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Potential Risks and Their Analysis of the Apparel & Textile Industry in Turkey: A Quality-Oriented Sustainability Approach

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Abstract
The most significant issues in businesses within the scope of manufacturing and services are the sustainability of production quality, setting quality standards and reducing the waste amount during the manufacturing process. From this point of view, the aim of this study is to provide a better quality level of supplying households' apparel needs while reducing the environmental, economic and social problems of the sustainable supply chain of the apparel sector and extending the lifecycle of apparel. The importance of risk analyses and calculations in the applications of industrial sectors plays a vital role in evaluating the factors of sustainability dimensions. In order to address this risk analysis in this research, quality-oriented implementations are applied to determine the failure modes and effect analysis (FMEA). The significant factors are determined via Pareto Analysis (PA) to control and prevent potential errors and failures in the manufacturing systems of the textile industry. To achieve the aim of this study, the methodology of the research focuses on discovering failures of negative impact based on the primary factor degrees with the computing of risk priority numbers (RPNs) in the manufacturing process of the textile-apparel industry in Turkey. According to the ranking of the RPNs, FMEA application and PA enable to decrease the effects of negative factors and risks as well as the waste amount of the apparel-textile industry, as well as to increase the lifecycle of apparel and products.

Key words: *failure mode, effect analysis, lifecycle, pareto analysis, quality, risk priority number, sustainability.*

Introduction

Globalization affects different conditions, changes and conversion movements. The nature of globalisation influences Turkey as well. This situation integrates economic, environmental and social aspects of Turkey with the universal context of the world economic structure. This integration has provided and supported the globalisation agreement progress and sustainability concept. Accordingly the sustainability approach has a huge impact on the world's economy, environment and social structure, supporting different conditions, changes and conversion movements.

There is a paradigm structure in the sustainable supply chain approach all over the world which is based and built on exponential growth in conjunction with compound interest . However, according to the laws of physics, this paradigm as a sustainability approach is not sustainable at all.

Uneconomically shortening the product/service lifecycle in the existing sustainability approach reduces the useful lifetime of products so that consumers would have to purchase again. This approach is named 'planned/programmed obsolescence' [1, 2].

Consumerism is the belief that our emotional and social needs are going to met by buying goods and services in ever-increasing amounts. People who believe in this paradigm explain and present their own wealth through all the things they possess. Hence overconsumption means that people buy, use and consume far more raw materials than they require and or the earth can sustain [3].

Designing and manufacturing products with limited lifespan allows the repurchase of these products and services. This is called planned obsolescence. However, a sustainability approach is needed which completely rejects this paradigm. The existing paradigm (planned obsolescence) does not seem possible or sustainable at a macro-level. This paradigm is leading humanity to a great ecological disaster, affecting the natural resources and economies of countries [2-4].

Planned obsolescence is a deliberately implemented strategy that limits the useful lifecycle of a product, design or service. The main purpose of this paradigm is to stimulate and sustain product consumption and production. The sustainability of this existing paradigm is not possible in the long term and at the macro level. In the end, the natural balance will be deteriorated and the world population will face a major ecological disaster.

The most significant issue of sustainable development is its own constraints, namely that there is a restriction on the quantity of locations, land, raw materials, water sources, air and all natural sources supported by the world. Due to this, there needs to be a paradigm change which completely rejects "planned obsolescence" for a sustainability approach [1-4].

Research results show that more than 100 million mobile phones and 300 million personal computers are thrown away in North America. Each year, only 20,000 televisions are repaired, while more than 20 million TVs are sold. This causes environmental deterioration due to hazardous materials such as lead, toxic glass and mercury glass [4, 5]. Today's sustainability approach and the sustainability-continuity of the performances of companies are measured by the companies' production quantity and the amount of raw materials used during manufacturing. On the other hand, based on the sustainable approach which is advocated within the scope of this research, the sustainability of the performance of companies evaluated by considering environmental, ethical, economic and social factors should be taken into account (In this case, the growth of companies, contrary to today's sustainability approach, should be provided by manufacturing to meet the basic needs of households).

The economic dimension provides industrial structures, employment, commercialism, business, and occupation. The social dimension influence deeply businesses, services and production systems as a result of factors like resources and material shortage, climate change, lifestyle replacement, expanding (healthcare) requirements in emergent economies, increasing the rate of chronic disease and aging populations. Organisations usually examine the activities of a firm with a "Triple Bottom Line" perception to improve their ecological, financial and social regulations [6, 7]. This perception is the basic item in providing a sustainable coordination. The sustainability paradigm is a concept to improve the environmental, economic and social regulation activities of a company.

The sustainability performance of a company should be calculated via the amount of materials consumed, type of procedures used or the structures of a system, such as the manufacturing system, according to the environmental, economic and social dimensions. In this context, sustainability measurements are made in order to provide a holistic approach via assessment of capacity calculations of consuming the environmental dimension [6, 8].

The sustainability approach requires observing the holistic approach in order to consider the bigger picture. This picture should not only consist of the sustainability structure of particular forests or climate change conditions, but also the population of cities or countries. This basically includes the whole world. The Sustainability Approach considers the total condition and holistic approach, instead of a certain part of the world. Consequently the planned-obsolescence paradigm as a sustainability approach mentioned above needs to be changed.

The paradigm known as planned/programmed obsolescence does not meet the requirements for the durability of products and the lifecycle span of their manufacturing process stages. In view of this opinion, an alternative structure should include the life expectancy of products, expanded services, and quality-oriented manufacturing actions. Environmentally sustainable design aids in reducing the amount of waste during the manufacturing of products and services. This structural design can provide the principles of sustainability.

In this study, by focusing on the impacts of the environment and dimensions of sustainability, quality-oriented manufacturing leads to improving the quality level of the product-garment as well as its longevity. Thus this policy supports increasing the lifecycle of products and decreasing the waste volume. This approach provides a means to avoid overproduction and overconsumption. The application of this research can support the extended life cycle of products, the waste volume can be reduced, and in this way the planned-obsolescence paradigm can be particularly avoided in this particular sector.

Sustainable clothing roadmap: sustainable textile and apparel industry

The sustainable clothing roadmap includes the sustainability of the clothing-apparel sector and lifecycle of products of the apparel-textile industry. The aim of this roadmap is to improve the environmental, economic and social performance of the textile industry and apparel industry by coordinating actions with the key clothing supply chain stakeholders. This roadmap supports and helps the traceability of a sustainable textile-apparel industry within the supply chain structure and focuses on FMEA application, which provides and sustains the development of the quality level of products. In the sector chosen for implementation of this research, the application of FMEA, which enables to improve the quality level of production and products, focuses on increasing the life-cycle (economic life) of products, thus enabling FMEA to reduce the amount of waste of end-user products (at the end of their lives after a year).

The Sustainable Clothing Guide aims to improve the environmental and social dimensions of the apparel-textile industry for management in the supply chain. This content generally contains vital and essential steps in removing negative ecological and social influences [9-11]. Some of the significant issues according to this scope are listed below;

Environmental and social impacts of clothing

The ecological influences of apparel along the supply chain of clothing include these issues:

- Energy consumption, generating greenhouse gas (GhG) emissions from washing-cleaning as a result of high temperature water-heating and drying the garment;
- Energy consumption, resource depletion and generating of GhG emissions-footprints from dealing with fossil fuels with synthetic fibers, for instance polyester and nylon;
- Consuming a significant amount of water, hazardous toxicity from using fertilisers, pesticides and herbicides, and GhG emissions associated with manufacturing fertilisers and irrigations systems for fibre crops like cotton.

