International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 16s,2025
https://theaspd.com/index.php

Enhancing Tyre Retreading Processes Through Quality Function Deployment: A Review Of Techniques And Approaches

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Abstract:
It is anticipated that as more cars and motorcycles are produced, especially in developing nations, the number of used tires will rise globally. It also takes a management plan to collect used tires from tire users and send them to a used tire recycler. Reviewing the evolution of used tire recycling and processing, as well as the application of quality function deployment and quality control tools in product and service-based industries, are the objectives of this paper.
Retreading, energy recovery, product recycling, material recycling, and pyrolysis are some of the methods for recycling used tires that have been identified. Around the world, there are numerous methods for recycling used tires. However, retreading tires is a very common practice these days, where the old sole is removed and a new one is applied to the old tire. It can happen two or three times. By doing this, the tire can be used to its full potential. Following this procedure, it is sent to the tire recycling process. The retreading procedure can be broken down into smaller steps, such as buffing, vulcanizing, treading, and enveloping. In this work, we have investigated tire retreading, a method that is cost-effective for retreaters. The retreading process and QFD applications are examined in this review paper.
Keywords: *Tyre Retreading, Quality Function Deployment, Quality control Tools, Waste Tyres*

1. INTRODUCTION:

QFD is a planning method that assists the company in organizing the efficient use of a variety of technical support tools that work in tandem to give each issue priority. Developing customer-focused products is accomplished through the use of Quality Function Deployment. QFD is a technique for raising the quality of goods and services by first identifying the needs of customers and then connecting those needs with technical features to create goods and services at every stage of production. Quality Function Deployment can be defined as the process of defining customer needs and wants and translating them into technical features that all functional areas and organizational levels can comprehend and use to improve in order to meet objectives.

There are no established guidelines for the recycling process; the remanufacturing industries have created their own methods for retreading tires, which has led to problems with the quality and performance of the remanufactured tires. In order to reduce the difficulties and enhance the tyres' quality and performance, this study aims to identify the difficulties associated with the tyre remanufacturing process. It does this by highlighting the different flaws in tyres that have been retread and their causes. [1, 2]

House of Quality

A tool from QFD called the House of Quality (HOQ) is used to establish design boundaries, illustrate the focus of the design team on producing high-quality products, and show the relationship between respondent needs and the matrix to meet those needs. The products with the highest score are those whose technical attributes are the company's main area of improvement; the products whose assembly process attribute has the highest value are those that need to be fixed to solve frequent issues. According to Akao (1990), QFD is a tool for service planning and development that gives service providers a systematic approach to guaranteeing

quality and client satisfaction while preserving a long-term competitive edge. A key strategy for controlling product quality during the product development phase, which seeks to create processes with practical process capabilities to generate products, is process quality planning. [3]

Fig 1. QFD Process [1]

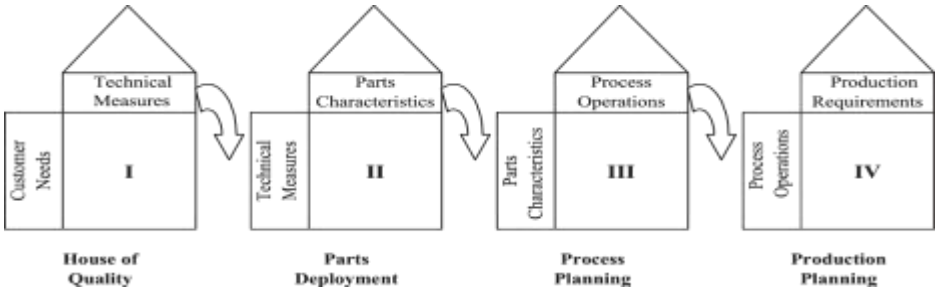


Fig 2. Four Phases of QFD [1]

