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Industrial Design Structure: a straightforward organizational integration of DFSS and QFD in a new industry and market reality

IDeS:
a DFSS–QFD
integration in
a new reality

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Abstract

Purpose – The aim of this research is to enlighten the methodology model of Industrial Design Structure (IDeS) that integrates the internal and external customer feedback embodied both in methods of quality function deployment (QFD) and as basis of design for six sigma (DFSS) steps to systematically bring the information across the entire organization, saving overall product development time and resources.

Design/methodology/approach – The paper describes the state of the art enlightened to establish the disadvantages and challenges of other methods taken into consideration in the study like QFD and DFSS that, together with the need of companies to react fast to changes they need to straightforwardly implement product development information across all departments, leading to a mass customization infrastructure. Several application trials of this methodology have been cited.

Findings – The IDeS method has established to be able to integrate other well-known methodologies to gather technical specifications starting from voice of customers (VOCs) like QFD that served to canalize the generalist approach of define, measure, analyze, design and verify (DMADV) of DFSS in order to reach into a larger share of the organization and englobe by following the overall product design steps of an industrial project.

Research limitations/implications – The research approach chosen for this document presents the concept of a methodology ought to operate most internal branches in a company driven by product design requirements and guidelines. Therefore, researchers are encouraged to develop further studies on the IDeS method are required in order to adapt this methodology to specific management tools that would help to ease information gathering for immediate analysis and modification.

Practical implications – The paper implicates that a need to interchange information systematically across all subdivisions in the organization, as brisk response to VOC reactions is needed to thrive in the market nowadays, leading to a fast product customization scene. However, the industry is heading into adopting an individual customer-centered product conceptualization ought to be driven by design as a key for individualizing an object. Afterward by taking this concept broadly and adopting it would lead to implement a company organization that would be directly affected by the customer's input.

Social implications – The methodology described aims to enable organizations to portray fast and accurate product prototyping, by exploiting technologies from Industry 4.0.

Originality/value – This concept proposes a method to canalize the implementation of DFSS by using the DMADV approach, whilst assessing the challenges of adaptation and keeping up with cultural pace that impacts the behavior of buying and consumption and moreover implementing a seamless communication within all departments in the organization to share the development progress and change requests by using similar information technology tools. This would imply important savings in resources, whilst delivering quality products to the society.

Keywords IDeS, DFSS, QFD, Six sigma, Engineering, Quality, Industrial design

Paper type Conceptual paper

1. Introduction

The aim of this study is to establish the potential that Industrial Design Structure (IDeS) methodology builds up for shaping the development phases of industrial projects, by creating

a link between the design section across the rest of the company organization, integrating execution tools from design for six sigma (DFSS) product development, together with exploiting the big data, Internet of Things and high bandwidth connectivity from the Industry 4.0 technology. This approach proves to be the best for delivering products and services ought to be focused on the customer demand and continuous evolution of such increased use of digital tools across all branches of the industry, from product conception and feasibility analysis, design consistency assessment, virtual and physical prototyping and until quality control tools. Adaptability of the shared data is required to be unfolded to other organization departments, enabling to take inputs from all stakeholders involved, from product conception toward production, quality control and logistics, and the correct implementation of such is of great importance in order to throw a high-quality product that would be economically feasible to the organization.

Since early organization structure guidelines established by [Mintzberg \(1989\)](#) outlined that the technical core was listed as one of the key elements for establishing an organization's know-how, the same of which has to be in a seamless feedback with other main units of the organization, enabling it to communicate with main technical and administrative support staff that would connect directly to the management responsibility, as seen in [Figure 1](#) organizations proved to be more effective if they provide an environment that transmits enough feedback to the technical core, reaching a balance between technology and process development. Although this core must deal with great complexity, uncertainty and interdependence, accurate feedback to this area is needed from the top management in order to know in a better way about important change requirements in technology and know-how that would determine important variations in the organization itself. The society impacts technology choice ([Luderer et al., 2019](#); [Mintzberg, 1981](#)).

Additionally, [Kohli and Jaworski \(1990\)](#) introduced the idea of organizing the structure by focusing solely on customer satisfaction; that switch would mean organizations to focus in the market orientation theory. Successive studies from [Ramani and Kumar \(2008\)](#) and [DiRomualdo et al. \(2018\)](#) expanded the later model by suggesting interactive cycles to reach to guide organizations to drive the changes. Nonetheless, it is not easy to build an organization entirely oriented to input from customers; this approach would depend on a reliant integration between customers or market analysis with most of the business processes ([Latyshova et al., 2015](#)). Eventually, companies have driven through expanding the customer knowledge analysis with the help of modern data analytics tools to discover the evolution of the most profitable customers and new areas for future market product introductions. This involves the need to enable each area of the organization to accurately understand customer-related data. Consequently, an organization could attract and retain the most valuable portion of the market by creating value to the customer; this would directly impact on the entire chain created to generate value, as later approaches on social responsibility ([Ali et al., 2020](#)).

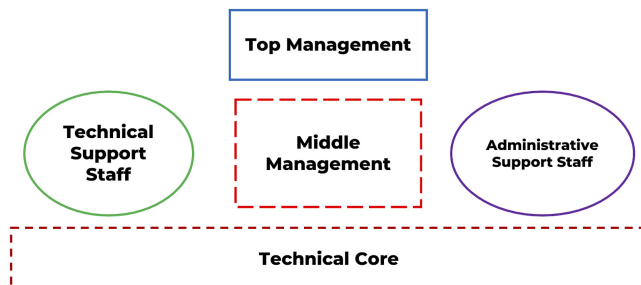


Figure 1.
The main entities of an organization

Statement was confirmed also by [Narver and Slater \(1990\)](#), [Powell and Bartolome \(2020\)](#) and [Seno et al. \(2019\)](#) who also underline the importance of taking into account each stakeholder across the entire value chain creation for better results in a cross functional organization.

Moreover, as market behavior shown to head toward choosing individualized products, companies are moving for adopting a strategic opportunity of switching to customer-driven processes by creating new procedures that adopt the will of every customer ([Jørgensen, 2009](#); [Medini et al., 2019](#)). Other analysis by [Alt et al. \(2019\)](#), [Neneh \(2018\)](#) and [Oyner and Latyshova \(2009\)](#) established that nowadays the volatility of the customer behavior turned the individual customer orientation concept in a more objective way for market analysis, and differentiating or customizing a product or service is useful to even get extra information about the customer maximum necessities. Therefore, increased data analysis capacity in tools from Industry 4.0 have enabled companies to develop complex evaluations to gather as much detailed information ([Perez et al., 2018](#)) that can give out the optimal solutions to the challenges solved with the integration of tools for manufacturing 4.0 ([Figure 2](#)).

However, dedicated manufacturing 4.0 technologies ([Lin et al., 2018](#)), aided with artificial intelligence ([Balamurugan et al., 2019](#)) gave the opportunity to exploit high data bandwidths in order to optimize information sharing across all the organization, giving the stage to new era manufacturing sequence, in which digital technologies are present seamlessly across the entire development process, namely circular manufacturing ([Delpla et al., 2022](#)), from the early conception of customer-oriented targets ([Ahmed et al., 2021](#)), initial 3D drawing and digital prototyping ([Lazorik, 2021](#)), until the ultimate automation and manufacturing with additive manufacturing technologies using Internet of Things ([Ashima et al., 2021](#); [Parmar et al., 2022](#)) ([Figure 3](#)) and quality control ([Dutta et al., 2021](#); [Silva et al., 2021](#)) solutions of which offer midterm cost-effectiveness ([Shivajee et al., 2019](#)).

2. Theoretical framework

2.1 Quality Function Deployment (QFD)

QFD is a structured method ought to define customer needs and requirements and then translating into specific plans to create a product that meet those needs. This methodology, created in Japan in late 1960s by Professors Shigeru Mizuno and Yoji Akao ([Akao, 2014](#)), is among the best-known approaches to translate the “voice of the customer” into customer needs and requirements; this tool is well-known and used in design for six sigma to gather the product requirements straightforwardly.

The QFD method displayed on [Figure 4](#) starts with a basic, six questions’ process (who, what, where, when, why and how) that are used in order to determine the elements in the

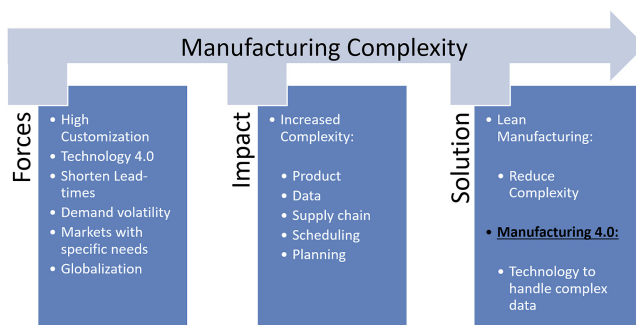


Figure 2.
Manufacturing
complexity assessment

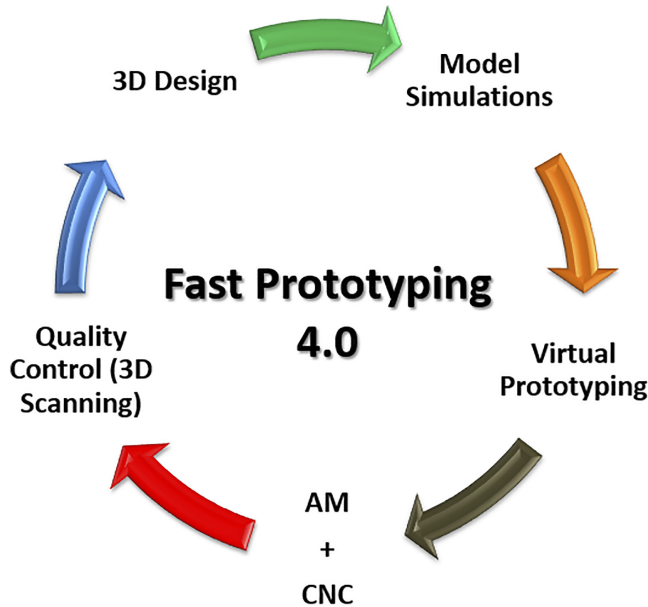


Figure 3. Manufacturing 4.0 technologies in product development

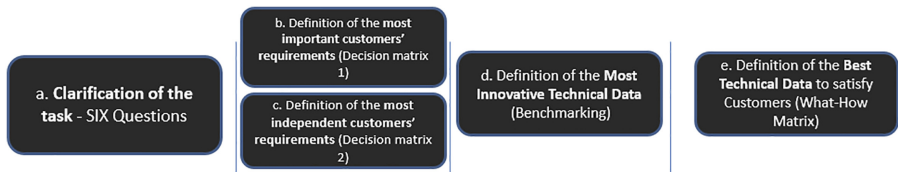


Figure 4. Six main steps for the QFD method

decision matrixes, depending on the accurate customer segmentation, by which technical specifications are obtained based on the results gathered of the decision matrixes and the benchmarking analysis. QFD guidelines have been widely adapted to product development in most industries (Erdil and Arani, 2019) from information technologies (Ping *et al.*, 2020) toward the food industry (Vanany *et al.*, 2019), service quality (Adiandari *et al.*, 2020) and chemicals (Gandara *et al.*, 2019) until medical services (Hasibuan *et al.*, 2019). As of today, the QFD method is still a very straightforward approach to improve business practices, by analyzing the potential markets to operate, as well as customer lifestyles and technology. Modern QFD is developed according to the new ISO 16355 standard that underlines interaction with today's information technologies to better reach customer satisfaction (Mazur and Belt, 2017). QFD output would be a customer-centered technical specification.