Sustainable apparel-garment

Ideally apparel helps to maximise the positive effects and minimise the negative impacts of environmental-ecological, social and economic factors along its supply and value chain. Sustainable apparel-clothing does not affect people or the world negatively by its manufacturing, transportation, retail or end of life management of the products. In operation, this is not achieved directly, it encapsulates trade-offs between different influences and prioritized improvements over the short, medium and long term developments and planning [11].

Describing and communicating sustainable clothing-apparel in terms that all

Table 1. Factors of issues about the textile-garment sector focusing on dimensions of sustainability [9-15, modified by author].

Enviromental problems	Economic problems	Social problems
Distribution of wealth vulnerability	Cost as accepted selling factor	Customer choice issues
Urban sprawl-urbanisation problem-causes	Price as the selling factor	Negative view of the textile sector
Issues that may protect or enhance the corporate image	Facilitating innovation to stimulate the market	Lack of expertise/skill/version
Health problems	Cost of adapting the process technologies	Society has changed from the region to other region
High greenhouse gasses-global warning	Transit cost recovery	Promoting the sector (stake holders, image etc.)
Quality life problems	Economic cost of raw materials of production	Urbanisaiton
Promoting the sector (stakeholders, image made in the country)	High proportion of city wealth spent on transportation--shipping	Quality of the life
Decimated enviromental systems	Public health costs from decreasing the amount of waste of apperal industry	Health problems related to lack of organic raw material produced suburbs
Not to try improve enviromental performance	Process technologies for apperal textile	Issues thay may product or enhance the corporate image
Water footprint-water volume and quality issues	Facilitating innovation to stimulate the market	National and organisational culture difference
Issues related to improved resource use	Issues that affect costs	Textile and apperal sector is not attractive for jobs
Desertification/bio-diversity	Increasing the competitive advantages	Breakdown of classical segments
Issues forced by legislation	Growth of niche/new markets	Cheap, disposable fashion culture
Air/water/soil qualty problems	Improving the sector (training, quality, and quick response)	Breakdown of classical segments
Greenhouse gas emissions	Reducing costs (labour, energy and waste)	Overseas competiiton
Issues related to sustainable production processes	Leading technologies abroad, not in the country	Traditions/ethics/crises problems
Process innovations and technical textile	Increasing competition from low cost countries	Expertise and competence of the country
Uneven enviromental legislation	Uneven legislation	Innovation and technology
Enviromental pressure will cause reponses	International law	Societal changes (buying power)
Resource and land availability	Employment regulation	Fast fashion towards slow fashion
Costs incurred due to enviromental issues	Trade rules (wto,quotas) and negotiations	Society has changed
Enviromental and safety and health registration	Employment rights	Negative view of the sector
Enviromental influences	Exchange rates, market trends	The clothes collected by charities is sold as second-hand clothing in developing countries

stakeholders and, specifically, particular costumers respond to is a key action in the roadmap.

The following action areas for the roadmap to be based on are listed below:

- Consumption fashion-trends and consumer behaviors,
- Developing environmental productivity across the supply chain (sustainable design, increasing reuse, recycling and end of life management, apparel cleaning),
- Agents and instruments for improvement traceability throughout the supply chain (economic, social, environmental and ethical) [11, 13].

By taking action in these areas both business and customers dealing with stakeholders-collaborators can develop the sustainability of apparel. For customers, this means changing behaviour to mitigate the effects of apparel buying, disposal and maintenance. This structure leads to changing attitudes as well as the habits of consumers in diminishing the influences of garments in their buying, repairing and amount of waste-disposal. Some of them are listed below [11-13]:

- Developing and offering ranges of clothing which have improved social and environmental sustainability qualities,
- Giving information and providing assistance for consumers in areas where they can make a difference,
- Improving and suggesting varieties of apparel which have developed the dimensional qualities of environmental and social impacts,
- Repairing apparel by using minimum energy and chemical substance,
- Using again and reprocessing, using again after the processing of undesired apparel-garments, And the reusing and recycling of unwanted clothing.

The impacts of the textile-apparel sector are classified according to the sustainability categories. A complex problem in the hierarchical structure is presented within the relationships of the overall goal, criteria, influences, effects and alternatives in ***Table 1***.

The factors of issues are divided into their main groups in ***Table 1***; environmental, economic, and social. These factors are evaluated according to the dimensions of sustainability. According to this table, the sustainable priority for classification of the factors of issues of the textile-apparel sector depends on the social system-dimension (communities, householders, occupations), which contains the particular resource, supports the long-term natural resource cycle-ecosystem integrity as an environmental dimension, and reduces the cost of the steps of production as an economic dimension.

The environmental, social and economic dimensions of systems perform at significantly different scales. The significant issue depending on the sustainability is how to create environmental solutions to integrate the system into the economic and social dimensions – the solutions techniques. This structure presents how to support the natural and global environmental as well as economic effects of the population life – the consumption and production of the apparel-textile industry. This structure presents the issues of sustainability according to the dimensional changes of this industry.

Evaluation of quality and durability process improvement due to sustainability

In parts of quality assertion, and according to the description of quality, it is absolutely certain that the word 'quality' has many more various meanings, and that the quality assertion actions and techniques are totally different at the various steps of the product lifecycle. ***Table 2*** summarises the interconnection (integration) between the quality and lifecycle of the product [16].

The quality domination method FMEA (Failure Modes and Effects Analysis) is applied during the development of new products and procedures to introduce, check and remove causes of failure. FMEA is a reliability fundamental, which requires declaring the failure types of a particular product or system, as well as their uniformity and possible causes [18]. This structure is applied and used as an engineering method which helps to avoid potential failures and offers a significant report of experience of responsibilities, quality achievement factors and components. QS 9000 FMEA states that FMEA classifiies facilities to define and develop the possibility of a product, system or process defects. Also its effects introduce activities which might elimiđnate, discard or help to reduce the numsber of potential failure types appearing [17]. The authors state that FMEA is an analytical method in which includes all "potential failure" modes; the effects that will occur if the failure actually occurs and all the reasons which can reveal the failure are determined [19-21]. Paparella [22] declares that the FMEA method is a beneficial way which analyses risk conditions, descriptions, defects, and fađtal avoidance. This fundamental values of RPNs could be implemented as risk criteria for failures in order to determine the significant impacts of these errors, and to discover the. In literature, Sinha et al. [23] applied FMEA to support serious risk criteria for an airline/aircraft production supply chain [23]. FMEA implementations summarised the risk of every phase of reverse logistics actions and applications for the medical sector in [24]. This concept enables to analyse the assortment of risk in examining the rational monitoring of drugs [25]. Chuang [26] analysed and discovered the effect of needs and requirements to expand his study to measure and assess the effects of intangible failure effects, such as consumer criticism and the defeat of the bazaar proportion.

Evaluation and assessment of scientific ways allow to improve products, household goods and services according to the opinions of customers. The approach consists of the cost of household goods and products which contribute desired items or components representing the expenditure of sources [20, 27]. Thus the specifics of the steps occurring in the structure of systems and sub-components are encapsulated by FMEA. According to this concept, the process items of the cotton apparel, garment-textile production system and fabric dyeing system are the most significant components. Therefore the fundamentals of systems and stages of processes are certainly considered and analysed by the FMEA technique.

