Conceptualizing DFSS an analysis of 107 studies

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**Conceptualizing DFSS an analysis of 107 studies**

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**Abstract.** The aims of this study are to capture the current state of Design For Six Sigma (DFSS) and to systematically review literature on practices of DFSS published between 2006 and 2018. The questions are: what is DFSS, the application, the essential ability, and limitations, the main trending topics of DFSS? All these questions are used to guide the search for journal in databases and other sources. Then, all relevant literature was reviewed and analysed. There were 18 topics found to be included in the review. The authors proposed two different issues relevant to DFSS. All these papers were interpreted by tools and techniques, such as the implementations of DFSS, its uses, applications, and how it is linked to other disciplines. Data was collected and clustered by year, topic, and keywords in DFSS to be used in configurations and progress improvement and innovation of DFSS. This review found four definitions of DFSS, eight applications and uses of DFSS, three challenges and obstacles in using DFSS, and two future direction of research of DFSS based on its fast-changing product design.

1. **Introduction**

One of the valuable tools in collecting assets in quality and performance is by using a series of quality drives like statistical control, zero defects, and total quality management. This tool is called Six Sigma, which is used in both manufacturing and services industries around the world [1]. Six Sigma is one of the newest quality performance measurements. It needs total commitment from companies, from the top management to all parts of company’s systems, including the suppliers, designers, productions, processing, distribution and after-sales services. Big companies that use Six Sigma often gain substantial benefits.

Design for Six Sigma (DFSS) is parts of Six Sigma methodology. It helps companies to eliminate and count errors or defects in products design, processes, and or services. Six Sigma is well known for its framework that is Define, Measure, Analyse, Improve, and Control (DMAIC). Several basics differences between the traditional Six Sigma DMAIC that is commonly used and the DFSS is that DFSS has many variance steps depending on the needs and applications. These variances ways need to be discussed. The one being studied is which actions are more appropriate for manufacturers and which activities are better to apply in services industries [2].

Conventional quality management approaches, containing Statistical Quality Control (SQC), Zero Defects and Total Quality Management (TQM), have been the primary tools for years. Six Sigma is...
one of the latest tools initializes quality improvement. It is well known in global industries. Since its
initiation at Motorola in the 1980s, many companies, including GE, Honeywell, Sony, Caterpillar, and
Johnson Controls, have already used Six Sigma and gained substantial advantages. DFSS is more
focused on front liners of the overall process, starting from the design production process for the
manufacture or service designs. DFSS in all aspect or variance analyses the customer’s needs, hopes
and expectations, and deliver technical requirements of the engineering tools, in all product design life
cycle [3].

DFSS is usually combined with other product development tools to achieve a standard
development tool in new product development steps. This product design steps are combined with
five steps of DFSS, which are define, measure, analyse, design and verify (DMADV). Many
companies approve that DFSS methodology is a more efficient, reliable and robust method to meet
customers’ needs and expectations and is critical to quality. It improves quality and also reduce errors
or waste. DFSS is not a fixed design tool, but it can be developed, and combined with other devices.
The systematic complex is also considered in the system integrity with DFSS [4].

The aims of this study are first to define DFSS methodology by reviewing journals and documents.
The second aim is to find the closest integration between DFSS and product development process. The
integration is conducted by widening keywords that are connected with DFSS methods and by
reviewing all identified journals. The third aim is to cluster issues by keywords, topic, and interest.

2. Methodology

2.1. Scope and research question

All journals were read and reviewed starting from the oldest works in DFSS topics: the provisional
applications of DFSS in product and service [2]. This review was conducted by reading and reviewing
DFSS journal from the broad works of Six Sigma or DFSS [5] and the works about services that use
DFSS [6]. Because of it, all the literature reviewed in this paper are those which were published
between 2006 and 2018. In terms of the subject of discussion in the literature review, the topics
covered were not only from the industry sector alone but also from other relevant journals. The
research questions are:
1. What is Design for Six sigma (DFSS)?
2. What is the application of DFSS?
3. What are the main barriers of DFSS?
4. What is the direction of DFSS future research?

