Q&R problems in such a rapid product development process, the following studies are performed:

- Analyzing the existing Q&R assurance systems of consumer electronic products;
- Identifying the Q&R methods/tools provided by the current assurance systems to see whether they are capable of handling the potential Q&R problems emerging from the rapid product realization process in a changing development environment;
- If not, what Q&R components/relations are missing from the Q&R assurance systems and how to improve them in terms of Q&R information management and Q&R information deployment throughout the fast product development processes.

Through the Q&R process characterization, Q&R components and interactions in the quality assurance systems can be identified. Fig. 1 shows the conceptual structure of one of such Q&R assurance systems for consumer electronic products design.

<table>
<tr><td>Customer demands</td><td colspan="2">Reliability & Quality Matrix</td><td>Supplier's Q&R data</td></tr>
<tr><td rowspan="3">Customer complaint</td><td rowspan="3">Corrective action</td><td>FMEA</td><td rowspan="2">Technical review</td></tr>
<tr><td>Design rules</td></tr>
<tr><td colspan="2">Electrical, mechanical, optical & software design</td></tr>
</table>

Fig. 1. Q&R system for consumer electronics design.

3.2 Q&R components analysis

FMEA – Failure mode and effect analysis (FMEA) [7] is one of the most widely employed techniques for enumerating the possible failure modes of product/function/process, and for tracing through the characteristics and consequences of each failure mode with the aim of reducing failures of products, functions and processes. The structured FMEA method identifies corrective actions required to prevent failures from reaching the customer, thereby assuring high quality and high reliability of the final products.

For consumer electronics, usually two types of FMEA analysis are conducted:

- Product design FMEA, which addresses potential product failures, causes, effects, and corrective actions in mechanical, electrical and optical components design;
- Production process FMEA, which identifies potential process failure modes, causes, likely effects, and recommended solutions and actions.

The FMEA form in the Q&R assurance system in Fig. 1 uses an alphabetical weight factor to assess the risk posed by each failure mode. It is recognised that a numerical risk priority number, consisting of three parameters of severity, probability of occurrence, and degree of possibility of a detection miss, should be calculated and assigned to each identified failure mode in the FMEA form of Fig. 1 to rank the risk of each problem.

RQM – The reliability and quality matrix (RQM) [8] is a Q&R method incorporating the basic functions from the QFD (quality function deployment) [9] and the FMEA methods. The RQM is designed for:

- Prioritizing the customer requirements and trade-off analysis;
- Identifying the relation between the customer requirements and the processes/parts;
- Predicting failure probability of the potential Q&R problems of the processes and parts identified;
- Evaluating the project risk and the project diversity toward the customer requirements.

The RQM is a comprehensive method for Q&R assurance in consumer electronic product development. However it is also a complex tool to use, which involves the large amount of data preparation and prediction, but is lack of the capability to quickly and easily draw a conclusion on project Q&R risk. Some other methods and tools are needed in the fast product development process to effectively manage both the Q&R information and the process data, to provide quick updates and comparisons on pro-

ject's progress status, performance, and Q&R metrics, and to support the fast and smart decision making process with precise and up-to-date information. The details of the Q&R process modelling methods and design process management tools from this CRP will be discussed in the following sections.

3.3 Q&R process modelling method

Product design is an extremely important process for ensuring high quality and reliability in consumer electronics. If we can accurately model all important aspects of the design process, especially the Q&R process, the design quality and the product Q&R performance would be expected to have significant improvement. The real value of a Q&R process model is its ability to capture and represent Q&R related information/knowledge and activity for prediction, evaluation, and improvement of design quality and product Q&R. In this project, the following steps are employed for Q&R process models development:

- Understanding the nature of Q&R problems in the consumer electronics design process – Product design should incorporate Q&R in all aspects based on design specifications, including design inputs for customer demands, in-house Q&R standards and procedures, and design rules. Product design passes through the stages of mechanical design, electrical design, optical design, software design, prototype and evaluation before reaching the industrial production release. The quality and reliability evaluation, technical review and design verification are carried out at strategic points throughout the design process to confirm that the design requirements and the Q&R standards are satisfied.

- Data collection – The industrial data collected for the Q&R process modelling include the design process progress data, the design process flow chart, the process performance indicator chart, and the Q&R evaluation metrics and procedure descriptions currently used in the industry.

- Identifying the Q&R related activities, their sequences, and relationships between each activity and the Q&R information – Company visits and interviews are conducted to identify the Q&R problems in product design and the countermeasures and plans to improve design quality. The usage of Q&R metrics, such as the FMEA, RQM, product/process maturity grid, and project risk list, is analysed to identify the flow of the metrics data across the Q&R process. The relationships of Q&R activities and metrics data are studied and modelled.