Table 2. *The connection between quality structure and life cycle expectancy of product [16].*

Product/Service Life-Cycle Stages	Quality assurance tasks	Quality methods
0. Impetus/Ideation	Ensure that the new technology and/or ideas ave robust against downstream development	Robust technology development
1. Customer and Business Requirements Study	Ensure that the new product/service concept comes up to the rigt functional requirements which satisfy consumer needs	Quality function development(qfd)
2. Concept Development	Ensure that the new concept can lead to sound design, free of design vulnerabilities. Ensure that new concept is robust against downstream.	Taguchi method/robust design triz axiomatic design doe simulation/optimization reliability-based design
3. Product/Service Design /Prototyping	Ensure that product designed (design parameters) delivers desired product fınctions throught its useful life. Ensure that the product design is robust against variations in manufacturing consumption, and disposal stages	Taguchi method/robust design triz simulation/optimization reliability-based design/testing and estimation
4. Manufacturing Process: Preparation/ Product Launch	Ensure that the manufacturing process is able to deliever designed product consistently	Doe taguchi method/robust design troubleshooting and diagnosis
5. Production	Produce designed product with a high degree of consistency, free of defects	Spc troubleshooting and diagnosis ınspection
6. Product/Service Consumption	Ensure that the consumer has a satisfactory experience in consumption	Quality in after sale service
7. Disposal	Ensure trouble-free disposal of the product or service for the consumer	Service quality

Quality-oriented implementation via failure modes and effect analysis (fmea)

This FMEA (Failure Mode Effects Analysis) methodology is substantial for the attempts to advance all specified compliances at each stage of the project after finalizing all the controls and related FMEA, even this may be required in this regard for the rapid improvement of the project. Actually this can provide essentials on this topic, depending on the benefits of effective advancement of the research scope. This type of risk evaluation method is used to determine failures or defects in projects carried out before they turn into a hazardous state, identify and control the priorities in solving failure problems, and to remove the potential failures and hazards before they occur [18, 28-30].

FMEA allows to determine and calculate dangers and undesirable events. However, FMEA includes an expansive spanning of the usage stage. It is also a hard evaluation method in avoiding failures by approximately assessing the significant risks. The benefits of this methodology are helping to develop the quality, dependability and freedom/security of products, improve consumer achievement, decrease the expenditure of projects, confirm priorities in design or procedure improvement situations, determine every hidden failure mode, impact and comparison for every design of products and phase of processes to help and provide assessment of the design conditions and design differences, to supply a description of possible, vital and significant dimensions, support the analysing of new manufacturing goods or research sections, to sustain a significant scope for failure avoidance, facilitate the description of disciplinary & preventative activities, and to approve and oversee risk decreasing actions [28, 30, 31]. This methodology can be implemented both during the draft examination parts of the research and in the application as well. Moreover this comprises an appropriate feature to handle the method in the design stages. Also it might be applied concurrently during the pattern reassessment stages of the study and in application/cases and installation stages. This technique can both be utilized during the design overview, application and installation stages of the project. On the other

Table 3. ***The Three Factors O-Or (Occurrence), S-Sr (Severity) and D-Dr (Detection) of System FMEA.***

Rating	Severity how severe is the effect on the customer	Occurrence how often does the cause or failure mode occur?	Detection how well can you detect the cause or the failure mode before passing to the next step?
10	Serious hazard to people or damage to equipment	Very high chance of occurence	Almost impossible to detect, no controls in place
9			
8			
7	Customer dissatisfied, distruption to business	Moderate chance of occurence	Low chance of detecting, may have some controls in place
6			
5			
4	Customer may notice but only minor concern, minor distruption to business	Low chance of occurence	High chance of detecting controls are in place
3			
2			
1	No effect	Remote chance of occurence	Almost certain to detect, reliable controls are in place

hand, implementations suggest that it is more appropriate to use the technique in design overview stages [32].

In the FMEA study, estimations of possibility, severity and discoverability are made for all specified potential failures and defects. At the end of these estimations, related solutions are searched by ranking bigger risks according to their priorities [31, 32].

FMEA components and calculation technique

This part presents FMEA application to improve the quality level of production in every phase of the production process, to support longer-life garment production and eliminate defective manufacturing. In this way, the amount of waste of the end-user can be reduced in a year and planned obsolescence perception can be partially prevented in the sectors.

The aim of this approach is to order the failure modes so as to prioritise the significance. Three indicators are explained for every failure mode: the occurrence degree (Or), severity degree (Sr), and detectability rating (Dr). A ten-point proportion is applied to score every correspondingly classified ten number-level of the rating, presenting the most serious, most commonly repeated and slightest perceptible failure mode [26]. The arrangement of a failure mode is regulated around the RPN, which is decided as the product, service or system of occurrence (or-O), severity (sr-S) and detection (dr-Dr) of the failure.

The potential issues including high RPN variables are preferred in order to decrease the risk level of failure situations for the suitable action. Concentration is also presented as a components of the system, where failure could construct unfavorable consumer opinion and loss of business prestige. Risk priority levels (RPL) or numbers (RPN) for FMEA ***Equation (1)*** are measured by accumulating the Occurrence (or), Severity (sr), and Detectability (dr) levels [28, 33, 34].

$$\text{RPN} = \text{Or (Occurrence)} \times \text{Sr (Severity)} \times \text{Dr (Detectability)} \quad (1)$$

Severity (Sr): “Severity” is a ranking number joined with the most serious impact for a given failure mode based on the factor from a severity scale.

Occurrence (Or): “Occurrence” is a ranking number joined with the feasibility that the failure mode and its associated cause will be present in the item being analysed.

Detection (Dr): “Detection” is a ranking number joined with the best control from the list of detecting-type controls, focused on the factor from the detection scale.

The three components Or, Sr, and Dr are all estimated using the rankings or scores from 1 to 10, as described in ***Table 3***. Failures including higher RPNs are avoided to provide higher, more significant preferences.

Table 3 is modified from the literature of Slinger et al. [19] and adapted for this application. The RPN is considered for every root purpose of hazardous errors. This value defines the connection probability of a failure mode, where the greater the statistics-variable, the greater the failure mode. According to the RPN, a critical summary can be used in order to underline the areas where new actions are mostly required. Apart from the RPN result, special attention must be given to any cause of failure with a severity rating of “9” or “10” [25]. After arithmetic computing of RPN values, the business should be protected by eliminating the basic errors from the identification according to the re-engineering. There are three solutions to be certainly included [36, 37].

(a) remove the issue as a whole through composition adjustment;
(b) decrease the potential for which the failure would happen/appear, and
(c) develop opportunities to discover around the development of quality control.

Certainly monitoring the development activities and re-assessment of the severity, occurrence and detection values might be executed, and a new RPN value could be computed. The bigger the RPN value, the more the unforeseeable mode would finally decline; this mode requests higher arrangement for disciplinary action [28, 38, 39].

RPN gives an explanation of defects to be proposed primarily in failure development research by adapting primary degrees. This value provides beneficial directions for appropriate persons who carry out the last FMEA evaluation and development researches of this concept. At the end of this evaluation, assessments and appropriate explanations are discovered via giving priority to the interconnectivity of higher risks. The benefits of the system are presented below;

- It develops the quality, reliability and safety of the product or plan.
- It provides customer satisfaction.
- It sustains significant media for failure prevention.
- It enables the description of disciplinary prevention activities
- It decreases the product or project improvement terms and expenditure.
- It provides a description of potential, essential and significant factors-requirements
- It determines the priorities in design or process improvement activities.
- It determines the whole potential failures modes, their impacts and simi-

larities for all products and phases of processes.
- It supports the evaluation of design requirements and design alternatives.
- It provides an assessment of new production or project stages.
- It supports and monitors risk reducing activities [28, 40].

