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An approach for producibility and DFM-methodology in aerospace engine component development

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Abstract

The competitiveness in the aerospace industry is steadilly increasing, at the same time there is a rapid development of new technology for next generations of jet engines. To achieve one of the most important goals, reducing weight, fabrication of structural components is one possible approach, common to many aerospace manufacturers. However, the engineering work becomes more difficult and requires new knowledge. Production becomes significantly more complicated as the need of different manufacturing processes increases, as well as the complexity of other production related activities. In the paper, definitions of *producibility* and *manufacturability* are discussed, together with related metrics for measurement of the impact of the product design on a production system. The result is a recommended set of methodologies and tools to manage and evaluate the manufacturing interests and targets, and how they must be reached and balanced within the product development process, in order to improve producibility. The work has also identified gaps and opportunities for improvements, and suggested an approach for next step in order to increase producibility in manufacturing of aerospace engine components.

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Keywords: Producibility; Design for Manufacturing; Fabrication; Aerospace; Engine Components

1. Introduction

One of the most important goals when designing current and future jet engines is to reduce weight while maintaining or improving performance. To accomplish this, different alternative concepts and designs for materials and physical configurations are under investigation and development nowadays. For some components, typically structural components, one approach is to use fabrication, instead of large forgings and castings [1].

The basic idea is to use smaller forgings, castings and sheet metal parts or plates, which are welded together into its final shape. However, with fabrication process as strategy, the engineering work will become more complex, requiring new knowledge due to the increment of the need for different manufacturing processes, as well as the complexity of other production related activities.

As Aerospace products are becoming increasingly complex, with high functional, technological content and many variants, this has resulted in an overall increased knowledge intensity, which necessitates a more explicit approach towards knowledge and knowledge management in product development. This implies the need to define the applicable criteria for analyzing products and processes from the aspect of an efficient manufacturing.

Nomenclature

DFM	Design For Manufacturing
DFA	Design For Assembly
DoE	Design of Experiment
MRL	Manufacturing Readiness Level
QFD	Quality Function Deployment
FMEA	Failure Mode and Effect Analysis
FTA	Fault Tree Analysis
RQ	Research Question

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There are extensive literature and industrial examples in the areas of manufacturability and/or producibility [2,3,4,5,6]. There are also many methods and tools, more or less specialized or generic, that can be used to analyze different aspects of the product, from which some are focused on evaluating manufacturing aspects. In the area of engineering design and product development there are also a large number of methodologies used.

In this paper an overview of different engineering methodologies and tools is given and their impacts on producibility aspects are investigated. The purpose is to find a set of methods that may serve as the base to build an engineering process, which would manage the manufacturing stakeholder interests and related metrics. Therefore, assessing the impact of the product design on the production system.

Two research questions have been defined for this paper:

- RQ1: Which engineering methodologies can be used to integrate the manufacturing aspects along the concept and product development process in the aerospace engine components industry?
- RQ2: Which analytical methods and tools can be used to evaluate alternative solutions in a qualitative and quantitative way?

An initial part of this research, section 2, consists of identifying the most suitable framework for producibility. The following section reports a literature survey of general engineering methodologies and an analysis of their benefits in the context of this research area. Within section 4, a set of more specific methods and tools are listed and analyzed regarding their contribution to producibility. In section 5 the most relevant methods and tools are discussed and a gap analysis is used to identify opportunities for further development and research. The paper finalizes answering to the research questions and related discussion, together with concluding remarks.

2. Producibility framework: Definitions and metrics

2.1. Producibility and manufacturability

In the literature written by academia, institutes, associations and industry, there is a large number of alternative definitions of producibility and manufacturability [2,3,4,5,6,7]. There does not seem to be a clear difference between the two. Instead, the terms seem to be used in a generic way in many cases. The purpose of this paper is not to make a detailed analysis and propose a solution to that, but an interpretation has been done to motivate the terminology used in this paper.

A common theme in many definitions for producibility, with some variants, includes; *... the capability to produce the product in a robust and efficient way to meet the design specifications for functions and reliability of the product*.

Some alternatives of the definitions only refer to the ease of manufacture parts and components [2], while some others include a very holistic view of how to produce the product or system [7].