2.2 Design for six sigma (DFSS)

This methodology, as defined by Baker (2003) and widely studied thanks to its great adaptability to most production industries (Gijo *et al.*, 2021) that could be individually fit to convenience for product development (Bidikar *et al.*, 2021), design process, improved specifications (Su and Su, 2019) and internal process improvement (Shojaie and Kahedi, 2019; Pai *et al.*, 2018) or as a business process management method related to traditional six

sigma (Yang *et al.*, 2018; Madhani, 2021). This approach, introduced by Motorola engineers in the mid-1980s led to a process driven to continuous improvement and afterward has been widely diffused across most industries, from engineering, energy management, electronics development until finance and marketing. This methodology could be implemented through the sequence process of *define–measure–analyze–design–verify* (DMADV), as outlined by Baptista *et al.* (2020), Cartagena Méndez (2021) and Li *et al.* (2018) among others and shown in Figure 5. Whereas the second approach given by *define–measure–analyze–improve–control* (DMAIC) (Jamil *et al.*, 2020; Soundararajan and Janardhan Reddy, 2019; Prashar, 2020; Shipa *et al.*, 2021) is aimed to improve products or processes at six sigma quality levels; therefore, a product or service has to be created beforehand (Selvi and Majumdar, 2014). Previous product research exercises applying the DMADV sequence in diverse industry sectors such as electronic devices (Purushothaman and Ahmad, 2022), home appliances (Bidikar *et al.*, 2021) and transportation (Rajendran and Popfinger, 2022). Therefore, DFSS final output by using the DMADV approach would be a customer-centered product concept, as findings of such are reported in Figure 6. However, DFSS lacks the knowledge of adaptation and must focus in keeping up with people’s cultural shifting that impacts the behavior of buying and consumption (Nurchahyanie *et al.*, 2020); it must be flexible enough to deal with rapidly changing environments (Antony *et al.*, 2017); another research outlined the high level of e-waste generated in the last generation, so a critical need to update the process is needed (Echegaray, 2016).

IDeS:
a DFSS–QFD
integration in
a new reality

2.3 Conceptual framework – Industrial Design Structure (IDeS)

The conception of product development has evolved drastically in the last 15 years with the introduction of technology-driven advanced design tools ought to speed up overall time to

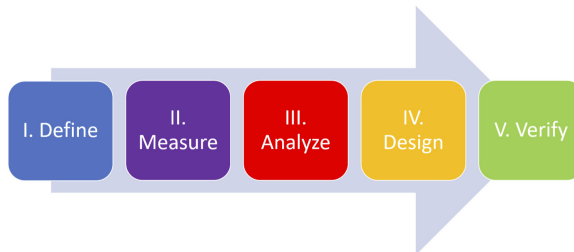


Figure 5.
DFSS sequence process
of DMADV

DFSS Project Steps	I. Define	II. Measure	III. Analyze	IV. Design	V. Verify
High-Speed Train Boogie 	<ul style="list-style-type: none"> Who uses the AV train? (What) what are the uses of the high-speed train? Where is the AV train used? When is the AV train used? Why is the AV train chosen? How is the AV train used? 				
System for remote control of home devices 					
Household appliance to recycle plastic 					

Figure 6.
Project development
using DFSS sequence

market. Therefore, high adaptability in early stages in product design processes is critically needed where most important decisions are made to the product functionality, quality, manufacturability, cost and environmental performance (Gu *et al.*, 2004), followed by various studies ought to prove the standpoint of design, as the main driver to better deal with known and unknown changes (Han *et al.*, 2020; Lv *et al.*, 2018) toward sustainable solutions (Cong *et al.*, 2020b), in addition to open architecture products toward a circular economy solution (Mesa *et al.*, 2019), using Industry 4.0 (Fu and Liang, 2020) (Cong *et al.*, 2020a; Kerin and Pham, 2020) later establishing the concept of design thinking (Liedtka, 2018), as a tool to drive innovation centered on the human behavior (Jaskyte and Liedtka, 2022), as a strategic management approach (Sandro, 2021) and as an implementation approach within large businesses (Tomlinson, 2018). Not surprisingly, companies have been following a new product implementation strategy in recent years. The original approach to the project was historically referred to as “Stage-Gate”, such that at the end of each design phase a series of project status checks and validations (milestones) were performed. This is therefore a series of activities arranged in a time series. Today, companies prefer to align the various project phases as temporally as possible, from design and planning to prototyping and manufacturing process fine-tuning, so that any economic, logistical or functional issues related to the process can emerge from the early stages of its development.

Thereafter, is the proposal of the IDEs structure to develop products aiming to organize all steps involved in the management of industrial projects across the whole company organization. This method draws a guideline for best efficiency in rapid product development by exploiting Industry 4.0 tools for data analysis and 3D computer-aided design (CAD), computer-aided manufacturing (CAM) and computer-aided engineering (CAE) technologies that are demonstrated to be exploited for achieving accurate, fast product prototypes (Frizziero *et al.*, 2022). Its strength lies in the fact that the entire product development activity is schematized according to a set of rigorous and efficient methodologies, so that small companies that lack individual roles for experts in the context of markets, engineering and business, can understand how to use the tools introduced with Industry 4.0 to accurately bring new products useful to consumers and capable to bring the innovation that is most valuable to the consumer.

The method establishes the creation of continuous feedback links between the design structure with the other departments related to product development across the organization. Likewise, the main three macro phases of this concept are exposed in Figure 7 summarizing the entire industrial product design processes (setup, development and production). Consequently, the main IDEs output is a customer-centered, technical and demand-wise secured product design company organization. This is obtained by structuring the organization transversally with quick adaptation in today’s industrial challenges and being able to train new professionals into the skills required for obtaining good results with manufacturing 4.0 in the company, obtained by joining

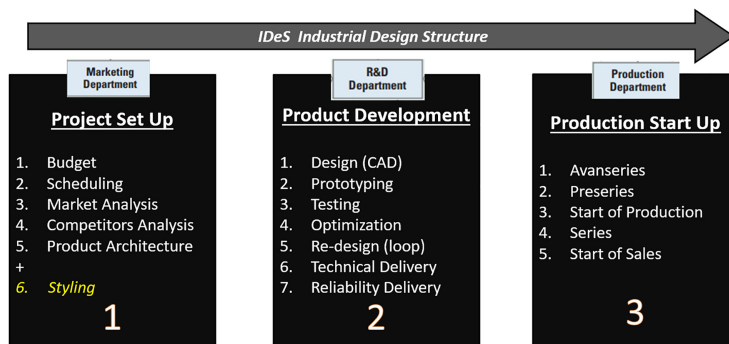


Figure 7.
IDEs methodology for product and process design

all organization departments from product developers to manufacturing and quality control areas. In the end, this information would switch an organization's effectiveness in maximizing consumer profitability (Burton and Obel, 2018) from the traditional, known methodologies centered in product effectiveness, as previously introduced by Maas (2000); this evolution has to be carried over the entire value chain (Volkov *et al.*, 2018) until redefining the sales structure (Thaichon *et al.*, 2018) therefore establishing a modern organization structure that would interactively update the knowledge of customer behavior and the evolving to understand the demand of specific requirements that would deliver exclusive value to its users.

The implementation of the IDeS method has been discussed and demonstrated in early product design research findings carried out by the affiliated institution of the authors that proposed this methodology as an innovative organization method for product development by providing product prototypes for different industry sectors ranging from the mobility solutions (Frizziero *et al.*, 2022), marine (Frizziero *et al.*, 2021) until medical (Frizziero *et al.*, 2019) examples of which are seen in Figure 8.

Additionally, the scheme shown in Figure 9 summarizes all stages of IDeS, the main technologies related to them and the tools applied. The work divided among the three main categories (project setup, product development and production start-up) is simultaneously deployed and continuously updated. Problems that might arise throughout the project are studied at the outset to speed up the timelines as much as possible and partial overlap between the various stages is sought as far as possible to increase efficiency by decreasing time and enabling dialogue for sharing errors, problems and solutions.