- Q&R process model establishment and validation – After performing the modelling steps described above, the Q&R process models and the information flow diagrams are established using ARIS toolkit [10]. The Q&R activities, sequences, interactions, and input/output information of each activity are documented in the eEPC (extended Event-driven Process Chain) model, while the flows of the Q&R process information are modelled in the ARIS information flow diagrams. All of these models have been validated through discussion with the industry involved.

3.4 Process-based Q&R management approach

To obtain high quality products it is necessary to effectively interface the Q&R assurance systems with the design process. To do so, it is required:

a) To build the Q&R process into the overall design process architecture;

b) To capture and manage the design process data and the Q&R information in software systems for support of the calculation, measurement, analysis, and control of the Q&R process;

c) To implement the Q&R improvement measures by integrating and sharing the design process information and the Q&R information with other components involved in the Q&R assurance system shown in Fig. 1, such as technical review, design rules, and customer complaints.

Currently the requirement (a) above has been deployed in industry by implementing the best practice and by quality systems standardisation. However the other two have not fully been deployed, as both require software systems' support. It is identified in this CRP that the software systems, together with the modelling methodologies and the process-based Q&R management approaches, should be developed to provide the functionality for:

- Design process management, and
- Q&R components integration,

in order to improve both the design process performance and the Q&R assurance capability.

The design process management system has been developed in this project. The Q&R components integration system will be implemented at a late stage of this CRP. Next section will discuss the details of the software development for the design process management system.

3.5 Design process management system

The following development methodology is used for the establishment of the NPI (new product introduction) process management system:

- User requirement definition – To analyse the design process flow and the current practice; to define the usage scenarios of the NPI system; and to validate the user requirements with the industry.

- Technical and functional requirement specification – Based on the validated user requirements to develop the system specifications by using descriptive texts and project documentation templates.

- Software design – From the user requirement analyses and the system specifications defined, to design the software components of the NPI system using UML techniques.

- Software implementation – To develop the NPI source code to fulfil the system functionality, including process architecture configuration, project setup, operational data entry, Q&R performance evaluation, problem area identification, and improvement analysis, etc.

- System test – To conduct on-site testing on the real design cases, to collect feedback from the industry, and to improve the software system.

- Final documentation – To review and document the NPI system development and implementation processes and to comment all source code developed.

4 RESULTS & DISCUSSION

4.1 Q&R process models

The design case studies of consumer electronic products are conducted for Q&R process modelling and Q&R information flow modelling across product design process. Fig. 2 shows one of the information flow diagrams in ARIS.

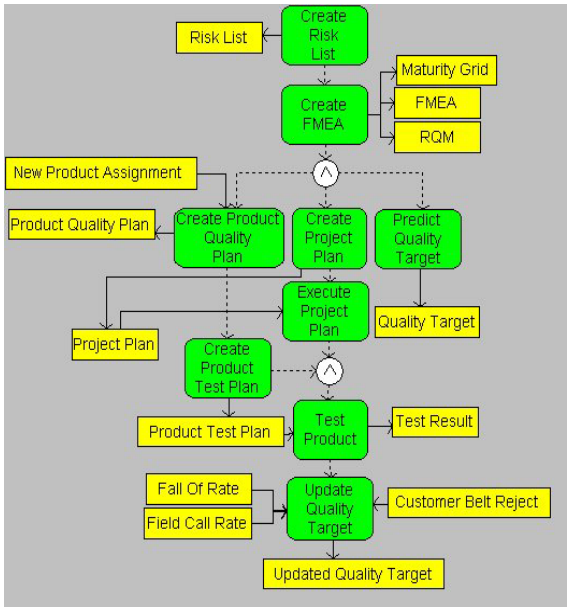

Fig. 2. Q&R information flow model.

The Q&R process starts with drafting a risk list at the early stage of design. It proceeds to determine the Q&R tools, including the project maturity grid, RQM, and FMEA forms for concept, project, design, and prototype. These tools will be used and updated throughout the design process. The next activities in the process are to create product quality plan, to create project plan, and to predict the quality target of the product, followed by creating a product test plan, executing the project plan, and testing the product. The quality plan will be used to guide the design activities compliant with the Q&R standards. The test plan will be execute in the prototype and qualification sampling phases to verify the product quality and functionality. The process ends with documenting the test report and updating product quality plan.

The process models developed can be used to design new Q&R tools/metrics and to simplify existing Q&R tools for satisfying requirements from the fast electronic product design process. They will also be implemented in the NPI process management system for making confident Q&R prediction and monitoring.