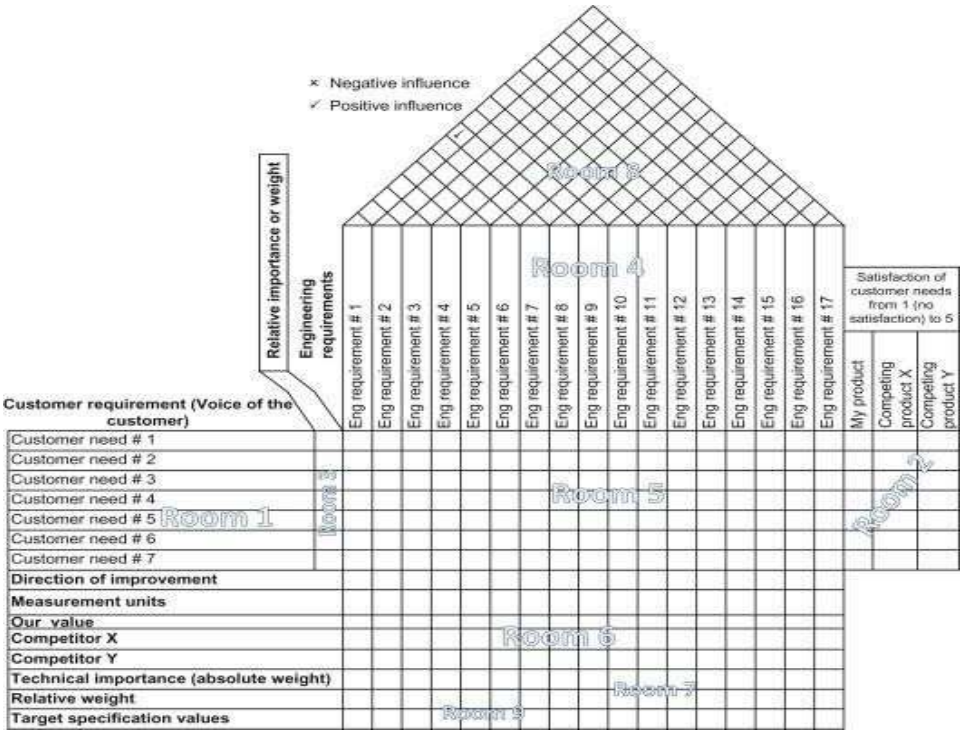


Fig 3. House of Quality with all rooms [3]

QFD is a methodical approach that assists in determining the needs of customers in order to design a product (or service) that takes their needs into account from the outset (Prasad and Chakraborty, 2013). The "HOQ" is another name for the QFD approach, which uses a matrix format that resembles a house. The approach helps make thoughtful decisions regarding customer feedback. It is a method for specifying the location and manner of property assignment in product development. The Product Planning Matrix, or HOQ, is a key tool in QFD and typically consists of nine distinct sections, or "Rooms. Use HOQ and quality control tools for study. [4]

2. LITERATURE REVIEW

2.1 History of QFD

QFD was first created and used in Japan in 1972 at Mitsubishi Heavy Industries' Kobe Shipyards. According to Hauser and Clausing (1988) and Hsiao (2002), Toyota was able to use QFD to cut costs associated with start-up pre-production by 60% between 1977 and 1984 and to cut development time by a third. Among the companies that use QFD are Ford Motor Company, Procter, Toyota, AT&T, Hewlett Packard, Digital Equipment Corporation, 3M Corporation, and Gamble (Cohen, 1995). GOAL/QPC (Growth Opportunity Alliance of Lawrence/Quality Productivity Center) in Methuen, Massachusetts, and the American Supplier Institute (ASI) in Dearborn, Michigan, are the main organizations providing an overview and workshop-style training since QFD was first introduced in the US in the early 1980s (Prasad, 1998).