The term manufacturability is often used in the producibility definitions and context, though it is very similar in many cases. There is, however, one aspect of producibility that can be identified as a distinction between the two, which is illustrated in Figure 1. In producibility there is a strong link to the product functions, characteristics and performance. In contrast, within traditional manufacturability or *Design For Manufacturing* (DFM), etc. the product function and its characteristics are of less concern, thus focusing on production optimization instead. The reason is that the maturity of product and process technology in e.g. automotive industry is much higher. In aerospace industry, the product performance is critical and often at the very front end of materials and process technology. Therefore, the term producibility is preferred.

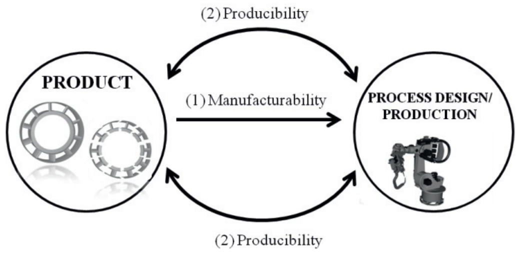

Fig.1. Producibility and Manufacturability frameworks

2.2. Metrics for producibility

To be able to compare different concept and design alternatives based on facts and data, quantitative targets and goals must be of relevant importance. Based on the common theme in many of the definitions, and the basic needs to provide relevant metrics and targets for the serial production performance, the following key metrics are selected as a baseline for the research project, which this paper is based on.

- Quality – process capability. The simulation or estimation of the expected output in comparison to the requirements for each process step.
- Time – (total) process time. The sum of time needed for each process step, to fulfill all specifications and quality requirements (not logistics/material handling). There is an option to exclude machine/automatic process time here and include that in “Cost” only.
- Cost – (total) process cost. Refers to the sum of manufacturing cost needed for each process step, calculated from the planned operation sequence, including special tooling.

The evaluation and estimation of the metrics has to be done using generic or standard data for the processes and equipments available (to avoid sub-optimization or not comparing “apples to apples”).

In a development project, targets should be set for each metric, and sometimes also a breakdown of the metrics to each process step, in order to make sure the production yield and production system performance can achieve the goals. As a holistic metric related to producibility, the *Manufacturing Readiness Level* (MRL) should be used [7]. Targets should be set to evaluate the technology maturity in order to identify manufacturing risks and proactively drive manufacturing maturation activities, thus addressing shortfalls [8].

The (producibility) *confidence index,* presented in [9], is an interesting approach to also consider the current knowledge level and an indication of the accuracy of the evaluations. This metric compares design alternatives based on design elegance, complexity, manufacturing readiness, cost, value, suppliers, and other relevant metrics [10].

3. Methodologies for producibility in the product development process

In this section, some typical methodologies are reviewed and analyzed, in the perspective of how they support the producibility aspects, thus addressing RQ1.

3.1. Product Development Process (PDP)

The way the engineering activities are organized is an important part for achieving effectiveness and efficiency in concept and product development in general. There are many kinds of models and approaches for the product development process and the product life cycle, from which the most are divided into a few phases [11,12,13,14,15,16]. The engineering development process basically contains the following phases.

- Planning – pre-studies to identify customer needs and different kinds of requirements
- Concept generation – development of alternative (principal) solutions
- Evaluation and selection of concept – finding out which alternative best fulfills the different requirements
- Detailed development and design – design of all ongoing parts and their properties
- Manufacturing preparations – production planning and startup of serial production (this is usually done in parallel with above)

Considering the life cycle of a product, it is obvious that the objectives differ over time, however all objectives relevant for the final solution must be considered during the early product development. During the idea and concept development phase, there are large possibilities to influence the detailed requirements. Thus, the objective would be to create a solution according to DFM and producibility.

Figure 2 is a principle model that shows the objectives for each phase and how manufacturing requirements and targets are managed. In Figure 2, requirements are an input to the idea/planning phase 1), the fulfillment of requirements and targets is validated 2) and verified 3) later on. The product development and production planning are done more or less in parallel. In addition, cross-functional work will integrate the manufacture aspects from concept development to detailed design in order to check that production targets are met.