4.2 Software system design

4.2.1 Requirement analysis

The NPI software functional requirements are captured by the use case diagrams of the UML. Fig. 3 shows one of the use case views in the NPI system for “Project Setup” functionality.

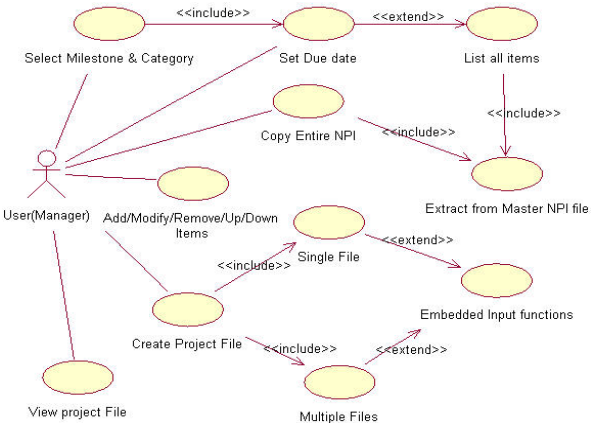

Fig. 3. Use case diagram for project setup.

4.2.2 System architecture

NPI system consists of five major functional modules providing services for process architecture configuration; project setup; operational data entry; data mapping and combining; and data analysis (such as design progress charting, Q&R performance evaluation, problem area identification, and improvement analysis) as shown in Fig. 4.

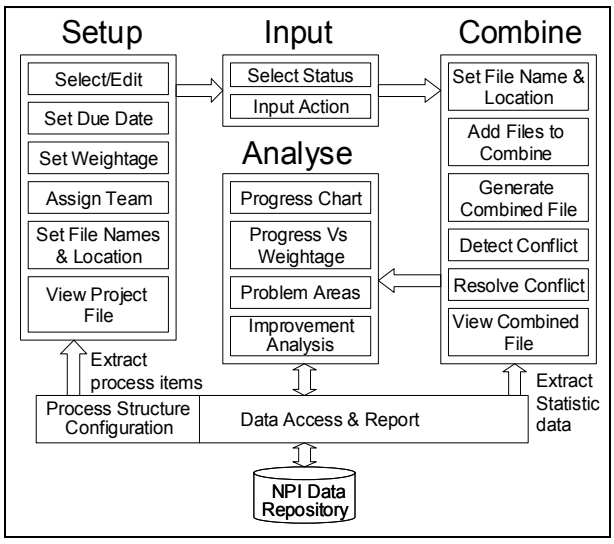

Fig. 4. NPI system architecture.

4.2.3 Component design

Configuration Module – It provides facilities to configure the process architecture and to specify the process data hierarchy for the product development processes.

Project Setup Module – which is used by a project manager to define the design process activities and interactions of a new product development project. Its functional requirements are described by the use case diagram in Fig. 3.

Data Entry Module – which is used by different functional teams to enter the process data. The daily data entries will be stored in the NPI data repository shown in Fig. 4.

Data Mapping and Combining Module – This module facilitates the data mapping, data conflict detection, conflict resolving, and data combination from different team data sources. New sets of project data will be generated from these sources for data analysis later. Fig. 5 illustrates a data conflict resolution and combination scenario of this module, which also shows the participating objects of the scenario, their interactions, and the messages sent between the objects.

Analytical Module – This module evaluates the design process performance by charts, identifies the bottlenecks in design process, sends the early warnings on problem areas, and provides analytical results for decision making on improvement actions. The Q&R quick analytical models identified from the previous process models is implemented in this module for analysing the Q&R information and evaluating the Q&R process performance.

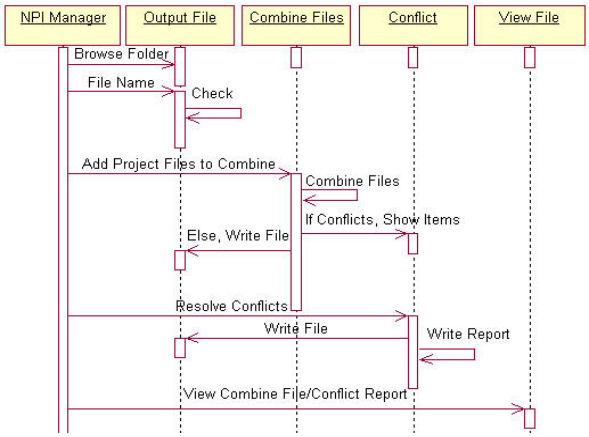

Fig. 5. Resolving conflicts and combining data.