The first phase, called project setup, is led by the Marketing Department; this encompasses the list of activities shown in the diagram, and each activity makes use of specific technologies, constantly changing, going to stimulate research in finding and if necessary, developing the solutions that allow for greater overall efficiency, for example, shown in the image is the Gantt chart, benchmarking as a competitor analysis and various product architecture development methodologies such as QFD or Stylistic design engineering (SDE) regarding to product style and design. The next process is product development. This phase is mainly the responsibility of the R&D Department and includes the seven main stages shown in the figure above. The first of these phases shown is that of CAD that includes the use of some specific software for the purpose, mainly 2D and 3D modeling, examples of which are listed among the most widely used similar with the prototyping phase that makes use of the most advanced digital construction technologies available at the time and adopted as needed, with the ultimate goal of obtaining a technical viable prototype, ready to be evaluated as needed. By using the latest technologies, it is also possible to work on a virtualization of the product,

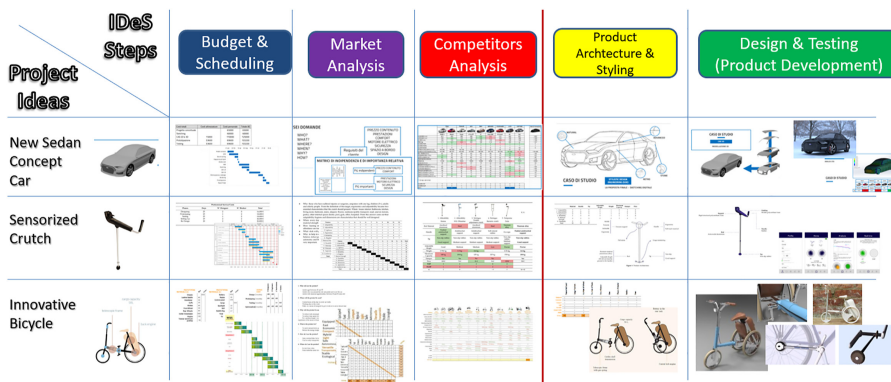


Figure 8.
Project development
using IDeS sequence

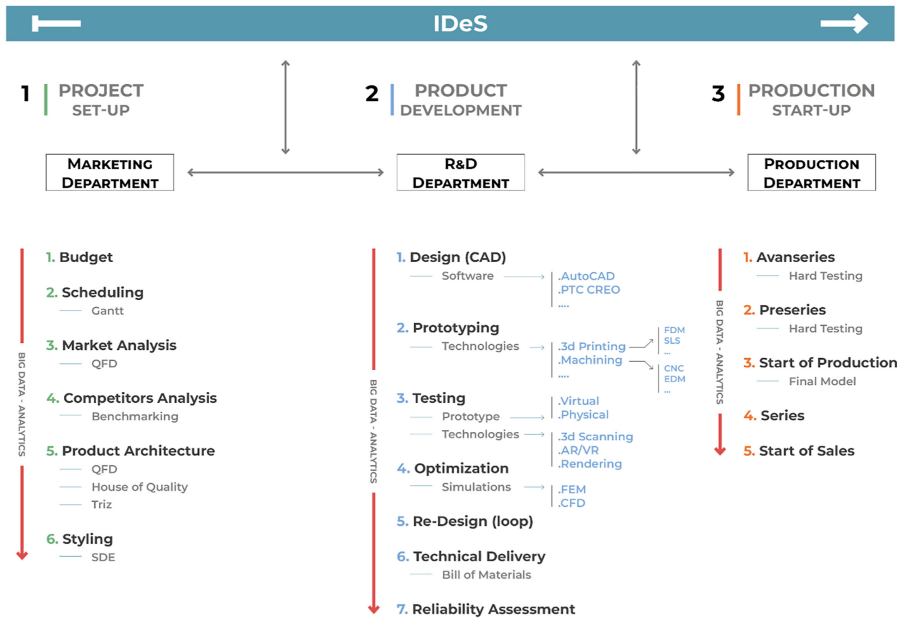


Figure 9.
IDEs method
deployment: tool
overview

through the creation of virtual prototypes that allow the evaluation of specific aspects, avoiding, when possible, the realization of physical models except when strictly necessary, so as to contract the timeframe, decrease the economic expenditure and the environmental impact resulting from the realization of many prototypes destined to be destroyed, often in 1:1 scale leading to the testing phase. Because of the previous step, testing can be carried out either virtually or physically. In the first mode, it is possible, in addition to carrying out the appropriate structural simulations, to go in for form checks and simulations of the product's functionality, so that the bulk of the findings can be made on the virtual model and errors and problems corrected in real time, arriving at testing on the physical model with already a good experience on the product and making it as quick and efficient as possible. This loop continues until it is finished and then proceeds to production start-up. In this last phase all tests and checks are carried out on prototype models that are gradually becoming more definitive and closer to what will be the series version of the final model, so that we can finally proceed to the preparation and start-up of the production chain and market entry.

3. Research methodology

One of the types of DFSS, as mentioned early in [Figure 5](#), is that referred to by DMADV. This approach is given to achieve six sigma quality standards in the creation of a product. Therefore, a correlation was found within the tools applied across DMADV processes ([Wang et al., 2016](#); [Mouaky et al., 2018](#)) and the tools applied across IDEs structure.

(1) Integration of QFD into DFSS

Even though the six sigma approach has become the key method used to improve business processes and problem-solving, a well-engineered implementation process according to each own company's nature is required to guarantee the success of DFSS ([Brue and Launsby, 2003](#); [Dias et al., 2020](#)); various studies of successfulness of DFSS by [Ericsson et al. \(2009\)](#) and [Swarbrick \(2018\)](#) concluded that companies very often have their own procedures to develop

the work tasks, so there is a need of creating structures and tools within the concept that could adapt the implementation of DFSS to most individual situations (Dias *et al.*, 2020). Subsequently, the main steps of QFD are known to be defined as a customer deployment tool by DFSS (Baptista *et al.*, 2020). This tool is widely used to evidence the voice of customer (VOC) data; therefore, the six questions are used in products (Johnson *et al.*, 2006) and services (Purushothaman and Ahmad, 2022) in the Define phase, as well as Measure towards both Decision Matrixes and Benchmarking, and using the What-How Matrix with Analyze. Synthesis of such integration could be seen in Figure 10.

Mainly speaking, QFD is the tool used by DFSS to help companies to gather VOC-sourced technical specifications and built the house of quality (HOQ) (Deshpande, 2016; Wang *et al.*, 2020), the process aimed to ensure an adaptive integration across DFSS during project definition, measuring and analysis areas for most industrial sectors, as shown in Figure 11.

Other research findings were about QFD application into DFSS in different industry sectors by means of complex-shaped mold design and manufacturing by Fatahillah *et al.* (2022) and Karasan *et al.* (2022), a conception of a green transportation vehicles (Cronemyr and Huge-Brodin, 2021; Rampal *et al.*, 2022; Giacobone and Mincoelli, 2020), until design methodologies improvement (Vimal *et al.*, 2021) and services improvement (Chan *et al.*, 2021).

(2) DFSS integration into IDeS

A right leadership approach enriched by the proper infrastructure must be supported by a straightforward strategic planning and managerial development. Many organizations have been deploying DFSS to build six sigma momentums in the area of design and development for their products and processes (Yoon and Byun, 2012), as evidences were found about major budget and schedule run over in applied systems. DFSS guidelines must play a key role in product design and research in order to achieve process sustainability (Gijo *et al.*, 2021; Ferryanto, 2008). In this way, IDeS methodology offers the capability of embracing the

IDeS:
a DFSS-QFD
integration in
a new reality

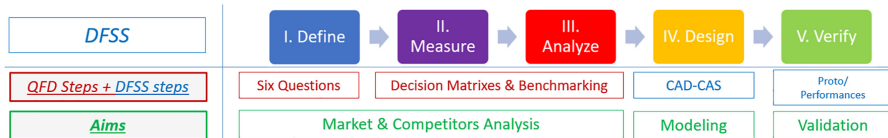


Figure 10.
QFD vs DFSS:
synthesis of the
methods' integration

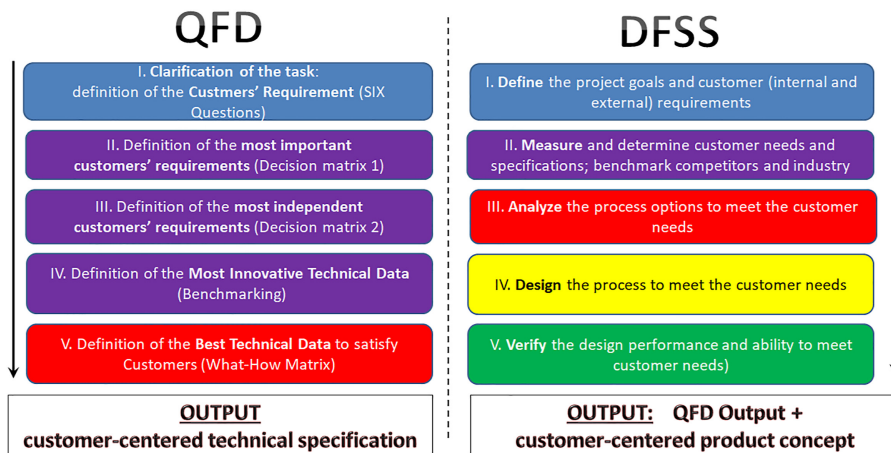


Figure 11.
Outline: integration of
QFD into DFSS

support of a major part of the organization, sharing information to reduce waste and internal bureaucracy time, whilst helping them to systematically grow into sustainability (Ericsson *et al.*, 2009).

In addition, the HOQ tool from DFSS has been used to assess the ultimate need to outline a method for product development, in line with benchmarking of existing research from Cooper (2019), Kang *et al.* (2018) and Setti *et al.* (2021) in the example shown in Figure 12. This tool aims to find out the customer requirements of a product, based on a QFD method.

Therefore, DFSS DMADV steps could be channeled, complemented with guidelines from lean productivity (Ikumapayi *et al.*, 2020) and correlated in Figure 13, to be integrated into the proposed IDeS methodology across its main three phases as seen in Figure 14, in which a complete coherence of using the DFSS methods into a wide organizational methodology could be also noticed.

Moreover, Figure 13 showed in detail, the list of the tools used by DMADV on IDeS the same that ought to be applied, partial or totally equal to the tools used by the proposed IDeS method. The similarity on the inputs, output characteristics and target process outputs resulting of the tools of DFSS.