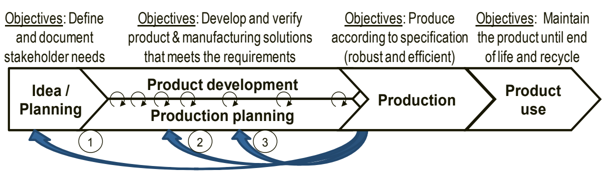

Fig. 2. Product life cycle and manufacturing requirements

3.2. Concurrent engineering (CE)

Concurrent engineering provides an integrated, parallel approach to the product development process in which multi-disciplinary teams work together from the requirements stage until the start of serial production. The purpose is to ensure that the requirements of all the stakeholders are implemented in the product, and to reduce lead-time as the multi-disciplinary work is conducted more or less in parallel. It should (if done right) reduce the number of late changes, time-to-market and cost, as decisions at each stage of the product development are based on the common point of view of people from different disciplines involved [17].

Concurrent engineering is considered to be an ideal environment for the producibility implementation and the integrated approach to product development [18,3].

3.3. Systems Engineering (SE)

An important part of the engineering activities is the identification and break down of requirements. SE is a methodology that focuses on defining customer and internal stakeholder needs and required functionality early in the development process. The key to success is to use a top down approach in documenting requirements, proceed with design/process synthesis and validation. In SE both business and technical needs of all customers should be considered with the goal of providing a quality product that meets the user needs. Systems Engineering can be used for both product and production development.

The V-model is used to break down the top level requirements into more detailed ones, sub-systems and component in order to provide a structured framework for development. Iterations between the requirements and possible solutions are conducted, in particular during concept generation and evaluation, to find a balanced design.

A complete set of requirements includes the functional requirements for the product, as well as all other internal and external needs. In this context, producibility requirements can be defined in a methodic way, and also be systematically analyzed using different tools at different levels/stages during the production development, see Fig. 3. There is also an opportunity to support the creative synthesis of solutions. Ideally, to achieve high producibility, both product design and the manufacturing process need to be defined in parallel.

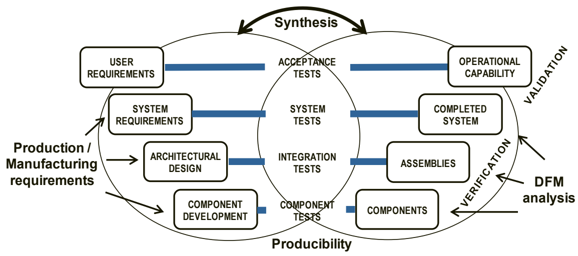

Fig. 3. The V model

3.4. Set based engineering

In the set-based engineering process, sets of solutions are developed and communicated in parallel and relatively independently. One key idea in set-based engineering is to systematically build knowledge about multiple design concepts, based on additional information from development, testing etc., and then successively eliminate concept alternatives. The design space is open as long as possible, in order to build up knowledge in a systematic way as the design processes gradually narrow their respective sets of solutions.

The purpose is to make the decisions about concepts and designs more robust, to reduce the risk for late changes [17]. The basic set-based design rules are summarized as follows:

- As constraints are involved, use a funneling process to reduce the number of feasible designs.
- Focus on keeping the design space as open as possible, and as long as possible, to build knowledge in a systematic way.
- Capture, store and retrieve the knowledge to be used in future designs.

Within the context of this paper, design engineering and manufacturing engineering can define broad sets of feasible solutions from their respective areas, and gradually refine the solutions by eliminating ideas. Important tools in the Set-based methodology are morphology and concept selection, to support the synthesis of solutions and a systematic evaluation of alternatives.

Set-based engineering is an advantageous approach to be able to manage and treat the producibility aspects. This is of special interest, and importance, when the product to be developed is a high end technology product, i.e. built on technology with limited experiences, from new or advanced materials and processes. In such a case, the knowledge about preferred manufacturing solutions and producibility could increase and be useful as the development progresses.

4. Tools for evaluating producibility

In this section, different methods and tools that support the process for analysis, evaluation, visualization and decision of alternative design solutions are described within a producibility framework, thus addressing RQ2. Access to right information is required, as a prerequisite to analyze and create ideas for how to develop the product design and manufacturing process. These methods are also used as a base for continuous improvements during the development process and can be combined in different ways.

4.1. Quality Function Deployment (QFD)

QFD is a management tool that systematically identifies customer demands on product features and design parameters, translates these demands into product characteristics, and incorporates them into the manufacturing process [19]. It helps companies to move from a technical features inspection-based approach to designing quality into products.

The QFD process requires developing a chart (house of quality) for each of the four main project phases, product planning, product design, process planning and process control. The main drawbacks lie in the time consumptions due to complexity of fulfilling the chart. The consequence is often an incomplete QFD process, where only the first phase, technical requirements, are developed neglecting the production analysis, and therefore not supporting the iterative work needed for producibility very well.