With the help of the above-defined table (***Table 3***), a system was created with experts and employees in departments for detecting and defining errors that may occur during the manufacturing of products. The failures were analysed by FMEA teams formed from experts and department employees, and a list of failures was formed. A fault tree structure was created with errors and their sub-error components. The possible severity, probability and detectability levels of these failure modes were defined and recorded on a FMEA form.

Based on these recorded values, Risk Priority Levels (RPL-RPN) were calculated. These calculated values were sequenced as per the magnitude of the risk, and precautionary studies were made toward reducing the risk priority levels [38, 40, 41]. In the scope of the failure mode effect analysis study applied, significant precautions measured for decreasing the high and medium level risks, discovered at the conclusion of the FMEA applications, were implied via remarks presented as suitable actions. Depending on this structure, it is organised to decrease the risk priority variables of the potential risk items in the expected development of design, process and system FMEA in the apparel industry. Moreover this way targets high and medium level risk items, which will be removed, and the procedure will be developed evenly.

Table 4 presents RPLs modified according to the case presented by the author and opinions of experts of this sector. This supports the description of errors in showing priority in failure development researches by sorting priority scoring and judgment. Grading of failures is beneficial for those people who hold onto previous FMEA analysis and RPL variable development researches.

Calculation of risk priority levels (RPL) and FMEA implementation in quality-oriented system design

It is important to establish failure control, quality analysis, social, economic, environmental sustainability etc. dominations at every step of the production system, focusing on quality-oriented engineering system design for the solution of possible risk factors and issues to be assembled in the design, process system and application of the quality-oriented system design.

In view of this, efficient risk execution has to be implemented as well for the dimensions that cause these issues or faults. This investigation and commands will allow the smooth advancement of the quality-based studies implemented, while bridging the way for further t researches to be conducted on dimensional infrastructures.

All ***Tables*** between ***5*** and ***7***, show comprehensive analysis of probable risks and failures (errors) that might be encountered during the engineering measurements of sustainability based project applications/implementations, based on the experiences gained from failure mode effect analysis method (FMEA) and risk priority levels tables.

These analysis and controls; provide a healthy progress in the apparel company, where the application study (research) is carried out for quality-oriented process development. Potential risks associated with the sustainability of apparel manufacturing systems are determined by the failure mode effect analysis (FMEA) method and the calculated risk priority values (risk priority levels-RPL) are determined on the basis of past experience shown in ***Table 8.***

In ***Table 8***, 22 main conditions (failures) have been dealt with in order to be dominated by the control and force, and may cause risk dimensions concurrently with the study. Among these 15 hidden failures and risk types, 5 of them were recognized as high-risk potential and outstanding, 7 as medium degree risk as per risk precedence variables measured. Those control points that can provide risk criteria are examined, and the structure of quality-oriented engineering studies among established control dimensions can improve risk dimensions. The protections submitted that are to be examined for reducing the high and medium risk variables are stated by presenting citation in the application of FMEA. Risk priority level variables are calculated to decrease this, showing that the significant protection declared in the FMEA is undertaken especially in quality-oriented engineering studies. Thus it is aimed that high and medium risk factors are removed for the benefit of the development of researches in a healthy and suitable method. On top of failure mode effect analysis, pareto analysis is also implemented, addressing

Table 4. *Risk priority Numbers-Levels RPNs-(RPLs) ([18]; modified by author).*

Risk Priority Levels (*RPL*)	Precaution
RPL < 90	No need to take action.
90 ≤ *RPL* ≤ 150	Medium risk measures can be taken.
RPL > 150	Caution needs to be taken due to high-risk.

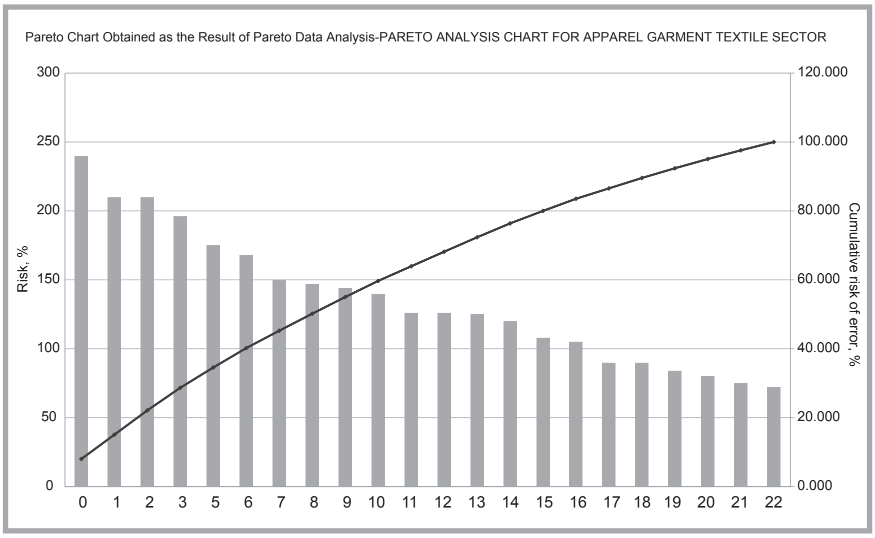

Figure 1. *Pareto analysis chart for Apparel-textile industry.*

***Table 5.** Comprehensive analysis of potential risks and failures to be encountered during sustainability assessment of the apparel-textile industry in Turkey.*