In order to create better products that meet or exceed the needs of customers, QFD was first proposed as a method for gathering and evaluating customer feedback. Consequently, QFD's main responsibilities are customer need analysis, quality management, and product development. The application of QFD has since expanded to include design, planning, engineering, management, teamwork, timing, costing, and decision-making (Chan and Wu, 2002). According to numerous studies (Clausing and Cohen, 1994; Cohen, 1995; Hauser and Clausing, 1988; King, 1989), QFD is a helpful tool for creating new product standards. [4, 5]

2.2 Process Analysis through QFD

Hari Abdul Hadi et al (2017) worked on two main objectives. In order to use QFD in the tire industry, the first research goal was to design a new product that would meet customer needs. Increasing competitiveness through consumer demands, non-explosive bans, non-slip tires, no bulges, and competitive pricing was the second research goal. In order to conduct the research, customer satisfaction was compared to that of rival businesses. Calculations using the QFD method indicate that, at around 30.57 percent, split liner has the highest percentage of technical requirements in the tire industry. Based on consumer demands, the researchers can thus suggest a number of quality improvement tactics for the tire sector. [5]

The publication of Guide et al. (1999) contains a comprehensive review of the literature pertinent to production planning and control, which we refer to in this context. There are many studies on different specific aspects of remanufacturing, but there aren't many that concentrate on tyre retreading. [6]

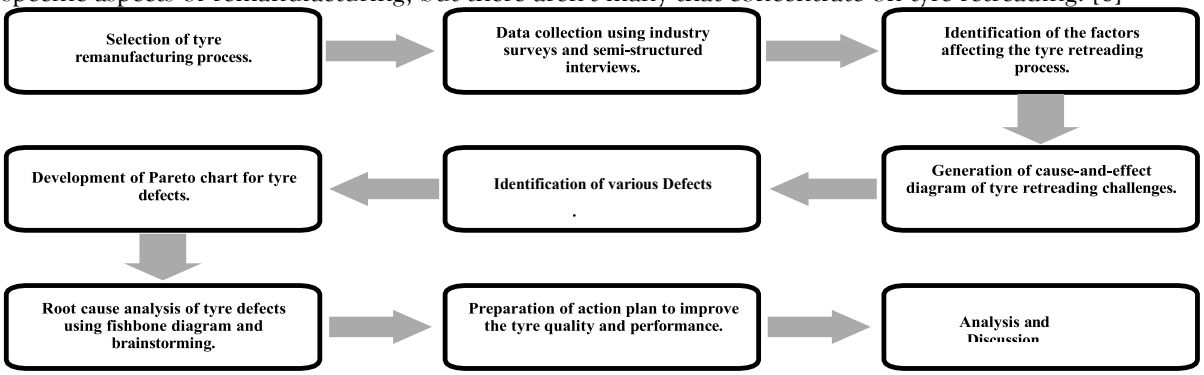


Fig 4. Research Methodology [2]