However, DFSS roles can originate challenges in an organization according to a six sigma point of view given the fact that product development tasks that are distributed over the entire organization from a product concept are not usually conceived at an expertise level (process driven) rather than an idealistic model (Cooper, 2019). Moreover, at an operations management level, or better said, the processes of production and logistics are also key infrastructure elements in today’s organizations in order to get a holistic understanding of the decisions made in the previous phases (Reche *et al.*, 2020). Researchers have outlined the benefits of applying DFSS methods adding up to Industry 4.0 technologies (Sallati *et al.*, 2019; de Medeiros *et al.*, 2018), and that could also be used internally to efficiently share important,

		Functional Requirements										Customer Competitive Assessment				
		Direction of Improvement														
Relative Weight	Customer Importance	Customer Requirements														
		Convenience	Differentiation	Coordination	Hardware + Software	Data Analysis	Stylish design	Attention to detail	Product Development Time	Flexibility	Top Quality Level	Our Method	Method 1	Method 2	Method 3	
13%	9	Cost Effective	●	●	▽	▽	▽	▽	●	●	○	●	4	1	3	3
9%	6	Customization	●	●	▽	▽	●	●	●	●	▽	●	3	1	1	2
10%	7	Coordination	○	▽	●	○	●	▽	○	○	○	●	3	2	1	2
9%	6	Technology	●	▽	○	●	●	○	○	○	▽	○	3	1	3	2
6%	4	Smart	▽	▽	●	○	●	▽	▽	○	○	▽	1	1	3	2
6%	4	Creativity	▽	●	▽	●	▽	●	●	▽	○	▽	4	1	1	1
13%	9	Market Driven - VoC oriented	○	▽	●	●	●	○	●	●	▽	●	3	3	3	3
13%	9	Time saving	●	●	●	●	●	▽	▽	●	▽	●	3	1	2	2
9%	6	Adaptability	●	▽	▽	○	▽	●	▽	▽	●	▽	2	3	1	1
10%	7	Compliance	●	○	○	○	○	○	●	●	▽	●	2	1	1	1
Importance Rating																
Sum (Importance x Relationship)		661.19	455	485	506	610	357	557	691	243	679					
Relative Weight		13%	9%	9%	10%	12%	7%	11%	13%	5%	13%					
Our Product		4	3	3	3	2	4	4	4	3	3	3				
Competitor 1 (Cooper, 2019)		2	1	2	1	1	1	3	2	1	2					
Competitor 2 (Kang et al., 2018)		2	2	1	2	4	1	2	3	2	1					
Competitor 3 (Setti et al., 2021)		3	1	2	3	3	2	3	3	2	3					
Technical Competitive Assessment																

Figure 12. HOQ IDeS method assessment

IDeS

Methodologies

- Budget
- Scheduling
- Market Analysis
- QFD
- Triz
- Competitors Analysis
- Product Architecture
- SDE
- Virtual Prototyping
- Physical Prototyping
- Optimization
- Simulation
- Re-Design Loop
- Final Prototyping
- Pre-Series Procedures

Tools

- Gantt
- Matrix Analysis
- Benchmarking
- Top-Flop Analysis
- Stylistic Analysis
- Sketching
- Cad 2D (Autocad, ...)
- Cad 3D (Creo, Inventor, Alias, ...)
- 3D Printing (FDM, SLS, ...)
- Machining (CNC, EDM, ...)
- 3D Scanning
- Augmented Reality
- Virtual Reality
- Rendering (Keyshot, VRed, ...)
- FEM Analysis
- CFD Analysis
- Bill of Materials
- Physical Testing
- Pre-Series Testing



DFSS - DMADV

Define

- Prepare Charter
- Assemble the Team
- Prepare Project Plans
- Assesses Risk

Measure

- Understand / Analyze Requirements
- Translate Requirements into Measures
- Set Performance Targets
- Deploy Needs to Requirements (QFD 1)

Analyze

- Conduct Functional Analysis
- Deploy Requirements to Functions (QFD 2)
- Resolve Contradictions (TRIZ)
- Generate Design Concepts
- Evaluate / Select Design Concepts

Design

- Deploy Design Elements
- Deploy Functions to Elements (QFD 3)
- Cascade Requirements
- Stack Capabilities
- Test / Optimize Design
- Deploy to Process Variables (QFD 4)

Verify

- Launch Pilot
- Verify / Validate Design
- Plan for Transition to product
- Manage Product Lifetime

IDeS:
a DFSS-QFD
integration in
a new reality

Figure 13.
DFSS and IDeS tool
comparison and
overlap

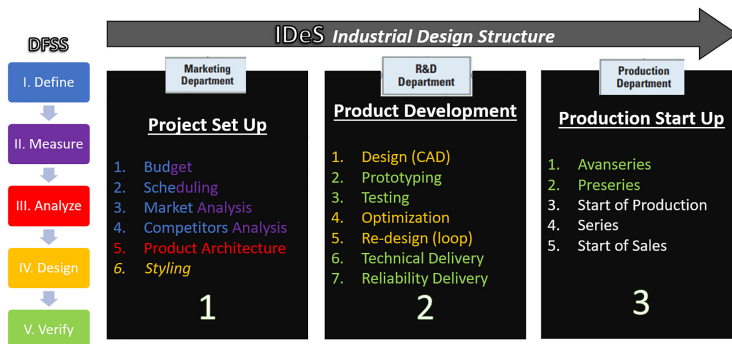


Figure 14.
Integration of DFSS
into IDeS

updated data throughout the entire organization. This could affect the final product development time, as well as configuration and overall quality levels, during the avanseries units (process design) throughout the first manufactured and reliability growth-driven studies carried out with the preseries units in which the final production processes are validated before the start of production (SOP).

- (3) IDeS as a methodology for organization structuring with quick adaptation in today's industrial challenges

Historically, companies lacked to understand the compromise of including manufacturing engineering and production from the start in product development practices that often results in a product arrival to market that lacks a defined manufacturing process, delivering poor process efficiency and poor process quality that leads to low profitability (Miles and

Roberts, 2019). Even though wide research has been made about improving the existing product development methodology of DFSS, authors agree that implementing DFSS to the reality of each sector made hard to present a general process model as achieved by the six sigma approach (Patel and Desai, 2018). The results of Miles and Roberts (2019) shown that 42% of surveyed consultants found difficulties at implementing DFSS and 38% found QFD and lean processes difficult to implement as well. Therefore a number of models based on DFSS have been proposed by Shokri and Li (2020), Ericsson *et al.* (2015), Patel (2017), Berryman (2002) and Soderborg (2004) among many others, findings that demonstrate how important is to have a tailored model true to every single reality. Nevertheless, a comprehensive, reliable method that considers the actual benefits of unified, cross functional interactions across the whole organization to speed up development times could be useful to conduit of organizations to implement DFSS in their organizations more efficiently.

Moreover, the approach proposed with IDeS would aid companies to systematically interact with all organization levels, therefore reaching all stakeholders' involvement into each project that is needed to reach industrial efficiency led by customization. Findings by Daft *et al.* (2010) correlated the concept of design into five of the author's seven main pursuits established by organizations (Figure 15), concluding that specific inputs and decisions from the top management and project leaders are key to be communicated and implemented into the design and styling department, whose outputs would spread systematically throughout the rest of the organization, affecting importantly the timing for decision-making in other departments. This would determine a different strategy for adapting the cultural behavior and environment across the entire organization.

Moreover, a different schematization would be required to arrange leadership within the organization based on the stages led by the product design phases that is to fully interact participants from all involved departments from early product feasibility and conceptualization analysis until production start-up. This change could suggest that a different scheme is required in a modern matrix-schemed organization in which the head of product design (style and engineering) would help the top management to better perceive upcoming challenges and efficiently take decisions as well as finding opportunities and threats, as seen in Figure 16. This approach establishes the value to appropriately design and engineer each individual component, adding up to an overall product success. The technical and style design departments could oversight digital information sharing based on latest technologies of Industry 4.0 as augmented reality (AR) (Xiong *et al.*, 2021), cyber physical systems (CPS), as well as other technological tooling and methods that also aid the pro-ecological design and assessment of sustainable product development practices (Paprocki, 2019) to convey product development information across all project stakeholders, helping to ease implementation costs by saving important resources, time and proving value savings over time (Miles and Roberts, 2019).

Afterwhile, IDeS would englobe all individual-skilled engineers from all departments into a single area called product engineering (PE), in which its knowledge would be spread systematically through the development stages.

Organization exist to do the following

1. Bring together resources to achieve desired goals and outcomest
2. Produce goods and services efficiently
3. Facilitate innovation
4. Use modern manufacturing and information technologies
5. Adapt to and influence a changing environment
6. Create value for owners, customers and employees
7. Accomodate ongoing challenges of diversity, ethics, and the motivation and coordination of employees

DESIGN
SIGNIFICANCE

Figure 15.
Importance of design to reach the goals of an organization

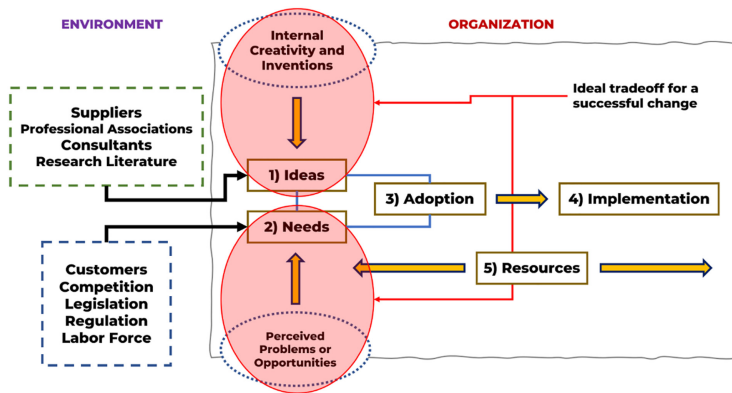


Figure 16.
Ideal trade-off for
initial product
decisions

4. Findings and research challenges

Numerous applications of IDeS have already been presented in the literature. Remarkably, the industry application range varies from the context of automotive car design and mobility solutions to biomedical and health care. This shows that an application of the described methodology is not constrained to a particular context but is suitable to most industrial areas whose product has to be sold to the final customer.

Different product prototypes and case studies were presented from different industry sectors like automotive (Frizziero *et al.*, 2022), marine (Frizziero *et al.*, 2021) until medical (Frizziero *et al.*, 2019).