4.3 System implementation results

Fig. 6 shows the main page of the NPI process management system, which provides access to different modules and to various overall statistical data outputs of a new product development project, such as percentage updated, completed, added, modified and due date, etc.

The usage of the Project Setup module is illustrated in Fig. 7, by which users can select, add, or modify the required process items from the

NPI data repository. Other project settings, such as task due date, weight factor, and ownership can also be set/modifies by using this module. Fig. 8 shows one of the bubble charts which are usually used by project managers to justify the design process progress, to identify bottlenecks, and to take decisions and actions based on the information provided.

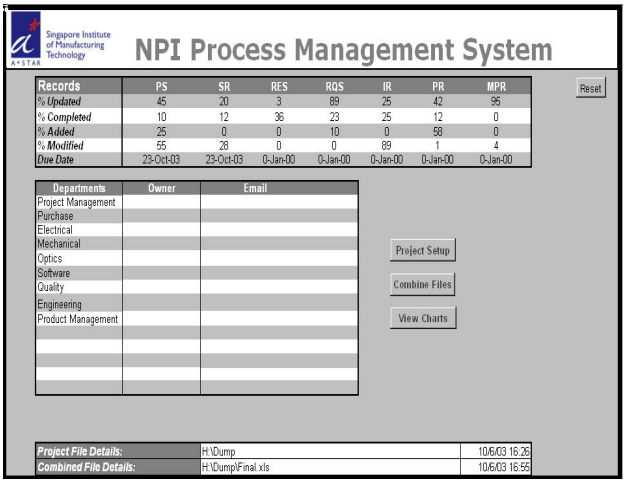

Fig. 6. NPI system main page.

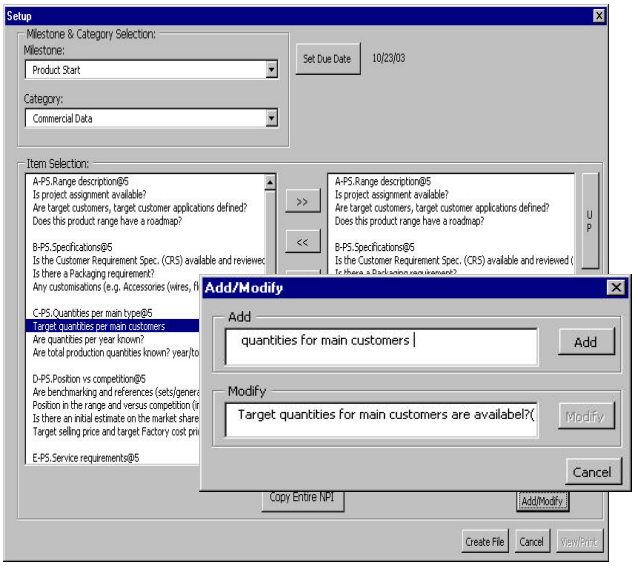

Fig. 7. Setting up a product development project.

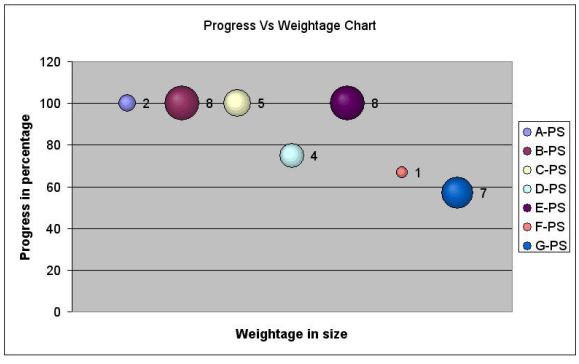

Fig. 8. Progress vs. weight-factor bubble chart.

5 CONCLUSION

It is critical for business success to satisfy the customers with high quality and reliable products in a timely and cost-effective manner. Collaborating with our industrial partners, this project has developed a Q&R framework, consisting of modelling methodologies; process information and Q&R management techniques; and supporting software systems for maximising the product Q&R capability and the design process performance in the fast product development. The case studies conducted for Q&R process modelling; Q&R information flows across product development processes; and process information analyses have shown the functionality of the framework in managing and improving both the Q&R performance and the design process performance for consumer electronic products development.

The implementation of the Q&R assurance measures requires close interaction and integration between the design process and the Q&R process, and between Q&R components. Software systems enable this interaction and integration thus facilitate the product quality and reliability improvement in the fast product development.

6 INDUSTRIAL SIGNIFICANCE

The process modelling methodologies and the process-based Q&R management approaches have been tested by the design cases in industry. The NPI process management system has also been deployed at one of our industrial partner's site. In the future, the project will focus on the further enhancement of these methods, approaches, techniques and software tools by apply them to more local electronics design companies.

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