Firm Name	Assesment Apparel-Textile Industrial Sector in Turkey					FMEA										
Product/Item:	Cloth (Fabric and Fibres, Garment)									FMEA No :	125-1	Security Class:			–	
Model/vehicle:										Prepared By ::	FMEA Team					
Process Resp.:	A					Key Date:				FMEA Date :		Rev:			0	
Core Team:	AE-Project Team Members															
Proceses/ Steps / Function	**Potential Failure Mode**	**Potential Effect(s) of Failure**	**Severity (S)**	**Potential Cause(s)/ Mechanism(s) of Failure**	**Occurence (O)**	**Current Process Control Prevention**	**Current Process Control Detection**	**Detection (D)**	**R:P:N**	**Recommended Action(s)**	**Responsi-bility &Target Completion Date**	**Action Results: Action Taken**	**Severity**	**Occurence**	**Detection**	**R:P:N**
The overall environmental profile & climate and enviromental aspects 1	The harmful effect while produce, use and design fibres and fabrics	The influence of product lifetime of textile raw material	7	Manufacture from artificial and sentetic material and cotton etc.	4	İmprove the method for understanding environmental impact	*Assessing materials for their sustainable content.	6	168	Focus on using sustainable materials *ımple-ment a program of detergent concentration.		*Try to reduce the harmful impacts *change the control schedule-plan	6	4	4	96
2	Reducing the environmental impact of the textiles sold	Fabric and gar-ment supply cause one-third of the waste	6	Use of substances harmful to the environment	4	Trialing new fibres such as bamboo, renew-able plastics	New ways of producing fibres such as organic cotton, linen and wool	5	120	Encourage the take-up of alternative fibres that have a lower environmental impact.		Existing and emerging fibres in sustainable clothing.	5	4	4	80
3	The chemicals used in fibres ,garment production	The environmental profile were identi-fied as toxicologi-cal effects from the chemicals used in cotton production	8	Consumers think, there is too little environmental infor-mation available on the clothes they buy.	5	Limitation of toxic residues in fibres	'Finishes' covers all physi-cal or chemical treatments giving to the textile fabrics specific properties such as softness, waterproof, easy care.	6	240	Develop sustain-able raw material sourcing strategy setting out as-sessment criteria for sustainable claims		Setting out assess-ment criteria for sustainable claims as well as producer and customer benefits.	6	4	5	120
4	Use of substances harmful for the enviroment and health process while manufacturing fabrics lifecyclestep	Heritable genetic damage substanc-es & harmful to health harmful to aquatic organisms	6	Consumption of crude oil for pesticides, artificial fertilisers, dyeing and the finishing process	3	Limitations of certain pesticides *dyes that are hazardous to aquatic ecosystems	Develop global organic textile standard (gots) compliant ink systems for textile printing.	5	90	No biocidal or biostatiic products active during manu-facture and use phase		Coatings, laminates and membranes shall not be pro-duced using plasti-cisers or solvents, which are assigned or may be assigned at the time of application	6	3	4	72
5	Probable risk and harm effects	*Cause harm to the unborn child *risk of impaired fertility *possible risk of irreversible effects	7	Heavy metals and formaldehyde in stripping and depigmentation	6	Measuring the amount of waste created during the design and manufacturing phase	Researching technologies such that in the future, for garments are made using sustainable raw materials e.G. From plant and tree sources as well as reused materials	5	210	Using environmentally preferred materials and by eliminating the use of toxins.		Develop moni-toring systems to measure impact of green factory initiatives	5	6	3	90
Carbon, water and energy footprint 6	Emissions of greenhouse gases	Increasing carbon and water use and causing the incre-ment of amount of waste in fibre and yarn production	6	Consumption trends and behaviour	5	Increasing con-sumer awareness on clothing impacts and what they can do to reduce these on	Selling a range of types of sustainable clothing (reused, remade, fair trade etc.	5	150	Aimed at changing consumer perceptions and buying trends.		Modelling decar-bonisation in all life cycles stages	5	5	5	125
7	Greasy wool and other keratin fibres	Dyeing and finishing by 50%	7	The carbon footprint for drying and ironing, an increment in the carbon intensity of electricity results	3	Reduce con-sumer footprint through be-havioural change	A criterion for process en-ergy consumption *energy generation technology or a future decarbonisation target for the energy sector	6	126	Increase size of washing and drying loads		Low energy and carbon economy	6	3	3	54

Table 6. Comprehensive analysis of potential risks and failures to be encountered during the sustainability assessment of apparel-textile industry in Turkey (continue – 2).

Firm Name	Assesment Apparel-Textile Industrial Sector in Turkey	**FMEA**		
Product/Item:	Cloth (Fabric and Fibres, Garment)	FMEA No: 125-1	Security Class:	–
Model/vehicle:		Prepared By: FMEA Team		
Process Resp.:	A	Key Date:	FMEA Date:	Rev: 0
Core Team:	AE-Project Team Members			

Proceses/ Steps / Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity (S)	Potential Cause(s)/ Mechanism(s) of Failure	Occurence (O)	Current Process Control Prevention	Current Process Control Detection	Detection (D)	R:P:N	Recommended Action(s)	Responsi-bility &Target Completion Date	Action Results: Action Taken	Severity	Occurence	Detection	R:P:N
Performance and durability 8	Nondurable -short lived garment	Use the tumble dryer more time	6	Washing machine use unchanged. Lifetime washes increased by 10%.	3	Design for durability [product lifetime optimisation]	Lean production replace 10% of cotton fabric with a 50:50 poly-cotton blended fabric	6	108	Zero waste by end of through working with new life charity		Evaluating the economic and market access barriers to attracting and increasing imports of environmentally preferred and sustainably designed product	6	3	5	90
9	Piiling of the fabric and unbalanced loop heights	Piiling the surface of the fabrics and garment production	6	*Detergents and other chemicals used for the washing of fillings *wash clothes at a slightly higher temperature	3	Extend the useful life of clothes in the country through design, use and re-use	Defining and communicating sustainable clothing to consumers	5	90	New knowledge development and to use design to develop positive change in the ecological, social and cultural impacts relating to fashion.		To inform consumers about impact on climate – through washing, drying, retailer choice and disposal – in the lifecycle of a garment	5	3	4	60
10	The lack of dry and wet abrasion resistance	Dimensional changes during washing and drying	5	Colour paleness to perspiration	3	Produce clothes that last and look good for longer gain a positive reputation	Develop a business case within the industry to design and develop more single fibres/polymer apparel	5	75	Heavy metal salts (except of iron) or formaldehyde shall not be used for stripping or depigmentation.		Running trials of new technologies to enable greater volumes of end of life clothing to be recycled into value add products for industrial sectors	5	3	4	60
Strength of the fabric cloth 11	The flexibility strength of the fabric	Causing permanent damage to deform the fabric	8	The material exposure over flexibility strength	3	Failure to do machine settings according to the type of fabric(cotton cloth)	It does not have solution.	5	105	Careful craftsmanship		Control plan was changed	7	2	4	56
12	Tribological behavior of the fabric (cotton cloth)	İt is caused deformation of the fabric	8	Be tight compared to the normal setting of the paint machine	3	To circulate freely smooth fabric made of rope adjustment	It does not have solution.	6	144	Control plan in certain frequency		Control plan was changed	8	3	5	120
13	Oil strain	It is caused that doing errors in the warping process	6	The oil flows(leakage) from the environment or from the machine	7	Doing regularly machinery maintenance	Using detergent and organic solvent drying	5	210	Safety working area must be provided for employee and workers		Serious process control	6	5	4	120

Table 7. Comprehensive analysis of potential risks and failures to be encountered during the sustainability assessment of the apparel-textile industry in Turkey (continue – 3).

Firm Name	Assesment Apparel-Textile Industrial Sector in Turkey	**FMEA**	
Product/Item:	Cloth (Fabric and Fibres, Garment)	FMEA No: 125-1	Security Class: –
Model/vehicle:		Prepared By: FMEA Team	
Process Resp.:	A	Key Date: / FMEA Date:	Rev: 0
Core Team:	AE-Project Team Members		