4.1 Case study

Further, a case study applied to the development of a new product according to the IDeS methodology, is shown in Figure 17 and helps to understanding it. The request was to develop a new city car model. The first thing IDeS requires is the determination of a project budget and the time scheduling constraints of activities, typically governed by a Gantt chart showing the start and end day of each activity. This is followed by the market and customer

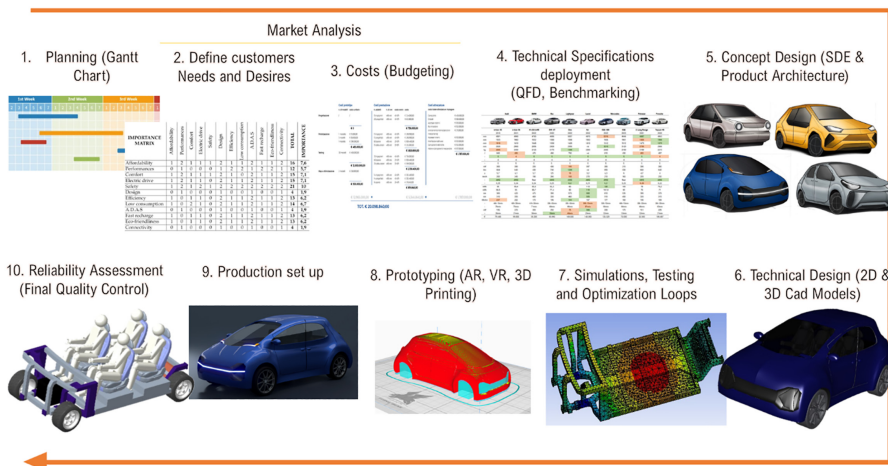


Figure 17.
Case study of IDeS
application – city car

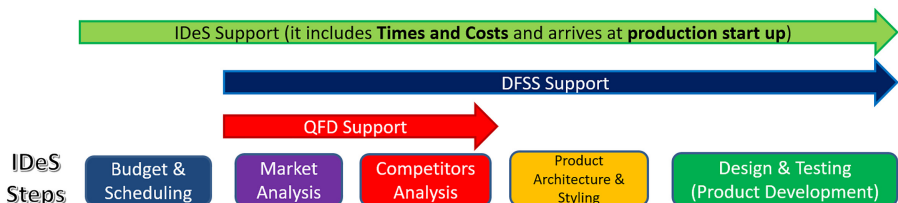
needs and desires ought to define the target market and customer segment to which the product will be targeted (young people, adults, the elderly, men, women, commuters, city dwellers only . . .). Therefore, an analysis of competitors cannot be missing, i.e. companies operating in the same market segment. Benchmarking makes it possible to understand which product features rival companies to put greater investments, thus outlining which ones need to be focused on to win over competitors and bring innovation. The next phase concerns the application of stylistic design engineering, a methodology for valuation of the stylistic trends that can be associated with the product (retro, advance, natural, stone, futuristic and so on) so as to choose for the best one, in line with the design specifications (volumes, geometries, maximum allowed overall dimensions and so on).

Instead, the product development macro phase includes the CAD design of the vehicle and, poststructural verifications performed with virtual finite element simulation tests, an initial physical prototyping of the product or some of its parts take place. This is followed by rapid prototyping and experimental testing phases for structural validation of each vehicle component. At that point, the product bill of materials (BOM) will be fully defined, and the organization of the manufacturing process and the first series prototypes of the vehicle can proceed.

Consequently, the IDeS method has proven to being able to track down the entire development stages of an industrial project, since the birth of the idea, from a “white sheet” project definition and then adding up budget and scheduling targets toward a market definition and positioning, continuing with product and process engineering until the SOP milestone. In this way, IDeS embraces a wide organizational management and traceability that otherwise is impossible with general management tools like QFD and DFSS, as seen in Figure 18.

Conventionally, customer requirement management entails an iterative process aimed to gather the needs, constraints and conditions from the end users, interpretation practices until reaching tangible product specifications (Hehn and Uebernickel, 2018). Afterward, the customer satisfaction is issued again to redesign the product in the upgrading phases (Zhang et al., 2019). Nowadays, agile contexts in organizations collect data from users continuously after the launch of the product and use this to portray technical improvements (Sjodin et al., 2020). However, digitalized services nowadays allows to systematically incorporate the request for satisfaction of customer needs to validate the existing performance (Poth and Riel, 2020; Montagna and Cantamessa, 2019). Hence, testing and validation phases will no longer follow the conception of the product but coexist in a continuous circle. Although today it is not possible to find this continuous circle of execution, satisfaction and validation in every sector, this is the direction that can be hypothesized (Cantamessa et al., 2020). Moreover, today’s conditions require to spread customers’ demands on all areas, aided by proper infrastructure and tooling to deliver the information, including physical and/or virtual models in which all parts of the organization can relate to (Figure 19) including process simulations ought to achieve a flexible manufacturing performance (Zghair et al., 2018) and virtual reality (VR) applications that could manage project-related outlines in all areas across most development

Figure 18. IDeS methodology embraces QFD and DFSS as it trades off product development with budget and scheduling



stages from environment evaluation (Vitali *et al.*, 2021), through preliminary customer-driven product assessment (Vanacore *et al.*, 2021), until virtual manufacturing (Peruzzini *et al.*, 2021).

5. Discussion

Figure 20 summarizes the fact that IDeS methodology for product design and development could integrate other well-known approaches intended for quality assessment like DFSS, and tools for specifications collection like QFD. With this, IDeS proved to have a wider approach to execute projects concentrated mainly on VOC inputs, awareness of which must be expanded across the entire organization in this way helping companies to improve the organization plan ought to react sooner to the continuous market and technology changes.

Moreover, the concept of IDeS summarized on Figure 21 has the potential to drive companies to rearrange their managerial organization to be compliant to the market reality at the present day. Unifying the platforms used to identify client requirements to share product information across the enterprise would increase the efficiency of management instruments to reach productivity and save important time and resources (Kjaer *et al.*, 2019).

Nevertheless, further research based on IDeS method application is required in order to evaluate the inclusion of specific management tools that would help to ease information collection and sharing driven by Industry 4.0 technology. Figure 22 summarizes the application of this method into the organization.

IDeS:
a DFSS-QFD
integration in
a new reality

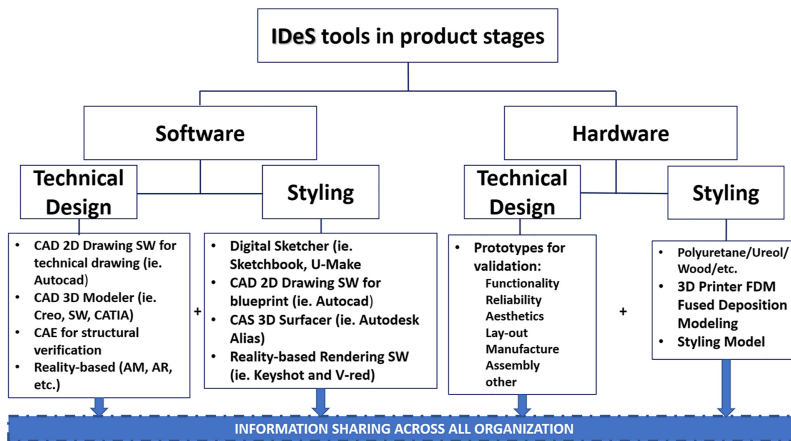


Figure 19. Tooling used in IDeS that include styling and engineering design areas

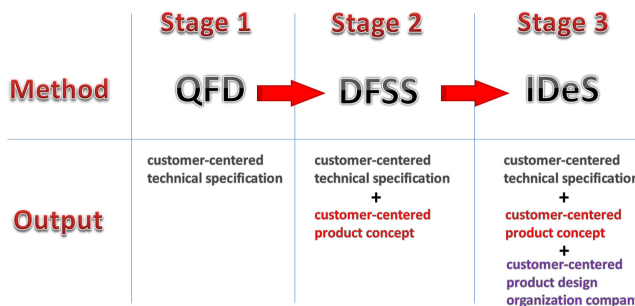


Figure 20. IDeS implementation of QFD and DFSS

IDeS - Outline

1. Customer needs and desires (Big Data and Analytics)
2. Technical Specifications (QFD)
3. Concept Design (Digital Sketching and Product Architecture)
4. Technical Design (3D CAD Model)
5. Model Simulation, Digital and Physical Prototyping (AR/VR, 3D Printing)
6. Testing and Loop of Optimization (Artificial Intelligence and Genetic Algorithm)
7. Additive Manufacturing Technologies for Production

Figure 21.
Outline of the IdeS method

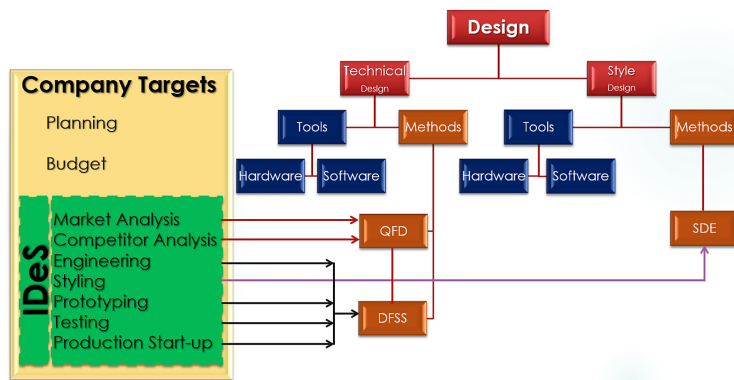


Figure 22.
Summary: IDeS methods to apply into the organization

6. Conclusion

The conception of IDeS as an integrated method for product development management has been established to be able to fully combine other known tools found in six sigma like QFD, customer data analysis, SIPOC, as well as the project charter, scope and timeline. IDeS was correlated with the DMADV approach of DFSS that guarantees a proven system aimed to reduce overall product time to market whilst achieving to account for current market requirements owned by a fast change in customer behavior.

Moreover, this concept enables organizations to practically implement proper Industry 4.0 technological tooling systematically across all product development areas. The information created could be known immediately across all parties involved, obtaining lower time and resources to perform changes. This updated approach based on the systematic use of technology for product development management enables organizations to widen their product efficiency and minimizing the risks. This last statement allowed to create a strong link between the design structure complexity (styling plus engineering) across the company organization. This engagement must be exploited to guarantee a product that answers immediately to the customer and the industry and a quick reaction to market demand fluctuation and would be a key guideline for companies ought to succeed.