In seminal work on the management of the tire retreading process, Ferrer (1997) [7] examined the economics of the process and offered a straightforward decision-making rule for determining how often a tire should be retread in order to optimize its use. Jang et al. (1998) outlined different ways to use used tires and conducted a literature review to compare recycling methods for used tires in the USA, Japan, and Korea. [8]
Amaria et al. (1999) [9] look at the methods for recovering the value of used tires as a source of energy or as rubber, which is used as an input for a variety of economic activities. For the treatment of used tires, Sharma et al. (2000) [10] highlight new, more effective, and environmentally friendly techniques like pyrolysis and incinerators (with energy recovery). In their study, van Beukering and Janssen (2001) examined how international policy measures pertaining to international trade, international recycling, and harmonizing laws can effectively lessen the environmental strain that the truck tire life cycle causes. [11]
Bicknell and Bicknell (1995) list the concrete advantages that frequently occur when QFD is applied correctly: reductions of 20–60% in start-up costs, 20–50% in warranty claims, 30–50% in engineering changes, and 30–50% in design cycles. They explain, using a table that specifically illustrates the immediate and striking benefits that some businesses have experienced since implementing QFD. [12]
In the food industry, A.I.A. Kosta (2001) explained QFD and its application. Methods such as the Lead Users Method, which targets groups more likely to embrace new technologies, or the Consumer Idealized Design, which attempts to include customers in the real design of goods and services, might merit more research. [13]
Chan and Wu (2002) conducted reviews of the literature on QFD for roughly 650 publications using a variety of sources from reputable journals. They reviewed the QFD method in a variety of ways and discussed its significance in the engineering domains of product development, quality management; customer needs analysis, product design, and product planning. [14]
The most crucial factors were determined by Marvin E. González (2003) in order to produce designs that are strong, long-lasting, low maintenance, inexpensive, and suitable for local industries using locally accessible materials. The case of the school furniture demonstrated that QFD theory could be a very motivating source for enhancements in a manufacturing system, aiding in the design of products, processes, and procedures in addition to cost reduction. [15]
Gonzalez et al. (2004) used Costa Rica as a starting point for their analysis of the furniture design used in developing nations' schools. A "Dynamic Process Model for QFD" was created by them. After carefully weighing the needs of the clients, this model helps the team make decisions that are both efficient and effective. This method uses a condensed version of QFD to guarantee product service features. [16]
In order to evaluate the profitability of the retreading process for automobile and truck tires in Germany, Lebreton and Tuma (2006) created a linear programming model. Considering that life cycle assessment (LCA) models are increasingly being used as tools for decision-making in waste management systems. [17]
Kumar Ashok (2006) intended to provide a structure for applying benchmarking and quality function deployment (QFD) together to develop an improvement plan that restructures or alters current procedures to maximize output value (as measured by customer satisfaction) while using the fewest resources possible. Using the mix of QFD and benchmarking strategies covered in the paper, the design of the product and process was improved. Consequently, the business achieved noteworthy monetary and strategic outcomes. [18]
According to a study by Lee et al. (2008), QFD was integrated into product life cycle management (PLM) in order to gather customer feedback. Customer complaints are the source of the customer requirements that make up PLM's input. The fuzzy Kano model was used to analyze these data. Both how the weights are calculated and how to determine which are the most important are explained. According to these authors, the use of AHP in the suggested integrated model should be the focus of future studies. [19]
In 2008, Kathiravan et al. published a study on the application of TQFD in The Indiar Block Rubber Factory, a rubber manufacturing company (henceforth referred to as Indiar). The Indian state of Kerala is where Indiar is located. Information about the processes used to process rubber at Indiar was gathered at the start of this

study. Ten customer voices were identified as a consequence of this operation. Customer feedback was incorporated into the customer requirement matrix. A scale from 0 to 10 was used in this matrix to indicate the significance of each customer voice. "0" denoted "not at all important" on this scale, while "10" denoted "most important." Work instructions, a planning and control chart, a component deployment matrix, and a product deployment/modification matrix were then created. [20]

The method of separation of reusing end-of-life (EoL) tires was examined by Pehlken and Müller (2009), who came to the conclusion that modeling such a process is difficult due to the numerous uncertainties that must be identified. [21]

Dehghanian and Mansour (2009) designed a network of used tire recycling facilities in Iran using a three-objective linear algorithm model that can simultaneously maximize financial and social advantages and minimize ecological effects. [22]

A mixed-integer nonlinear programming model was created by Sasikumar et al. (2010) to optimize the revenue of a multi-echelon reverse logistics network for retreading truck tires. However, a number of parameters, such as cost factors, have been found to be deterministic, which restricts the model's practicality. [23]

According to Hilmi Yuksel (2010), the design of environmentally friendly products and those intended for remanufacturing have grown in significance in tandem with the rise in environmental issues. The use of QFD methodology in the design of remanufactured products is presented in this paper. This paper's primary objective is to identify the engineering features of automotive engines that businesses must prioritize when designing them for remanufacturing. [24]

In order to develop dashboard products for automobiles, Hamidullah R. Akbar et al. (2010) used information from the customer requirements survey, technical descriptions, and relative importance to build the HOQ for the dashboard. The HOQ results serve as the foundation for the concept-making process. Using the Pugh chart, the concept for the car's A/C blower system and the adaptable glass holder on the dashboard are chosen. [25]

In order to incorporate consumer desires and requirements into the production process and boost demand for tempered glass made by the SAT Glass manufacturing company, Shamsuddin Ahmed (2010) employed QFD. In order to become more competitive, the company added more functional features, like after-sales service and product customization tactics that will draw in new clients and boost existing ones. [26]

In a different study, Chen and Ko et al. (2010) used the end chain concept (MEC) to examine the close relationships between the four phases of QFD and suggested a series of FLP models to assess the degree to which HOWs contribute to customer satisfaction. It was suggested that other ideas, like Kano's model, be used in QFD modeling in place of MEC. [27]