4.2. Failure Mode and Effect Analysis (FMEA)

FMEA is a risk analysis tool. The purpose is to, at an early stage, identify all catastrophic and critical failures in order to eliminate or minimize them through early design improvements. Therefore, it is a prevention tool rather than a detection tool. The analysis work is systematically documented and driven using a specific worksheet. At a component level, the failure is identified and evaluated, and given a rank according to the criticality and the probability of the failure to occur. It presents a possible use for producibility requirements verification. However, advanced detailed information regarding the design is needed [20,21].

4.3. Fault Tree Analysis (FTA)

Based on the same purpose of the previous tool, assessing risk, FTA is a systematic way, which is widely used for estimating process quality. Starting from the top level of a system, the fault-tree method uses a Boolean algebra and logical modeling to make a graphical representation of the relations among various failure events at different levels of the process. This type of logic helps to establish a clear and detailed scheme of relationships between steps or events in the process that can affect the system functions and quality [22]. Working as a root cause analysis tool, it could be useful to apply while assessing tolerances variations to find their sources. Therefore, supporting the robust design method [23].

4.4. PUGH Matrix Analysis

A Pugh matrix is used as a tool during concept evaluation that provides the selection of a winning concept, supporting team consensus and creating a record of the decision-making process. Nevertheless, this method involves qualitative comparison of each alternative, requirement by requirement. Once more, the optimum requirements breakdown and weightiness, as well as the subjective engineer opinion to give a qualitative comparison, will influence the effectiveness of this tool. Approaching in an opposite way to set based methodology, the main drawback is the (risk of) early selection of a false winner [11].

4.5. Design For "X" (DF"X")

DF"X" is systematic approach to analyze and support decision making in product and production development. The "X" refers to different aspects of requirements and product characteristics throughout the product life cycle e.g. manufacturing, assembly, service/maintenance, environment, etc. The "X"s may sometimes be in conflict, and the procedure needs to be able to balance the different “X” criteria’s. The generic aspect of the “X”, gives to this approach a rather holistic perspective and there are different opinions of what DF”X” is or does. For some, it is a tool helping the designers to find the best detailed design, and others treat it as procedures with different checklists to tick of the demands. From its holistic perspective, it could be considered as a “way of thinking” for designers, offering the methods, but also the principles to support the thinking. DF”X” is also an important building block to achieve high producibility.

4.6. Design For Manufacturing or Assembly (DFM/DFA)

The DFM approach provides methods and tools for quantitative and qualitative analyses, evaluating how well the product component designs are adapted to different manufacturing methods. DFA is directly applicable to the assembly process, i.e. the process of putting two or several parts together and joining them into a sub-assembly or complete product, thus covering more of a system level. DFM and DFA are usually used together as an inseparable and logical approach to avoid sub-optimization (this is an example of methods within DF”X”). These are generally assimilated to assess the feasibility industrialization of the product.

DFM and DFA tools have various focuses, but they all share the same concepts, built on an extensive knowledge base, which is structured into guidelines, best practice requirements, and tools. They are developed to support tasks to: present a non-patterned approach to problem solving, yielding desirable solutions that will simplify assembly techniques, reduced cost, ease of components handling, appropriate selection of materials and processes, help in achieving a final robust design and improve product quality [24]. These methods fall under two categories: creative thinking that rely on the intuition of the designer (qualitative approach) and, logical methods (quantitative approach), which encourage a systematic approach to design [24].

4.7. Taguchi / Design of Experiment (DoE) / Robust Design

The Taguchi method is a combination of an engineering approach and a statistical method to achieve improvements in product/process's cost and quality, accomplished through design optimization. The goal is to identify parameters that can be controlled (control factors) and to reduce the sensitivity of engineering designs to uncontrollable factors (noise), thus aiming for robust design. This is achieved by using small-scale experiments, similar to the DoE approach, in the laboratory to find reliable designs for large-scale production [25].

5. Summary, discussion and gap analysis

In this section, the most relevant product development methodologies and analytical methods and tools to deal with producibility, in aerospace engine components development, are summarized and discussed, in the perspective of RQ1 and RQ2.