References

- Adiandari, A.M., Winata, H., Fitriandari, M. and Hariguna, T. (2020), "Improving the quality of Internet banking services: an implementation of the quality function deployment (QFD) concept", *Management Science Letters*, Vol. 10 No. 5, pp. 1121-1128, doi: [10.5267/j.msl.2019.10.029](https://doi.org/10.5267/j.msl.2019.10.029).

-
- Ahmed, S., Irshad, L. and Demirel, H.O. (2021), "Prototyping human-centered products in the age of industry 4.0", *Journal of Mechanical Design*, Vol. 143 No. 7, pp. 071102-071112.
- Akao, Y. (2014), "The method for motivation by quality function deployment (QFD)", *Nang Yan Business Journal*, Vol. 1 No. 1, pp. 1-9.
- Ali, H.Y., Danish, R.Q. and Asr-arul-Haq, M. (2020), "How corporate social responsibility boosts firm financial performance: the mediating role of corporate image and customer satisfaction", *Corporate Social Responsibility and Environmental Management*, Vol. 27 No. 1, pp. 166-177.
- Alt, R., Ehmke, J.F., Haux, R., Henke, T., Mattfeld, D.C., Oberweis, A., Paech, B. and Winter, A. (2019), "Towards customer-induced service orchestration-requirements for the next step of customer orientation", *Electronic Markets*, Vol. 29 No. 1, pp. 79-91.
- Antony, J., Snee, R. and Hoerl, R. (2017), "Lean Six Sigma: yesterday, today and tomorrow", *International Journal of Quality and Reliability Management*, Vol. 34 No. 7, pp. 1073-1093.
- Ashima, R., Haleem, A., Bahl, S., Javaid, M., Mahla, S.K. and Singh, S. (2021), "Automation and manufacturing of smart materials in Additive Manufacturing technologies using Internet of Things towards the adoption of Industry 4.0", *Materials Today: Proceedings*, Vol. 45, pp. 5081-5088.
- Baker, B. (2003), "Design for six sigma: the revolutionary process for achieving extraordinary profits", *Quality Progress*, Vol. 36 No. 6, p. 97.
- Balamurugan, E., Flaih, L.R., Yuvaraj, D., Sangeetha, K., Jayanthiladevi, A. and Kumar, T.S. (2019), "Use case of artificial intelligence in machine learning manufacturing 4.0", *2019 International Conference on Computational Intelligence and Knowledge Economy, (ICCIKE)*, pp. 656-659.
- Baptista, A., Silva, F.J.G., Campilho, R., Ferreira, S. and Pinto, G. (2020), "Applying DMADV on the industrialization of updated components in the automotive sector: a case study", *Procedia Manufacturing*, Vol. 51, pp. 1332-1339.
- Berryman, M.L. (2002), "DFSS and big payoffs", *Lean and Six Sigma Review*, Vol. 2 No. 1, p. 23.
- Bidikar, S.G., Rane, S.B. and Potdar, P.R. (2021), "Product development using Design for Six Sigma approach: case study in switchgear industry", *International Journal of System Assurance Engineering and Management*, Vol. 13 No. 2022, pp. 203-230, doi: [10.1007/s13198-021-01199-4](https://doi.org/10.1007/s13198-021-01199-4).
- Brue, G. and Launsby, R. (2003), *Design for Six Sigma*, McGraw Hill Professional.
- Burton, R.M. and Obel, B. (2018), "The science of organizational design: fit between structure and coordination", *Journal of Organization Design*, Vol. 7 No. 1, pp. 1-13.
- Cantamessa, M., Montagna, F., Altavilla, S. and Casagrande-Seretti, A. (2020), "Data-driven design: the new challenges of digitalization on product design and development", *Design Science*, Vol. 6 No. E27, doi: [10.1017/dsj.2020.25](https://doi.org/10.1017/dsj.2020.25).
- Cartagena Méndez, M.J. (2021), "Assay report documentation and storage process improvement using DMADV methodology", *Manufacturing Engineering Program*, available at: <http://hdl.handle.net/20.500.12475/1152>.
- Chan, W.C., Ibrahim, W.H.W., Lo, M.C., Suaidi, M.K. and Ha, S.T. (2021), "Determinants of customer satisfaction and loyalty in public transport: a PLS-SEM approach", *Studies of Applied Economics*, Vol. 39 No. 8.
- Cong, J., Chen, C.-H. and Zheng, P. (2020a), "Design entropy theory: a new design methodology for smart PSS development", *Advanced Engineering Informatics*, Vol. 45, 101124.
- Cong, J., Chen, C.-H., Zheng, P., Li, X. and Wang, Z. (2020b), "A holistic relook at engineering design methodologies for smart product-service systems development", *Journal of Cleaner Production*, Vol. 272, 122737.
- Cooper, R.G. (2019), "The drivers of success in new-product development", *Industrial Marketing Management*, Vol. 76, pp. 36-47.

-
- Cronemyr, P. and Hüge-Brodin, M. (2021), "Green Karma—promoting environmental initiatives by adapting and using QFD as a proactive tool", *Total Quality Management and Business Excellence*, Vol. 33 No. 16, pp. 1826-1845, doi: [10.1080/14783363.2021.2004887](https://doi.org/10.1080/14783363.2021.2004887).
- Daft, R.L., Murphy, J. and Willmott, H. (2010), *Organization Theory and Design*, Cengage Learning EMEA, Hampshire.
- de Medeiros, J.F., Lago, N.C., Colling, C., Ribeiro, J.L.D. and Marcon, A. (2018), "Proposal of a novel reference system for the green product development process (GPDP)", *Journal of Cleaner Production*, Vol. 187, pp. 984-995.
- Delpla, V., Kenné, J.-P. and Hof, L.A. (2022), "Circular manufacturing 4.0: towards internet of things embedded closed-loop supply chains", *The International Journal of Advanced Manufacturing Technology*, Vol. 118 No. 9, pp. 3241-3264.
- Deshpande, S. (2016), *Introducing Design for Six Sigma's DMADV Methodology to the Packaging Industry*, Rochester Institute of Technology, Rochester.
- Dias, A.S.M.E., Abreu, A., Navas, H.V.G. and Santos, R. (2020), "Proposal of a holistic framework to support sustainability of new product innovation processes", *Sustainability*, Vol. 12 No. 8, p. 3450.
- DiRomualdo, A., El-Khoury, D. and Girimonte, F. (2018), "HR in the digital age: how digital technology will change HR's organization structure, processes and roles", *Strategic HR Review*, Vol. 17 No. 5, pp. 234-242, doi: [10.1108/SHR-08-2018-0074](https://doi.org/10.1108/SHR-08-2018-0074).
- Dutta, G., Kumar, R., Sindhvani, R. and Singh, R.K. (2021), "Digitalization priorities of quality control processes for SMEs: a conceptual study in perspective of Industry 4.0 adoption", *Journal of Intelligent Manufacturing*, Vol. 32 No. 6, pp. 1679-1698.
- Echegaray, F. (2016), "Consumers' reactions to product obsolescence in emerging markets: the case of Brazil", *Journal of Cleaner Production*, Vol. 134, pp. 191-203.
- Erdil, N.O. and Arani, O.M. (2019), "Quality function deployment: more than a design tool", *International Journal of Quality and Service Sciences*, Vol. 11 No. 2, pp. 142-166, doi: [10.1108/IJQSS-02-2018-0008](https://doi.org/10.1108/IJQSS-02-2018-0008).
- Ericsson, E., Gustafsson, P., Lilliesköld, J. and Sörqvist, L. (2009), "DFSS—evolution or revolution? A study of critical effects related to successful implementation of DFSS", *Proceedings of ICQSS Conference, 2009*.
- Ericsson, E., Gingnell, L. and Lilliesköld, J. (2015), "Implementing Design for Six Sigma in large Swedish product developing organisations—an interview study", *Total Quality Management and Business Excellence*, Vol. 26 Nos 5-6, pp. 648-660.
- Fatahillah, F., Rimawan, E., Waskito, A. and Apfiyari, S. (2022), "Strategy to win the competition by developing products and services using the QFD method in moldbase manufacturing", *International Journal Of Special Education*, Vol. 3 No. 3, pp. 2487-2499.
- Ferryanto, L. (2008), "The path to improved product development", *Lean and Six Sigma Review*, Vol. 8 No. 1, p. 21.
- Frizziero, L., Donnici, G., Liverani, A., Alessandri, G., Menozzi, G.C. and Varotti, E. (2019), "Developing innovative crutch using IDeS (industrial design structure) methodology", *Applied Sciences (Switzerland)*, Vol. 9 No. 23, doi: [10.3390/app9235032](https://doi.org/10.3390/app9235032).
- Frizziero, L., Liverani, A., Donnici, G., Conti, E., Dello Preite, B., Lamanna, U., Leon-Cardenas, C. and Garulli, M. (2021), "GD (generative design) applied to a plastics recovery drone (PRD) using IDeS (industrial design structure)", *Inventions*, Vol. 6 No. 4, p. 82.
- Frizziero, L., Leon-Cardenas, C., Colasurdo, G., Vicaretti, A. and Liverani, A. (2022), "IDeS (industrial design structure) method applied to the automotive design framework: two sports cars with shared platform", *Inventions*, Vol. 7 No. 2, doi: [10.3390/inventions7020036](https://doi.org/10.3390/inventions7020036).
- Fu, Y.-L. and Liang, K.-C. (2020), "Fuzzy logic programming and adaptable design of medical products for the COVID-19 anti-epidemic normalization", *Computer Methods and Programs in Biomedicine*, Vol. 197, 105762.