Proceses/ Steps / Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity (S)	Potential Cause(s)/ Mechanism(s) of Failure	Occurence (O)	Current Process Control Prevention	Current Process Control Detection	Detection (D)	R:P:N	Recommen-ded Action(s)	Responsibility &Target Completion Date	Action Results: Action Taken	Severity	Occurence	Detection	R:P:N
Dyeing of fabric(cloth) 14	Paint stains	It is caused failure of template fracture.	7	Not covered nylon on the waiting (queue), by he flight of the dyes, they stick to the pending fabric	3	Covered nylon on the waiting (queue)	However, if you noticed before the painting process., It can be cleared and has solution	4	84	Dye matter which degree of process control substantific identified			6	3	3	54
15	Caustic stain	It causes that the material in some areas staining darker before colour situation	8	Because of not being given caustic homogeneously	3	Given and implemeted caustic progressively and appropriately	It does not have solution.	3	72	Implemnting step by step via controlling stages		Process control	6	3	3	54
16	Wing-aerofoil differences	It is caused unrelieved failure	7	Inhomogeneity of the fabric moisture content	3	Movement of the fabric has sufficient level and fabric temperature difference hydrophility	It does not have solution.	7	147	Ensuring, providing the circulation of the fabric			8	3	5	120
17	Yarn faults in the knitted fabric	Leaving traces in the tranverse direction to the fabric	7	Inability to perform the function of knitting machines and the difference between the used yarn	4	Minimized by reducing the difference in machine yarn	If ıt is noticed during knitting , ıt has solution and cleared	5	140	Regularly machine controls			7	3	5	105
18	Physical fracturres	It leads self-improve malaise and wrinkles on fabric	5	The fabric is not properly inserted in the machine	5	To provide setting of the rope-failure to do regularly, so preventing rotation of the fabric	Moistens the fabric by passing the iron	5	125	Fracture prevention should be used			5	3	4	60
19	Burrs	It is caused deformation of the fabric	7	Improper setting of the rope-failure to do regularly,the fabric is not properly inserted in the machine	3	Must be careful during transport and machinery works, processing time	If ıt is not too much ,quality control is performed, cleared	6	126	Implement the top quality shipping, transportation			7	2	5	70
Peroxide bleaching of fabrics 20	Abrage	In the dying stages, leads to color differences in the form of cloud and shadow	7	The unremoval h2o2 before the dyeing process	7	Using antiperoksit (sodium thiosulfate)	It is implemented to the fabric wash well after the processes	4	196	Using the complex-forming in the dye bath	It is implemeted in the first procution stage.	Control plan was changed	6	3	3	54
21	Splash	Caused the unwanted traces	4	Not properly dried after washing	5	To eliminate the water droplets in the workplace	Analysable via the washing process	4	80	To be sensitive for the drying process			4	4	3	48
22	Lycra melting	Leads to strength loss	7	The lycra, not to be resistant to high temperature	5	Using quality lycra and selection the dyeing process according to lycra		5	175	Using quality lycra		Control plan was changed	8	3	4	96

Table 8. Designed Pareto analysis in the sustainability assessment of the apparel-textile sector.

Pareto analysıs table for apparel-textıle sector								
Sequence no	**Proses/steps**	**Potential faılure mode**	**Potential effect (S) of failure**	**Process no**	**Rısk prıorıty level value**	**Risk, %**	**Cummulatıve rısk %**	**Risk level**
3	The overall environmental profile & climate and enviromental aspects	The chemicals used in fibres, garment production	The environmental profile were identified as toxicological effects from the chemicals used in cotton production	20	240	8.051	8.051	Unacceptable High Risk
5	The overall environmental profile & climate and enviromental aspects	Probable Risk and Harm Effects	* cause harm to the unborn child * risk of impaired fertility * possible risk of irreversible effects	80	210	7.045	15.096	Unacceptable High Risk
13	Strength of the Fabric Cloth	Oil Strain	It is caused that Doing errors in the warping process	10	210	7.045	22.140	Unacceptable High Risk
20	Peroxide beleaching of Fabrics	Abrage	In the dying stages, leads to color differences in the form of cloud and shadow	90	196	6.575	28.715	Unacceptable High Risk
22	Peroxide beleac-hing of Fabrics	Lycra Melting	Leads to strength loss	30	175	5.871	34.586	Unacceptable High Risk
1	The overall environmental profile & climate and enviromental aspects	The harmful effect while produce, use and design Fibres and Fabrics	The influence of product lifetime of textile raw material	110	168	5.636	40.221	Unacceptable High Risk
6	Carbon, Water and Energy Footprint	Emissions of greenhouse gases	Increasing carbon and water use and causing the increment amount of waste in fibre and yarn production	100	150	5.032	45.253	Unacceptable High Risk
16	Dyeing of Fabric (Cloth)	Wing-aerofoil differences	It is caused unrelieved failure	60	147	4.931	50.185	Unacceptable High Risk
12	Strength of the Fabric Cloth	Tribological behavior of the fabric (cotton cloth)	It is caused deformation of the fabric	140	144	4.831	55.015	Unacceptable High Risk
17	Dyeing of Fabric (Cloth)	Yarn faults in the knitted fabric	Leaving traces in the tran-verse direction to the fabric	40	140	4.696	59.712	Unacceptable High Risk
19	Dyeing of Fabric (Cloth)	Burrs	It is caused deformation of the fabric	50	126	4.227	63.938	Unacceptable High Risk
7	Carbon, Water and Energy Footprint	Greasy wool and other keratin fibres	Dyeing and finishing by 50%	70	126	4.227	68.165	Unacceptable High Risk
18	Dyeing of Fabric (Cloth)	Physical Fracturres	It leads self-improve malaise and wrinkles on fabric	120	125	4.193	72.358	Unacceptable High Risk
2	The overall environmental profile & climate and enviromental aspects	Reducing the environmental impact of the textiles sold	Fabric and garment supply cause one-third of the waste	130	120	4.025	76.384	Unacceptable High Risk
8	Performance and durability	Nondurable -short lived garment	Use the tumble dryer more time	150	108	3.623	80.007	Unacceptable High Risk
11	Strength of the Fabric Cloth	The flexibility strength of the fabric	Causing permanent dam-age to deform the fabric	90	105	3.522	83.529	Medium Risk
4	the overall environmental profile & climate and envi-romental aspects	Use of substances harmful for the enviroment and health process while manufac-turing fabrics lifecyclestep	Heritable genetic damage substances harmful to health harmful to aquatic organisms	60	90	3.019	86.548	Medium Risk
9	Performance and durability	Piiling of the fabric and Unbalanced loop heights	Piiling the surface of the fabrics and garment production	95	90	3.019	89.567	Medium Risk
14	Dyeing of Fabric (Cloth)	Paint Stains	It is caused failure of template fracture.	70	84	2.818	92.385	Medium Risk
21	Peroxide beleaching of Fabrics	Splash	Caused the unwanted traces	30	80	2.684	95.069	Medium Risk
10	Performance and durability	The lack of dry and wet abrasion resistance	Dimensional changes during washing and drying	20	75	2.516	97.585	Medium Risk
15	Dyeing of Fabric (Cloth)	Caustic Stain	It causes that the material in some areas staining darker before colour situation	60	72	2.415	100.000	Medium Risk

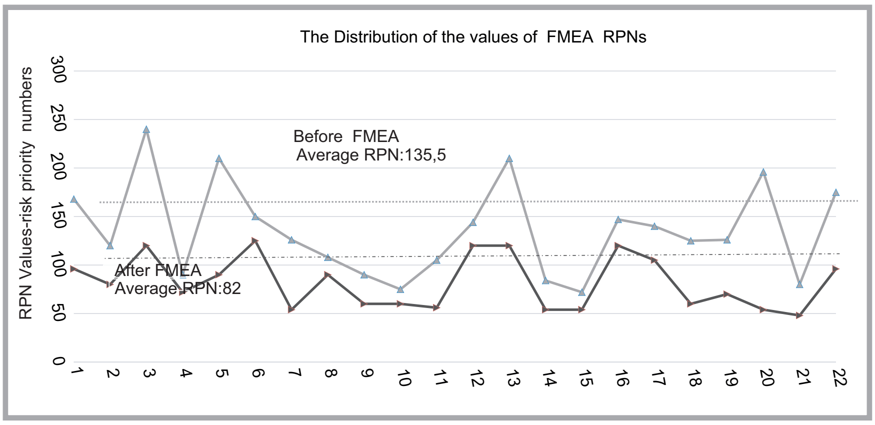

Figure 2. Before and after the FMEA Critical Risk Values (Risk Priority Numbers-RPN).