In 2010, Satyendra Sharma and Rajneesh Katarne determined the current level of service quality provided by a typical car dealership in a city in India. In order to conduct the study, a representative survey of respondents who owned vehicles from a popular brand was used. The service center's performance was deemed inadequate at the moment. The primary objective of this study was to assess the present state of service quality at a car dealership located in a city in India. [28]

Extended producer responsibility (EPR)-based policy tools are discussed by Ferrão et al. (2008) as a way to enhance the environmental performance of goods and services within their life cycles. In order to create an integrated management system for EOL tires, it also examines the interactions between governmental, private, and academic institutions, taking into account the environmental effects as well as the technical, political, and legal aspects. [29]

Milanez and Ton (2009) outline the creation and execution of an EPR-inspired tire waste management policy in Brazil and examine its limitations. [30]

From an environmental and economic standpoint, Li et al. (2010) compare various end-of-life tire (ELT) treatment technologies, such as ambient grinding, devulcanization, pyrolysis, and illicit tire oil extraction in China. The environmental impact of each treatment has also been assessed using life cycle assessment (LCA),

which is based on the Eco-indicator 99 (Hierarchist approach) approach offered by GaBi 4 Software. [31]
In 2011, Sardar*1 examined how the quality of services in India's passenger car industry is measured and how customers' expectations and perceptions of service quality differ. The SERVQUAL instrument was utilized in the study. According to the findings, the sample population has perception issues with the service providers they use. The examination of the gap scores and the rank ordering of the dimensions reveals a perceptual issue. [32]
In order to address the used passenger car tire retreading issue, Abdul-Kader and Haque (2011) used an agent-based simulation approach, identifying a tire, collection center, recycling plant, and retreading plant as "agents" involved in the management of used tires. [33]
Sandeep Mondal et al. (2012) noted that tire retreading is a procedure in which used tires undergo a series of value-adding processes to become reusable. The used tires go through two sets of procedures, followed by an inspection phase and tire rejection if the tires are determined to be unretreadable. Use system simulation to help the decision maker plan for prudent manpower deployment for labor-intensive operations while taking into account the variability in collection and processing during the retreading process. [34]
Kuo et al. (2012) have documented the rising consumption of health foods in developing nations. The authors examined the purchase of black beans as a health food by consumers in Taiwan. To execute this task, the researchers employed the Kano integrative QFD model. The research was carried out in seven stages. Initially, the questionnaires were formulated and distributed to customers aged 20 in Taiwan. [35]
Shih and Chen (2013) utilized quality function deployment for the design concept of a prospective mobile or portable healthcare device. They integrated the analytical network process (ANP) with the theory of inventive problem solving (TRIZ). The outcomes of the integrated method assist in delineating the priorities of the product in question. [36]In 2013, Federico Giubilato Investigated the formulation of a method for quantitatively correlating quality requirements with the product characteristics of sporting equipment. This signifies a substantial enhancement of the methodology suggested by QFD. The results exhibited no inconsistencies, and the high and low correlation coefficients aligned with the anticipated analysis of bicycle riding dynamics. [37]
Joseph and Reddy (2013) noted that QFD is a systematic, customer-oriented methodology for the design and development of new or enhanced products/services aimed at maximizing customer satisfaction. The textile industry is advancing swiftly. The LC 300 carding machine model has been revised utilizing the QFD methodology. [38]
Bukhari Imron (2014) employs Quality Function Deployment (QFD) to address consumer requirements for a product, aiming to develop a solar-powered charger. Mobile phones, as electronic devices, require a battery charger. Solar energy can recharge cell phone batteries by converting it into electricity. Research is necessary to effectively harness solar energy as a viable alternative energy source. [39]
Moldovan (2014) employed Quality Function Deployment alongside information management to ascertain customer requirements for a product, thereby ranking the technical characteristics for a new product produced by a mineral water company. [40]
Chatree Homkhiew (2015) employed Quality Function Deployment (QFD) in the creation of a novel plywood wardrobe prototype to enhance customer satisfaction. Recently designed and developed products differ in form, pattern, hue, functionality, and material quality. Customer satisfaction with products is assessed by categorizing different user groups and sales agent locations. The hypothesis regarding average customer satisfaction between existing and new designs was significantly enhanced in relation to the QFD approach. [41]
Ionica and Leba (2015) endeavored to amalgamate a new product development process with quality function deployment (QFD). They enhanced the product design's robustness by incorporating customer feedback. The outcomes of QFD concentrated on identifying the requirements pertinent to the design and product development phases. [42]