5.1. Analysis of methodologies, methods and tools

Based on the review and assessment of different methodologies, methods and tools, made in section 3 and 4, Table 1 has been created to summarize how well they support producibility in the product development process. Here, there are only two levels of correlation where (X) indicates a strong influence on the results, and (O) indicates a weak influence. The purpose at this stage is not to make a detailed ranking, but to identify the most important ones, in order to establish a focus for further development, and to answer the RQ 1 and 2.

Table 1. Methodologies and tools influencing product development process

PD process phases:	**Methodologies**	CE	SE	Set-based	**Tools**	QFD	FMEA	FTA	Pugh	DF”X”	DFA	DFM	Robust Design	DoE
Idea / Planning		x	x	x		o	o	o	o	x	o	o	o	o
Concept Development		x	x	x		o	o	o	x	x		x	x	o
Detailed Development		x	x	x		o	x	o	o	x	x	x	x	x
Verification		o	o	o		o	x	o	o	x	x	x	x	x
Validation		o	o	o		o	o	o	o	x	o	o	o	x

Thus, there are a large number of methods and tools for handling different aspects of the product concept and design, in relation to quality, time and cost. They are applicable at different phases and levels of concept and product development.

Looking at the methodologies, a concurrent engineering approach, applying systems engineering and set-based engineering, is a feasible solution. Among the methods and tools, the Pugh concept selection has a central role, as long as it includes a good breakdown of producibility requirements, supported by DFM and DFA methods to evaluate especially time and cost. The best methods and tools to assess and secure quality are robust design and design of experiments.

5.2. Gap analysis and opportunities for industrial application

One goal for the ongoing research project at the industrial partner is to clarify a suitable framework for producibility, as well as to define pre-requisites and building blocks required for such a methodology. This is based on a sub-set of methodologies, methods and tools that has the strongest influence on producibility. In Table 2, a gap analysis is made based on experiences and *Lessons Learned* from the industrial partner, implementing *Lean Product Development*. A subset of methods and tools are selected for the analysis, with special focus on the ones that have a very strong influence on producibility (DFM, DFA and Pugh). In addition, the opportunities and needs for further development and research are identified.

Table 2. Gap Analysis & Opportunities

Methods	Purpose	Gaps from lessons learned	Opportunities
PDP	Manage the sequence of activities Deliver required information for project decisions	Not followed as defined Not enough cross functional work / too late	Follow the defined process /Improve communication Make the right competences available Define standards for all producibility activities
CE	Enable multi-dicipinary work	Few methods to support cross functional work	Develop better methods (e.g. as the tools below)
SE	Manage stakeholder interests/requirements and plan to verify them	Not established yet All stakeholders are not defined and producibility is not measurable in early phases	Introduce SE training & experience Identify producibility as a stakeholder. Requirements and targets should be better defined and communicated
Set-based	Systematically build knowledge and step by step elimination of alternatives	Not established yet Lack of experience/ knowledge (new technologies)	Build up knowledge areas and apply them in methods for concept selection and other analysis tools Analyse producibility besides other requirements
DFM guides	Generic knowledge – rules/ recommendations about what is a better design – qualitative	Difficult to apply without experience Lack of guidelines for new technologies No quantitative data to compare alternatives	Need to continue building knowledge and defining applicable guidelines Documentation, visualization and communication
DFM/ DFA	Methods to analyse a certain aspect of the design – quantitative measures	Lack of experience and methods/data (new technologies) Tools exist, but are under development	Build more knowledge about cost, quality/capability and time for relevant materials and fabrication methods Investigate alternatives/solutions for IT support
Pugh	A matrix method to compare alternative solutions relative to each others	Overlapping and undefined criterias Concept ranking is subjective/ sensitive to knowledge level	Requirements / Concept selection criterias definitions Adapt ranking and scoring to the curren knowledge level – use a maturity index / criteria

6. Conclusion

The research, in this paper, has studied a large number of definitions for producibility and manufacturability. The conclusion is that producibility is more relevant to aerospace engine component development, due to the strong link to the product performance in relation to process capabilities. A set of metrics has been identified, which together with a set of requirements, should be used as input from the start of concept development, throughout the product development process and finally verified in the serial production.

The answer to RQ1 is that combined *set-based concurrent engineering and systems engineering methodology* has a great potential to manage the producibility aspects, due to the ability to build knowledge in parallel, especially for advanced and non mature technologies, before decisions are frozen.