2.2. Search strategy

The procedure used in the current research is as follows: (1) Search for and find relevant databases
from previous journals. (2) Set the time frame to see the data from the year 2006 until 2018. Because
the range is very wide, the included papers are those starting from 2006. (3) Take a set of journals that
were collected based on keywords. We tried to make the combination reasonable and relevant to
DFSS.

In this paper, we used three kinds of database and journal search engine, and they were Google
Scholar, DeepDyve, and Mendeley search engine. After we decided which search engine to use, then
we built a series of questions to find the appropriate journals or other literature. Table 1 shows the
series of questions used to retrieve the appropriate journal. It shows publications found if we use these
questions in three search engines. The issues must be related to DFSS method. As we know DFSS has
been introduced as parts of Six Sigma itself [7], and DFSS also one of the robust tools to build reliable and low-cost manufacturing [8].

Table 1. DFSS questions to build the database of papers

| No | Question String | Google Scholars | DeepDyve | Mendeley |
|----|-----------------|----------------|----------|----------|
| 1  | Design For Six sigma | 1.750.000 | 5.248 | 199.937 |
| 2  | DFSS + Definitions | 6.040 | 378.315 | 216.796 |
| 3  | DFSS + implementations | 5.110 | 596.002 | 84.858 |
| 4  | DFSS + Product Design | 5.000 | 262.537 | 171.329 |
| 5  | DFSS + Product Development | 5.590 | 604.313 | 233.137 |

From the first question, we found that there were thousands of journals and papers. Then we made narrower questions, and the aims were to have smaller strings to find papers with the best fit. It was almost impossible for anyone to read thousands of papers. So, we have to decide to build smaller strings of questions. To build smaller strings, we have to set a series of individual questions with narrower DFSS topics into the subjects shown in table 2.

The papers we included in this research were the papers that use DFSS methodology. We did not go more in-depth to examine the whole dissertations of each document.

Table 2. The result of the series of questions search

| No | Question String | Google Scholars | DeepDyve | Mendeley |
|----|-----------------|----------------|----------|----------|
| 1  | Short cycle product and design for Six Sigma | 330.000 | 984 | 3.220 |
| 2  | Quick cycle product and DFSS | 1.520 | 1.209 | 2.802 |
| 3  | Sharp cycle products and DFSS and remanufactured products | 317 | 265 | 3.450 |
| 4  | Short cycle products and DFSS and remanufactured products and new product development | 289 | 0 | 5.349 |
| 5  | DFSS and closed loop manufacturing | 562 | 109 | 242 |

From Table 2 above, we can see the smallest string we can use to find the best fit and the number of papers we need to read more in-depth. From these 242 – 265 string results, then we read the abstracts to know the scope of these research. After that, we tried to cluster those papers based on the similarity of the topic. In this paper, we excluded manuscripts and patents.

3. Result and analysis

The result was 242 to 265 journals related to DFSS: closed-loop manufacturing and short cycle products. The procedure begins with reading the abstracts. The topics were not always in the scopes, but at least had some degree of relevancy. However, because some did not match with DFSS, or lacked of details and examples, or nor related to the current works, the number was reduced to 107 readings, and they were all papers in journal. After that, it was necessary to see who the writers were, whether the authorship was from the industrial background or the educational background. Then we also needed to find out that DFSS was suitable not only for manufacturing design but also suited the services design process. The relationships were associated with tools or methodology or with bases data as part of DFSS. All these clustered areas were the standard for the literature to be included in the review. All papers included in this study did not go deeply into studying in depth of methodology that
was used, but only the upper limit. Then we needed to know the author background. Industry authors deal with the industrial improvement in their daily lives. Academia might not deal with industrial in their everyday lives, but they were doing particular research in DFSS area.