80% the vital threshold risk measurement required.

In our application research, a significant 80% of the Pareto analysis is selected as the threshold risk variable, focusing on errors and risk factors which might happen when designing and modifying quality-oriented engineering researches, which are graded due to the severity of the risk criteria according to the quality dimensions, and computing variables of relevant ratio % are presented [36].

Team study is essential in these types of studies. One of the important benefits of the analysis, as reaching a critical point, is taking actions in order to avoid possible failures which have a high-risk level, computed in the center of the risk priority level (RPLs) variable table. The results of calculation according to the Pareto analysis are presented in ***Table 8***, and the applicable diagram is shown in ***Figure 1***.

The below-mentioned problems are observed to remain in the high-risk group:

- The chemicals used in fibres and garment manufacturing (the environmental profile was identified as having toxicological effects from the chemicals used in cotton production)
- Probable risk and harmful effects (to do harm to unborn child; to increase the risk of unhealthy fertility; to increase the risk factor of irreversible impacts)
- Oil stain (caused by errors in the wrapping process)
- Abrage (In the dyeing phases, showing as colour differences in the structure of cloud and shadow)
- Lycra melting (leads to strength loss)
- The harmful effects while producing, using and designing fibres and fabrics (the influence of the product lifetime of textile raw material) – emissions of greenhouse gases (increasing carbon and water use, and causing an increment amount of waste in fibre and yarn production) – tribological behaviour of the fabric (cotton cloth), which is caused by the deformation of the fabric – yarn; defects in the knitted fabric – burrs (caused by the deformation of the fabric)
- Greasy wool and other keratin fibres (dyeing and finishing by 50%)
- Physical fractures (leads to self-wrinkles on fabric) – reducing the ecological impact of textiles sold (fabric and garment supply cause one-third of the waste) – nondurable-short life-cycle garment (using the tumble dryer more)

In Pareto Analysis, among all the possible failure types that are specified, when high risk failure types (failure causes) are reevaluated, 80% threshold which includes the first 15 higher risk failure types, are featured. This technique helps to identify the top 20% of causes that need to be addressed to resolve 80% of the problems.

The RPN of the possible errors detected in the system before the process of FMEA was found to have a high value. As per the FMEA process rule, after evaluating the precautionary measures (the result of second risk analysis) that are taken for each error, it was observed that high RPN risk levels show a reducing tendency after the action taken. This is presented in ***Figure 2***.

FMEA is easily applicable and gives good results in the product, service, system and process development activities of the initial stages. Upon evaluation of failure modes, either one by one or considering relative group form weights, it is noticed that the weights of failure modes that emerged during the measurement and assessment stage appeared as significant [17, 37]. Failure Mode Effect Analysis made towards eliminating failures shows that the time-dependent effect of the failures follows an opposite trend generally. It is apparent in the result of this study that the improvement percentage in one area is realised theoretically 135.5% (100) and actually 82% (60). Since the resources allocated for the improvement is rather limited, the level of all risks may not be reduced to a significant level. It is intended that the risk prevention activities as per the updated risk priority levels will be repeated for each term, and hence continuous improvement will be maintained.

Conclusions

In summary, FMEA analysis in sustainability researches plays a significant role, particularly during the design stage of research, in providing the risks items as well as the priority regulation of significance and development studies for these researches to be focused on. In the sustainability of lifecycle studies, Risk Priority Level-Number (RPL-RPN) variables take on a vital role, occurring in previous examinations and assessments of FMEA, will be a good guide for the specialists who are trying to make a difference in their field of study by carrying out improvement studies. In this research, the initial 15 are significant risk components.

The RPN value is generally presented in FMEA for concluding the risk prioritisation of failure types. The FMEA situation specified may be critical for design management to organise the choice standards. Future studies may focus on the efficient investigation of two suitably chosen indicators.

The sustainable production and manufacturing model is for the interconnection of location determination and quality improvement. Moreover this research is based on shared common connection in climate change, green production and risk dimensions, providing an improvement to the arrangement, considering the fact that FMEA is a group decision function and cannot be done on an individual basis and different FMEA team members may provide different assessment information.

Risk aspects are certainly collected in a nonlinear way which is neither the basic extension norbasic product of risk dimensions. Additional risk features can be involved if this structure is essential. The FMEA suggested is not restricted to Or, Sr and Dr but is relevant to a certain number of risk criteria. This study focuses on the environmental dimension of sustainability, for which Lean Six Sigma can be used, implemented to decrease the volume waste and to integrate with supply chain management for future study.