For RQ2, traditional tools, e.g. DFM and DFA, are useful to some extent, at least for qualitative analysis. However, as the goal is to have quantitative targets, methods and tools need to deliver that as well. Today, they are of limited use for newer and advanced technologies, especially for the materials and processes needed for aerospace engine components.

Future research will focus on building the knowledge base and its implementation into requirements, methods and tools, in order to support the synthesis and quantitative evaluation of concepts and design alternatives.

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8. References

[1] H. Runnemalm, H. Tersing and O. Isaksson.Virtual manufacturing of light weight aero engine components. *Proc. ISABE*. 2009.

[2] J. Bralla, *Design For Manufacturability: Handbook*, 2nd ed., McGraw-Hill Handbooks, 2004.

[3] D. T. Koening. *Manufacturing engineering: principles for optimization*, 2nd ed., Taylor & Francis, Washintong DC, 1994.

[4] G. Chryssolouri. *Manufacturing systems: theory and practice*, 2nd ed., New York: Springer Science + Business Media, Inc., 2006.

[5] A. P. Sage and W. B. Rouse, *Handbook of System Engineering and Management,* 2nd ed., New Jersey: John Wiley & Sons, Inc., 2009.

[6] D. A. Sanders. *Modeling & Simulation Investment Needs for Producible Designs and Affordable Manufacturing. systems Engineering Implications*. NIDA JCSEM M&S. Sub-Committee , USA. Feb 2010.

[7] OSD Manufacturing Technology Program. Manufacturing Readniness Level (MRL) Deskbook. Joint Service/Industry MRL Working Group.

[8] A. Sanders. Manufacturing Maturity in S&T an Industry Perspective. *The annual Defens Manufacturing Conference (DM*C), Orlando. 2009.

[9] J. R. Hadley and D. J. McCarthy. Producibility and confidence indices during defense acquisition. NDIA Ground Vehicle Systems Engineering and Technology Symposium, Michigan, August 2011.

[10] J. Feord Michigan Company Helps DoD Understand and Reduce Cost and Complexity for Defense Programs. Defense&AerospaceWeek 2011.

[11] S. Pugh. *Total Design: Integrated Methods for Successful Product Engineering.* Wokingham, 1990.

[12] V. Hubka and W. Eder. *Theory of Technical Systems: A Total Concept Theory for Engineering Design.,* Berlin: Springer-Verlag, 1988.

[13] N. Roozenburg and J. Eekels. *Product Design: Fundamentals and Methods*. Wiley & Sons, 1995.

[14] G. D. Ullman. *The mechanical design process*. McGraw-Hill, 2003.

[15] K. Ulrich and S. Eppinger, *Product Design and Development, New York: McGraw-Hill*, 2003.

[16] G. Pahl and W. Beitz. *Engineering Design: A systematic Approach*. New YorkSpringer-Verlag, London.1988.

[17] D. K. Sobek, A. C. Ward and J. K. Liker.Toyota´s Principles of Set-Based Concurrent Engineering. vol. 2, no. 40, Winter 1999.

[18] J. Clarkson and C. Eckert. *Design Process Imporvement: A Review of Current Practice*. Springer-Verlag London Limited, 2005.

[19] B. Bergman and B. Klefsjö. *Quality: from Customer Needs to Customer Satisfaction.* 3rd ed., Lund: Studentlitteratur AB, 2004.

[20] D. Ginn,D. Jones,H. Rahnejat, M. Zairi.The QFD/FMEA interface. *European Journal of Innovation Management.*1,1, pp. 7-20, 1998.

[21] L. S. Lipol , J. Hag. Risk analysis method: FMEA/FMECA in the organizations. *Int.Journal of Basic & Applied Science*.,11,5. 2011.

[22] E.Povolotskaya and P.Mach, "FMEA and FTA Analyses of the Adhesive Joining Process using Electrically Conductive Adhesives," Acta Polytechnica, vol. 52, no.2, 2012.

[23] M. Čepin. *Assessment of Power System Reliability*. Springer-Verlag London Limited, 2011.

[24] S. Ramaswamy, "A Survey of DFM Method," Department of Mechanical and Aerospace Engineering, Arizona State University, 1998

[25] Bouchereau,Viavianne, H. Rowlands. Methods and techniques to help (QFD). Benchmarking: An Int. Journal, vol. 7, no. 1, pp. 8-19, 2000