Based on previous papers discuss about DFSS and another methodology, we clustered DFSS topics of interest into 18 types, as shown in Figure 1. We gave code in these types of DFSS topics. They are code T1 DFSS Literature, code T2 Quality Concepts, code T3 Six Sigma and learn fundamentals, code T4 DFSS product development process, code T5 DFSS Six Sigma Development, code T6 DFSS Algorithm Project, code T7 DFSS and Quality Function Deployment (QFD), code T8 DFSS and axiomatic design, code T9 DFSS and Theory of Inventive Problem Solving (TRIZ), code T10 DFSS and design for X, code T11 DFSS and Failure Mode Effects Analysis (FMEA), code T12 DFSS and Design of Experiments (DOE), code T13 DFSS and Taguchi, code T14 DFSS and Supply Chain, code T15 DFSS and Supply Chain Remanufacturing, code T16 Rapid change product and technology, code T17 Planned obsolesce, and code T18 Consumer behaviour.

These codes based on the methodology used in previous literatures about DFSS. The combination of DFSS methodology based on the study cases taken by researcher. Every cases have different conditions so that influence the methodology to answer their research questions.

![Figure 1. Articles based on article codes](image1)

![Figure 2. Articles based on the author’s background](image2)
From those 18 coding topics of DFSS, then we grouped them into four main interests. Those four DFSS interest are: the use of DFSS for product development, the combination of DFSS and TRIZ to product design, the use of DFSS in supply chain and the use of DFSS and remanufacturing. The progress utilization of DFSS itself has been grown rapidly. It is not just for designing manufactures things, but also for services such as education, health, and supply chain services like transportation service. In DFSS use, sequences or steps may vary depend on the subject need to get solved. The well known step is DMADV (Define, Measure, Analyse, Design and Verify). Then the steps are keep on changing like IDDOV (Identify-Define-Design-Optimize-Validate), IDOV (Identify-Design-Optimize-Validate), DMADOV (Design-Measure-Analyse-Design-Optimize-Verify) and many more. DMADV and IDOV are the most frequent cycle used by researcher [3].

It is interesting to find the background of the authors, how DFSS can be grow that fast and has so many sequences. It is interesting to know the author background. We divided the author’s background into two categories, first from industrial background and second from academia background. From industrial background, the authors may come from a professional design firm, or from a marketing division. The second type of author were those from academic background, they might be a researcher, a student or a lecturer. We can see the author’s background from Figure 2. It can be identified that most writers were academia background. The DFSS topics that were reviewed by academia are code T2, T3, T7, T11, T13, T14, T15. Most of the topics are only in academic research and have not been implemented in industrial application yet. The sequences of DFSS for non manufacturing uses like health care services is very suitable. In health care service zero defect design is completely needed. So in academic perspectives DFSS is highly developed as purposed method. Some writers were from the industries, and some others were quality assurance consultants. Some papers were collaborations between the industry and academic researchers, with the topics codes T1, T4, T5, T6, T8, T9, T10, T16, T17 and T18.

3.1. Definitions of Design for Six Sigma
To recall, the first question was: what is DFSS? The first definition, DFSS is a structured and organized method by using tools quantifications by specific numerical data for product design development from six sigma. Manufacturing industry design firms, and quality assurance consultants mostly use DFSS for their new design product development, as the first stage of total production cycle. They can combine DFSS with another tools as can be seen in the cluster codes based on the product type variations. But the use in services industry like health care, finance and banking, they use it for developing performance in [3].

The second definition, DFSS can be built in the engineering process to give better product quality and lower the cost and speed up deliverance to the customer. Not all product development needs customer's voice. Sometimes, an engineer has their own products decisions to be renewed or repaired with the current trends of closed loop supply chain followed by types of organizations, projects, acquires, and suppliers [9]. The third definition, DFSS is a technique for appraising supply chain development and achievement analysis. The requirement need administration process defined as a critical to customer requirements and it is before business conduct is enlarged [7]. The fourth definition of DFSS is a set of procedure of training and schooling aspect approach using DFSS concentrating on ideas in engineering and business cases and developing the model implementation in higher education [10].
3.2. The Application of DFSS