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References

1. Erdil A, Tacgin E. A holistic approach of sustainability to economics, ethics, environment, and quality of life cycle time of production. *Global Journal of Business, Economics and Management: Current Issues* 2017; 7: 49-61. http://sproc.org/ojs/index.php/gjbem.
2. Guiltinan J. Creative Destruction and Destructive Creations: Environmental Ethics and Planned Obsolescence. *Journal of Business Ethics.* 2009;89: 19-28, Springer. https://doi:10.1007/s10551-008-9907.
3. Miao CH. Planned obsolescence and monopoly undersupply. *Information Economics and Policy* 2011; 23, pp. 51-58. DOI: 10.1016/j.infoecopol.2010.03.003.
4. Boland M. Water and the Environment. *Forbes*, 2001, 168, 6: 60-62.
5. Slade G. Made to Break: Technology and Obsolescence in America-Cell Phones and E-Waste. Cell Phones and E-Waste. *Harvard University Press Paper Back Edition*, Cambridge, Massachusetts, 2006, 264.
6. Greene JP. Sustainable Plastics: *Environmental Assessments of Biobased, Biodegradable, and Recycled Plastics*. John Wiley & Sons, Inc., Canada, 2014, pp.2-12, ISBN 978-1-118-10481-1.
7. Esteves F, Santos J, Anunciacao P. Sustainability in the information society: a proposal of information systems requirements in view of the DPOBE model for organizational sustainability. *Procedia Technology* 2012; 5: 599-606. https://doi: 10.1016/j.protcy.2012.09.066.
8. Basurko OC, Mesbahi E. Methodology for the sustainability assessment of marine technologies. *Journal of Cleaner Production* 2014; 68: 155-164. https://doi.org/10.1016/j.jclepro.2012.01.022.
9. Maxwell D. Sustainable Clothing Action Plan, Department for Environment-*Lead Sustainable Clothing Roadmap, Food and Rural Affairs,* 2008, pp. 2-11.
10. https://glasaaward.org/wp-content/uploads/2014/01/Clothing-Actionplan.pdf
11. Climate Challenges facing the Clothing Sector. Master of Science in Innovation and Entrepreneurship, Dr. Dorothy Maxwell, *DEFRA Sustainable Clothing Roadmap*, 2007, pp. 1-25.
12. Defra. *A framework for pro-environmental behaviours*. London: Department for Environment, Food and Rural Affairs Report, 2008, pp.109.
13. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/69277/pb13574-behaviours-report-080110.pdf. (accessed on 10.05.2015)
14. OECD. OECD Environmental Strategy for the First Decade of the 21st Century, 2001. http://www.oecd.org/environment/environmentalindicatorsmodellingand-outlooks/1863539.pdf. (accessed on 10.06.2015).
15. Turkey's Sustainable Development Report: *Claiming the Future, Ministry of Development*, June 2012, Ankara, 1-77.
16. www.surdurulebilirkalkinma.gov.tr.
17. https://sustainabledevelopment.un.org/content/documents/853turkey.pdf, (accessed on 10.05.2015).
18. Allwood J M, Laursen SE, Rodríguez C M, Bocken NMP. *Well dressed? The present and future sustainability of clothing and textiles in the United Kingdom, Technical Annex,* University of Cambridge Institute for Manufacturing, 2006, pp. 3-56. ISBN 1- 902546-52-0.
19. Global Sustainable Development Report, http://sustainabledevelopment.un.org/globalsdreport/ (accessed on 10.06.2015).
20. Yang K, Basem S, El-Haik BS. *Design for Six Sigma,* McGraw Hill Professional, 2003, p. 624.
21. Estorilio C, Posso RK. The reduction of irregularities in the use of process FMEA. *International Journal of Quality & Reliability Management* 2010; 27, pp. 721-733. https://doi.org/10.1108/02656711011054579.
22. Akın B. *Implementation of ISO 9000 in Business, Failure Mode and Effects Analysis (FMEA)*. Bilim Teknik Publishing, Istanbul, 1998, p. 182.
23. Slinger M. To practise QFD with success requires a new approach to product design. *Kontinuert Forbedring,* 1992, pp. 20-21.
24. Slack N, Chambers S, Johnston R. Operations Management. 2nd edition, *Harlow- Financial Times, Prentice-Hall, Inc.*, 2001, pp. 86-138.
25. Hekmatpanah M, Fadavinia A. The Evaluation and Application of FMEA in Sepahan Oil Co, World Academy of Science, Engineering and Technology. *International Journal of Industrial and Manufacturing* 2011; pp. 769-774. scholar.waset.org/1307-6892/7613.
26. Paparella S. Failure mode and effects analysis: a useful tool for risk identification and injury prevention. *Journal of Emergency Nursing* 2004; 33, pp. 367-71. https://doi.org/10.1016/j.jen.2007.03.009
27. Sinha PR, Whitmann LE, Malzan D. Methodology to mitigate supplier risk in an aerospace supply chain. *Supply Chain Management of International Journal* 1996; pp. 154-168. https://doi.org/10.1108/13598540410527051.
28. Kumar S, Dieveney E, Dieveney A. Reverse Logistic Process Control measures for the Pharmaceutical Industry Supply Chain. *International Journal of Productivity and Performance Management* 2009; 58: 188-204. https://doi.org/10.1108/17410400910928761.
29. Van Leeuwen JF, Nauta MJ, de-Kaste D. Odekerken-Rombouts, YMCF., Oldenhof, MT., Vredenbert, MJ., Barends, DM. Risk Analysis by FMEA as an Element of Analytical Validation. *Journal of Pharmaceutical and Biomedical Analysis* 2009; 50: 1085-1087. https:// doi: 10.1016/j.jpba.2009.06.049.
30. Chuang PT. Incorporating disservice analysis to enhance perceived service quality. *Industrial Management & Data Systems* 2010; 110: 1-22. https://doi.org/10.1108/02635571011030033.
31. Ashi M, Farith AI, Isaac I. Investigation of Foundry Emissions Using Six Sigma. *International Journal of Research and Scientific Innovation* 2015; 2, http://www.rsisinternational.org/Issue17/87-93.pdf. (accessed on 10.06.2015). ISSN 2321-2705.
32. Chin KS, Wang YM, Poon GKK, Yang JB. Failure mode and effects analysis using a group-based evidential reasoning approach. *Computers & Operations Research* 2009; 36: 768-1779. https://doi.org/10.1016/j.cor.2008.05.002.
33. Tsarouhas PH, Arampatzaki D. Application of Failure Modes and Effects Analysis (FMEA) of a Ceramic Tiles Manufacturing Plant, *1st Olympus international conference on supply chains proceedings*, 1-2 October, Katerini, Greece, 2010, pp. 1-17.
34. http://www.teicm.gr/logistics/images/logisticsdocs/icsc2010/fullabstracts/7_2_ICSC2010_017_Tsarouhas_Arampatzaki.pdf. (10.06.2015).
35. Liu H-C, Liu L, Liu N. Risk Evaluation Approaches in Failure Mode and Effects Analysis: A Literature Review. *Expert Systems with Applications* 2013; 40: 828-838. https://doi.org/10.1016/j.eswa.2012.08.010.
36. Wang Y-M, Chin K-S, Poon GKK, Yang J-B. Risk Evaluation in Failure Mode and Effects Analysis Using Fuzzy Weighted Geometric Mean. *Expert Systems with Applications Part 1* 2009; 36: 1195-1207. https://doi:10.1016/j.eswa.2007.11.028.

37. Hekmatpanah CM, Shahin A; Ravichandran N. The application of FMEA in the oil industry in Iran: The case of four litre oil canning process of Sepahan Oil. *African Journal of Business Management* 2011; 5: 3019-3027. https:// doi:10.5897/AJBM10.1248 ISSN 1993-8233.
38. Xiao N, Huang H-Z, Li Y, He L, Jin T. Multiple Failure Modes Analysis and Weighted Risk Priority Number Evaluation in FMEA. *Engineering Failure Analysis* 2011; 18: 1162-1170. https://doi:10.1016/j.engfailanal.2011.02.004.
39. Su X, Deng Y, Mahadevan S, Bao Q. An Improved Method for Risk Evaluation in Failure Modes and Effects Analysis of Aircraft Engine Rotor Blades. *Engineering Failure Analysis* 2012; 26: 164-174. https://doi.org/10.1016/j.engfailanal.2012.07.009.
40. Van Leeuwen JF, Nauta MJ, de-Kaste D, Odekerken-Rombouts YMCF, Oldenhof MT, Vredenbert MJ, Barends DM. Risk Analysis by FMEA as an Element of Analytical Validation. *Journal of Pharmaceutical and Biomedical Analysis* 2009; 50: 1085-1087. https://doi.org/10.1016/j.jpba.2009.06.049.
41. Sankar NR, Prabhu BS. Modified approach for prioritization of failures in a system failure mode and effects analysis. *International Journal of Quality & Reliability Management* 2001; 18: 324-35. https://doi.org/10.1108/02656710110383737.
42. Pillay A, Wang J. Modified failure mode and effects analysis using approximate reasoning. *Reliability Engineering & System Safety* 2003; 79: 69-85. https://doi.org/10.1016/S0951-8320(02)00179-5.
43. Franceschini F, Maurizio Galetto M. A New Approach for Evaluation of Risk Priorities of Failure Modes in FMEA. *International Journal of Production Research* 2001; 39: 2991-3002. https://doi.org/10.1080/00207540110056162.
44. Chang D-S, Sun KLP. Applying DEA to enhance assessment capability of FMEA. *International Journal of Quality & Reliability Management* 2009, 26: 629-643. https://doi.org/10.1108/02656710910966165.
45. Erbıyık E, Can E, Delici Y, Karaboga K. Potential Risks Associated with The Route Selection in Railway Construction Projects, *2nd International Symposium on Railway Systems* Engineering in Processing Book (ISERSE'13), 2013, Karabuk, Turkey.
46. Zairi M, Duggan R. Best Practice-Process Innovation Management in Slinger M (1992). To practise QFD with success requires a new approach to product design. Kontinuert Forbedring, Butterworth-Heinemann, 1999, pp. 104-139.
47. Başlıgil, H. (1997-1998). *Unpublished Management Information System Lecture Notes*, Faculty of Mechanical Engineering, Y.T.U., 2004, Istanbul.

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