- Gandara, G.S., Muri, R. and Purba, H.H. (2019), "Increase service selling of formaldehyde products by implementing Quality Function Deployment (QFD)", *Journal of Applied Research on Industrial Engineering*, Vol. 6 No. 3, pp. 219-231.
- Giacobone, G.A. and Mincoelli, G. (2020), "Human-centered design for automotive styling design: conceptualizing a car from QFD to ViP", *International Conference on Intelligent Human Systems Integration*, pp. 59-65.
- Gijo, E.V., Bhat, S., Antony, J. and Park, S.H. (2021), "Ten commandments for successful implementation of design for six sigma", *The TQM Journal*, Vol. 33 No. 8, pp. 1666-1682, doi: [10.1108/TQM-01-2021-0014](https://doi.org/10.1108/TQM-01-2021-0014).
- Gu, P., Hashemian, M. and Nee, A.Y.C. (2004), "Adaptable design", *CIRP Annals*, Vol. 53 No. 2, pp. 539-557, doi: [10.1016/S0007-8506\(07\)60028-6](https://doi.org/10.1016/S0007-8506(07)60028-6).
- Han, X., Li, R., Wang, J., Ding, G. and Qin, S. (2020), "A systematic literature review of product platform design under uncertainty", *Journal of Engineering Design*, Vol. 31 No. 5, pp. 266-296.
- Hasibuan, A., Parinduri, L., Sulaiman, O.K., Suleman, A.R., Harahap, A.K.Z., Hasibuan, M., Rupilele, F.G.J., Simarmata, J., Kurniasih, N. and Daengs, G.S.A. (2019), "Service quality improvement by using the quality function deployment (QFD) method at the government general hospital", *Journal of Physics: Conference Series*, Vol. 1363 No. 1, p. 12095.
- Hehn, J. and Uebernickel, F. (2018), "Towards an understanding of the role of design thinking for requirements elicitation-findings from a multiple-case study".
- Ikumapayi, O.M., Akinlabi, E.T., Mwema, F.M. and Ogbonna, O.S. (2020), "Six sigma versus lean manufacturing—An overview", *Materials Today: Proceedings*, Vol. 26, pp. 3275-3281.
- Jamil, N., Gholami, H., Mat Saman, M.Z., Streimikiene, D., Sharif, S. and Zakuan, N. (2020), "DMAIC-based approach to sustainable value stream mapping: towards a sustainable manufacturing system", *Economic Research-Ekonomska Istrazivanja*, Vol. 33 No. 1, pp. 331-360.
- Jaskyte, K. and Liedtka, J. (2022), "Design thinking for innovation: practices and intermediate outcomes", *Nonprofit Management and Leadership*, Vol. 32 No. 4, pp. 555-575, doi: [10.1002/nml.21498](https://doi.org/10.1002/nml.21498).
- Jørgensen, K.A. (2009), *Product Configuration and Product Family Modelling*, Department of Production, Aalborg University, Aalborg.
- Johnson, J.A., Gitlow, H., Widener, S. and Popovich, E. (2006), "Designing new housing at the university of Miami: a "six sigma" DMADV/DFSS case study", *Quality Engineering*, Vol. 18 No. 3, pp. 299-323.
- Kang, X., Yang, M., Wu, Y. and Ni, B. (2018), "Integrating evaluation grid method and fuzzy quality function deployment to new product development", *Mathematical Problems in Engineering*, 2451470, doi: [10.1155/2018/2451470](https://doi.org/10.1155/2018/2451470).
- Karasan, A., Ilbahar, E., Cebi, S. and Kahraman, C. (2022), "Customer-oriented product design using an integrated neutrosophic AHP and DEMATEL and QFD methodology", *Applied Soft Computing*, Vol. 118, 108445.
- Kerin, M. and Pham, D.T. (2020), "Smart remanufacturing: a review and research framework", *Journal of Manufacturing Technology Management*, Vol. 31 No. 6, pp. 1205-1235, doi: [10.1108/JMTM-06-2019-0205](https://doi.org/10.1108/JMTM-06-2019-0205).
- Kjaer, L.L., Pigosso, D.C.A., Niero, M., Bech, N.M. and McAlloone, T.C. (2019), "Product/service-systems for a circular economy: the route to decoupling economic growth from resource consumption?", *Journal of Industrial Ecology*, Vol. 23 No. 1, pp. 22-35.
- Kohli, A.K. and Jaworski, B.J. (1990), "Market orientation: the construct, research propositions, and managerial implications", *Journal of Marketing*, Vol. 54 No. 2, pp. 1-18.
- Latyshova, L.S., Syaglova, Y.V. and Oyner, O.K. (2015), "The customer-oriented approach: the concept and key indicators of the customer driven company", *DIEM: Dubrovnik International Economic Meeting*, Vol. 2 No. 1, pp. 637-645.

-
- Lazorik, P. (2021), "SMART production system with full digitalization for assembly and inspection in concept of industry 4.0", *Future Access Enablers for Ubiquitous and Intelligent Infrastructures: 5th EAI International Conference, FABULOUS 2021, Virtual Event, May 6-7, 2021, Proceedings*, Vol. 382, p. 181.
- Li, N., Laux, C. and Antony, J. (2018), "Designing for Six Sigma in a private organization in China under TQM implementation: a case study", *Quality Engineering*, Vol. 30 No. 3, pp. 405-418.
- Liedtka, J. (2018), "Exploring the impact of design thinking in action", *In Darden Working Paper Series*.
- Lin, W.D., Low, Y.H., Chong, Y.T. and Teo, C.L. (2018), "Integrated cyber physical simulation modelling environment for manufacturing 4.0", *2018 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM)*, pp. 1861-1865.
- Luderer, G., Pehl, M., Arvesen, A., Gibon, T., Bodirsky, B.L., de Boer, H.S., Fricko, O., Hejazi, M., Humpenöder, F. and Iyer, G. (2019), "Environmental co-benefits and adverse side-effects of alternative power sector decarbonization strategies", *Nature Communications*, Vol. 10 No. 1, pp. 1-13.
- Lv, W.-D., Tian, D., Wei, Y. and Xi, R.-X. (2018), "Innovation resilience: a new approach for managing uncertainties concerned with sustainable innovation", *Sustainability*, Vol. 10 No. 10, p. 3641.
- Maas, J. (2000), "Driving customer equity: how lifetime customer value is reshaping corporate strategy", *MIT Sloan Management Review*, Vol. 41 No. 4, p. 106.
- Madhani, P.M. (2021), "Lean Six Sigma in finance and accounting services for enhancing business performance", *International Journal of Service Science, Management, Engineering, and Technology (IJSSMET)*, Vol. 12 No. 6, pp. 141-165.
- Mazur, G. and Belt, Q.F.D.R. (2017), "Beyond ISO 16355: QFD for a digital world", *Tokyo: Proceedings of the 23rd International QFD Symposium*, pp. 106-110.
- Medini, K., Andersen, A.-L., Wuest, T., Christensen, B., Wiesner, S., Romero, D., Liu, A. and Tao, F. (2019), "Highlights in customer-driven operations management research", *Procedia Cirp*, Vol. 86, pp. 12-19.
- Mesa, J.A., Esparragoza, I. and Maury, H. (2019), "Trends and perspectives of sustainable product design for open architecture products: facing the circular economy model", *International Journal of Precision Engineering and Manufacturing-Green Technology*, Vol. 6 No. 2, pp. 377-391.
- Miles, M. and Roberts, D. (2019), *Overcoming Barriers to Implementing and Sustaining Product Development Tools*, Rochester Institute of Technology, New York.
- Mintzberg, H. (1981), *Organization Design: Fashion or Fit?*, Graduate School of Business Administration, Harvard University, Cambridge, MA.
- Mintzberg, H. (1989), "The structuring of organizations", *Readings in Strategic Management*, Springer, pp. 322-352.
- Montagna, F. and Cantamessa, M. (2019), "Unpacking the innovation toolbox for design research and practice", *Design Science*, Vol. 5 No. 8, doi: [10.1017/dsj.2019.3](https://doi.org/10.1017/dsj.2019.3).
- Mouaky, M., Benabbou, L. and Berrado, A. (2018), "DMADV approach to evaluate the Adaptive Kanban performance for inventory management process: the case of Moroccan public pharmaceutical supply chain", *Supply Chain Forum: An International Journal*, Vol. 19 No. 3, pp. 178-190.
- Narver, J.C. and Slater, S.F. (1990), "The effect of a market orientation on business profitability", *Journal of Marketing*, Vol. 54 No. 4, pp. 20-35.
- Neneh, B.N. (2018), "Customer orientation and SME performance: the role of networking ties", *African Journal of Economic and Management Studies*, Vol. 9 No. 2, pp. 178-196, doi: [10.1108/AJEMS-03-2017-0043](https://doi.org/10.1108/AJEMS-03-2017-0043).
- Nurcahyanie, Y.D., Singgih, M.L. and Dewi, D.S. (2020), "Conceptualizing DFSS an analysis of 107 studies", *IOP Conference Series: Materials Science and Engineering*, Vol. 722 No. 1, 12055.