We grouped the application of DFSS into eight clusters. The first is use of DFSS in product and service industrial development. Despite the various procedures, DFSS is so versatile and flexible to become a tool that is applicable and fits into many aspects of business augmentations [2]. The second use of DFSS mode or procedure is to draw a conclusion from the analysis of intelligence reports in every step-in supply chain from the raw material up to the consumer, the provisional investigation of authentications and the baseline calculation of transaction [11]. The third application of DFSS is a more scalable approach unaffected by customer requirements. DFSS usually is combined with others quality methods to solve the customer problem [12]. The fourth application of DFSS is an aggressive trade or service actions which take advantage of the information’s from market or consumer into the model of all systems. Developing product through buyers need will give more competitive advantage that satisfy customers [13]. The fifth use of DFSS is deformation in generating concept by integrating Axiomatic Design as one of the essential factors in the development, which proves that DFSS is a robust mechanism to make it work [14]. The sixth application of DFSS is to design a procedure for one automotive part to make all system running well for all machine used [15]. The seventh application of DFSS is to enhance integrations to improve quality of service process by design or resign. The Eight application of DFSS is as a tool and mechanism to develop system health services, especially in hospital emergency area. The scope is how long the patients stay or length of stay (LOS) and how long the patients need wait for service [17].

The eighth application of DFSS is as a tool for new services and new product development. It can interact with intelligence reports in every step in supply chain, from raw material to the end user or customer. DFSS can also generate concepts by integrating Axiomatic Design as one of the essential factors in the development of a product from the very beginning. DFSS is also able to design a procedure for one automotive part. The way it works is to mix and combine quality initiatives by building a system called Supply Chain Operations Reference (SCOR) [16].

3.3. The main barries of DFSS

We discuss the main barriers and the possible development of DFSS applications. There is no perfect tools or systems in this world, all tools, and all orders have to be developed along with the changing of the people, technology, and culture. Improvement is important in this challenging era.

First challenge of DFSS is that it applies the internet of things (IOT) as part of the strategic thinking, continuous upgrading for the company. Statistical engineering like big data has to be used to solve problems quickly. Second, DFSS should be applied to keep up with people cultural changing that impact consumer buying style and consuming behaviour. These days, consumers need mobility and sustainability becomes an insignificant parameter of buying [18]. The third challenge of DFSS is that it must be flexible in accepting all rapidly changing environments [19]. The rapid changing technology has a negative impact. It also produces high level of e-waste, particularly in the last decades in which it has been quite critical and need new design to solve this problem [18].

3.4. The trend that emerge study of DFSS

In this section we discuss what trending topics of DFSS in the future applications. First the prospective using of DFSS must be collaborated with particular needs, and all systems in the company net must be involved. The globalization impacts are highly competitive, resulting in rapid change technology. All organizations will face uncertainty and a complex unstructured problem, and they must be able to obtain strategies to solve the problems [19]. The second trend of DFSS is to use DFSS at the pre-design stage because several fast-changing products are difficult to break apart or to dismantle so they
are unable to be recycled. In this stage, products must use new material, must have extended durability, easy to disassemble, recyclable, reusable, or able to be remanufactured to reduce environment destruction [20][22].

To do so, it is necessary for the government to create specific policy. Government has to present reasonable argumentation that it has financial benefits, so that the volume of product rebound will rise significantly. Government should use creative approach so people have a great willingness to overcome these problems [21].

4. Conclusion

The utilization of DFSS has a lot of variations in the last decades. Some papers have been reviewed and the results are presented in this paper. However, there are also more papers suggesting a different point of view regarding DFSS. These journals have indicated some findings, have used various methods, and have mixed methods to overcome problems. From 107 journals reviewed in this study, DFSS can be clustered into 18 groups, based on topics and also writer’s background. We found that there are four definitions of DFSS, eight applications of DFSS, three challenges in using DFSS, and two future uses of DFSS considering the fast-changing product design.

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