-
- Oyner, O.K. and Latyshova, L.S. (2009), "An impact of companies market oriented behaviour upon business efficiency", *Proceedings of the Xth International Scientific Conference for Economic and Society Development*, Moscow: GU-HSE, pp. 287-296.
- Pai, A., Veeram, V.S., Babu, B.S. and Pareek, P.K. (2018), "Six sigma approaches used in implementing in supply chain management: a review", *Research and Applications of Web Development and Design*, Vol. 1 No. 2, pp. 12-16.
- Paprocki, M. (2019), "Contemporary trends in the design and management of product development", *Mechanik*, Vol. 92 Nos 1, pp. 64-66, SE-Articles, doi: [10.17814/mechanik.2019.1.14](https://doi.org/10.17814/mechanik.2019.1.14).
- Parmar, H., Khan, T., Tucci, F., Umer, R. and Carlone, P. (2022), "Advanced robotics and additive manufacturing of composites: towards a new era in Industry 4.0", *Materials and Manufacturing Processes*, Vol. 37 No. 5, pp. 483-517.
- Patel, S. (2017), *The Tactical Guide to Six Sigma Implementation*, CRC Press, Boca Raton, FL.
- Patel, M. and Desai, D.A. (2018), "Critical review and analysis of measuring the success of six sigma implementation in manufacturing sector", *International Journal of Quality and Reliability Management*, Vol. 35 No. 8, pp. 1519-1545, doi: [10.1108/IJQRM-04-2017-0081](https://doi.org/10.1108/IJQRM-04-2017-0081).
- Perez, O., Saucedo, S. and Cruz, J. (2018), *Manufacturing 4.0: The Use of Emergent Technologies in Manufacturing*, Palibrio, Bloomington, IN.
- Peruzzini, M., Grandi, F., Cavallaro, S. and Pellicciari, M. (2021), "Using virtual manufacturing to design human-centric factories: an industrial case", *The International Journal of Advanced Manufacturing Technology*, Vol. 115 No. 3, pp. 873-887.
- Ping, Y.-J., Liu, R., Lin, W. and Liu, H.-C. (2020), "A new integrated approach for engineering characteristic prioritization in quality function deployment", *Advanced Engineering Informatics*, Vol. 45, 101099.
- Poth, A. and Riel, A. (2020), "Quality requirements elicitation by ideation of product quality risks with design thinking", *2020 IEEE 28th International Requirements Engineering Conference (RE)*, pp. 238-249.
- Powell, D.J. and Bartolome, C.P.F. (2020), "Enterprise-wide value stream mapping: from dysfunctional organization to cross-functional, collaborative learning and improvement", *2020 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM)*, pp. 551-555.
- Prashar, A. (2020), "Adopting Six Sigma DMAIC for environmental considerations in process industry environment", *The TQM Journal*, Vol. 32 No. 6, pp. 1241-1261, doi: [10.1108/TQM-09-2019-0226](https://doi.org/10.1108/TQM-09-2019-0226).
- Purushothaman, K. and Ahmad, R. (2022), "Integration of Six Sigma methodology of DMADV steps with QFD, DFMEA and TRIZ applications for image-based automated inspection system development: a case study", *International Journal of Lean Six Sigma*, Vol. 13 No. 6, pp. 1239-1276, doi: [10.1108/IJLSS-05-2021-0088](https://doi.org/10.1108/IJLSS-05-2021-0088).
- Rajendran, S. and Popfinger, M. (2022), "Evaluating the substitutability of short-haul air transport by high-speed rail using a simulation-based approach", *Transportation Research Interdisciplinary Perspectives*, Vol. 15, 100632.
- Ramani, G. and Kumar, V. (2008), "Interaction orientation and firm performance", *Journal of Marketing*, Vol. 72 No. 1, pp. 27-45.
- Rampal, A., Mehra, A., Singh, R., Yadav, A., Nath, K. and Chauhan, A.S. (2022), "Kano and QFD analyses for autonomous electric car: design for enhancing customer contentment", *Materials Today: Proceedings*.
- Reche, A.Y.U., Junior, O.C., Estorilio, C.C.A. and Rudek, M. (2020), "Integrated product development process and green supply chain management: contributions, limitations and applications", *Journal of Cleaner Production*, Vol. 249, 119429.
- Sallati, C., de Andrade Bertazzi, J. and Schützer, K. (2019), "Professional skills in the Product Development Process: the contribution of learning environments to professional skills in the Industry 4.0 scenario", *Procedia Cirp*, Vol. 84, pp. 203-208.

- Sandro, G. (2021), "Design thinking for strategizing?—A critical literature review", *Journal of Emerging Trends in Marketing and Management*, Vol. 1 No. 1, pp. 110-119.
- Selvi, K. and Majumdar, R. (2014), "Six sigma-overview of DMAIC and DMADV", *International Journal of Innovative Science and Modern Engineering*, Vol. 2 No. 5, pp. 16-19.
- Seno, J.P., Pimenta, M.L., Hilletoft, P. and Eriksson, D. (2019), "Cross-functional interconnectedness as an enabler of customer value", *Journal of Business and Industrial Marketing*, Vol. 34 No. 4, pp. 821-835, doi: [10.1108/JBIM-04-2017-0101](https://doi.org/10.1108/JBIM-04-2017-0101).
- Setti, P.H.P., Junior, O.C. and Estorilio, C.C.A. (2021), "Integrated product development method based on Value Engineering and design for assembly concepts", *Journal of Industrial Information Integration*, Vol. 21, 100199.
- Shipa, R.A., Bon, A.T. and Ali, A. (2021), "Empirical models development and analysis of green supply chain management of manufacturing sector in Malaysia", *Proceedings of the International Conference on Industrial Engineering and Operations Management*, pp. 323-324, available at: <https://www.scopus.com/inward/record.uri?eid=2-s2.0-85130291283&partnerID=40&md5=06582e0b8736f16a6af33104f45afb22>
- Shivajee, V., Singh, R.K. and Rastogi, S. (2019), "Manufacturing conversion cost reduction using quality control tools and digitization of real-time data", *Journal of Cleaner Production*, Vol. 237, 117678.
- Shojaie, A.A. and Kahedi, E. (2019), "Auto parts manufacturing quality assessment using design for six sigma (DFSS), case study in ISACO company", *International Journal of System Assurance Engineering and Management*, Vol. 10 No. 1, pp. 35-43.
- Shokri, A. and Li, G. (2020), "Green implementation of Lean Six Sigma projects in the manufacturing sector", *International Journal of Lean Six Sigma*, Vol. 11 No. 4, pp. 711-729, doi: [10.1108/IJLSS-12-2018-0138](https://doi.org/10.1108/IJLSS-12-2018-0138).
- Silva, C.S., Borges, A.F. and Magano, J. (2021), "Quality Control 4.0: a way to improve the quality performance and engage shop floor operators", *International Journal of Quality and Reliability Management*, Vol. 39 No. 6, pp. 1471-1487, doi: [10.1108/IJQRM-05-2021-0138](https://doi.org/10.1108/IJQRM-05-2021-0138).
- Sjödín, D., Parida, V., Jovanovic, M. and Visnjic, I. (2020), "Value creation and value capture alignment in business model innovation: a process view on outcome-based business models", *Journal of Product Innovation Management*, Vol. 37 No. 2, pp. 158-183.
- Soderborg, N.R. (2004), "Design for six sigma at Ford", *Six Sigma Forum Magazine*, Vol. 4 No. 1, available at: <https://asq.org/perl/msg.pl?prvurl=/six-sigma/2004/11/six-sigma/design-for-six-sigma-at-ford.pdf>.
- Soundararajan, K. and Janardhan Reddy, K. (2019), "Cost-reduction and quality improvement using DMAIC in the SMEs", *International Journal of Productivity and Performance Management*, Vol. 68 No. 8, pp. 1528-1540, doi: [10.1108/IJPPM-10-2018-0360](https://doi.org/10.1108/IJPPM-10-2018-0360).
- Su, F.-M. and Su, C.-T. (2019), "TFT-LCD contrast ratio improvement by using design for six sigma disciplines", *IEEE Transactions on Semiconductor Manufacturing*, Vol. 33 No. 1, pp. 128-139.
- Swarbrick, B. (2018), "Quality by design in practice", *Multivariate Analysis in the Pharmaceutical Industry*, pp. 125-171, Elsevier.
- Thaichon, P., Surachartkumtonkun, J., Quach, S., Weaven, S. and Palmatier, R.W. (2018), "Hybrid sales structures in the age of e-commerce", *Journal of Personal Selling and Sales Management*, Vol. 38 No. 3, pp. 277-302, doi: [10.1080/08853134.2018.1441718](https://doi.org/10.1080/08853134.2018.1441718).
- Tomlinson, M. (2018), *The Impact of Design Thinking on Driving Innovation within Large Businesses*, ResearchGate, available at: https://www.researchgate.net/profile/Max-Tomlinson/publication/324569820_The_Impact_of_Design_Thinking_on_Driving_Innovation_Within_Large_Businesses/links/5ad5f674a6fdcc2935815aaa/The-Impact-of-Design-Thinking-on-Driving-Innovation-Within-Large-Businesses.pdf.

-
- Vanacore, A., Lanzotti, A., Percuoco, C. and Vitolo, B. (2021), "Statistical modelling of comfort preferences and uncertainty in subjective evaluations of aircraft seat comfort", *Congress of the International Ergonomics Association*, pp. 178-183, doi: [10.1007/978-3-030-74608-7_23](https://doi.org/10.1007/978-3-030-74608-7_23).
- Vanany, I., Maarif, G.A. and Soon, J.M. (2019), "Application of multi-based quality function deployment (QFD) model to improve halal meat industry", *Journal of Islamic Marketing*, Vol. 10 No. 1, pp. 97-124, doi: [10.1108/JIMA-10-2017-0119](https://doi.org/10.1108/JIMA-10-2017-0119).
- Vimal, K.E.K., Kandasamy, J. and Duque, A.A. (2021), "Integrating sustainability and remanufacturing strategies by remanufacturing quality function deployment (RQFD)", *Environment, Development and Sustainability*, Vol. 23 No. 9, pp. 14090-14122.
- Vitali, A., Togni, G., Regazzoni, D., Rizzi, C. and Molinero, G. (2021), "A virtual environment to evaluate the arm volume for lymphedema affected patients", *Computer Methods and Programs in Biomedicine*, Vol. 198, 105795.
- Volkov, D.V., Vinogradova, M.V. and Kulyamina, O.S. (2018), "The synthesis of modern consumer preferences with the use of social networks in supply chain", *International Journal of Supply Chain Management*, Vol. 7 No. 5, pp. 851-857.
- Wang, F.-K., Yeh, C.-T. and Chu, T.-P. (2016), "Using the design for Six Sigma approach with TRIZ for new product development", *Computers and Industrial Engineering*, Vol. 98, pp. 522-530.
- Wang, C.-C., Chang, H.-T. and Cheng, K.-Y. (2020), "Application of six sigma to improve smartphone lens holder quality-an empirical study", *Proceedings of the 8th IIAE International Conference on Industrial Application Engineering*, doi: [10.12792/iciae2020.008](https://doi.org/10.12792/iciae2020.008).
- Xiong, J., Hsiang, E.-L., He, Z., Zhan, T. and Wu, S.-T. (2021), "Augmented reality and virtual reality displays: emerging technologies and future perspectives", *Light: Science and Applications*, Vol. 10 No. 1, pp. 1-30.
- Yang, X., Gao, S., He, Z. and Zhang, M. (2018), "Application of design for six sigma tools in telecom service improvement", *Production Planning and Control*, Vol. 29 No. 12, pp. 959-971.
- Yoon, H.-K. and Byun, J.-H. (2012), "A design for six sigma: a robust tool in systems engineering process", *Industrial Engineering and Management Systems*, Vol. 11 No. 4, pp. 346-352.
- Zghair, H., Elakrash, S. and Ali, A. (2018), "Design characteristics optimization of flexible-automated manufacturing system", *Proceedings of the 2018 ASEE North Central Section Conference*, American Society for Engineering Education.
- Zhang, L., Chu, X. and Xue, D. (2019), "Identification of the to-be-improved product features based on online reviews for product redesign", *International Journal of Production Research*, Vol. 57 No. 8, pp. 2464-2479.

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