Amin et al. (2017) introduced a mixed-integer linear programming model aimed at optimizing the profit of a tire remanufacturing closed-loop supply chain network in Toronto, Canada. They employed a rudimentary graphical instrument to evaluate decisions amid uncertain demand and returns. [43]
Pedram et al. (2017) introduced a mixed integer linear programming model aimed at optimizing the profit of a multi-echelon closed-loop supply chain within the tire industry in Tehran, Iran. A straightforward scenario-based methodology was employed to illustrate risks in demand, exchange rate, and the value of used tires. [44]
Afrinaldi et al. (2017) established a two-objective non linear programming model aimed at establishing an optimal preventive replacement schedule for bus tyres by reducing economic and environmental impacts. [45]
Simic and Dabic-Ostojic (2017) formulated an interval-parameter chance-constrained programming (IPCCP) model for decision-making under uncertainty in the tire retreading sector. The proposed model can assess different permissible risk levels associated with breaching retreading capacities. [46]
Piyush Kumrawat and Dr. Devendra Verma (2017) Utilizing the QFD house of quality model, we can understand the essential customer requirement. This paper presents a straightforward case utilizing the use of QFD during the design phase of a commercial vehicle project as a tool for improving various product features. .By acquiring the conclusive results regarding the significance of weight and relative weight of the technical requirements, the design team was able to prioritize and execute the features outlined in the specification and design. [47]
Rosnani Ginting et al. (2019) enhanced the quality of crumb rubber products Type SIR 20 in accordance with respondent requirements by employing the QFD method to identify product design attributes and ascertain the priority of the product's technical characteristics. This may serve as the company's primary reference for enhancing the standard of crumbs Rubber Type SIR 20 products. [48]
Serkan Altuntas et al. (2019) focus their research on innovative new product development. This study employs the QFD methodology for electric vehicle technology. The developed technology is a form of electric towing vehicle. Seventy-seven customer requirements have been identified through the survey study. The requirements are categorized into five clusters: performance, ergonomics, security, maintenance and after-sales service, and functionality. The newly developed product is a fully electric and multifunctional vehicle. [49]
Tire retreading, according to Wang Qiang et al. (2020), is a resource recycling technique that can preserve rubber raw materials, address the environmental contamination caused by waste tires, and fully utilize the tire's value. Prevulcanization retreading of used tires does not produce any "three-waste" emissions. It's a green environmental protection industry that can reduce, reuse, and recycle used tires in addition to saving a lot of rubber, steel wire, petroleum energy, and other resources. This paper provides a thorough discussion of the features, technological process, current state, and development trend of tire retreading technology. [50]
A study conducted by Jeevan Gaidhane1 and colleagues in 2022 Tire remanufacturing companies have come up with their own methods for retreading tires, but because there aren't any standardized guidelines, the resulting tyres don't always perform up to par. This study aims to identify the many defects in these tires and the reasons behind them. All of the data used in the aforementioned analysis came from extensive fieldwork and semi-structured interviews. The defects that were identified through cause-and-effect analysis include tread failure caused by an absence of a standard tread joint method, side bulge generation caused by sidewall degradation, and buffer layer failure caused by a crack in both the tread and the sidewall. [2]
Czarna Dorota et al. (2023) Investigating waste management techniques is highly advised because the growing volume of used tires is correlated with the annual increase in vehicle production. By 2027, it is anticipated that the global tire market will have grown to 2.67 billion units from 2.27 billion in 2021. Retreading, energy recovery, and material recovery are the three main approaches used for disposing of waste tires. It was determined that the ideal pH range was between 6 and 7. [51]

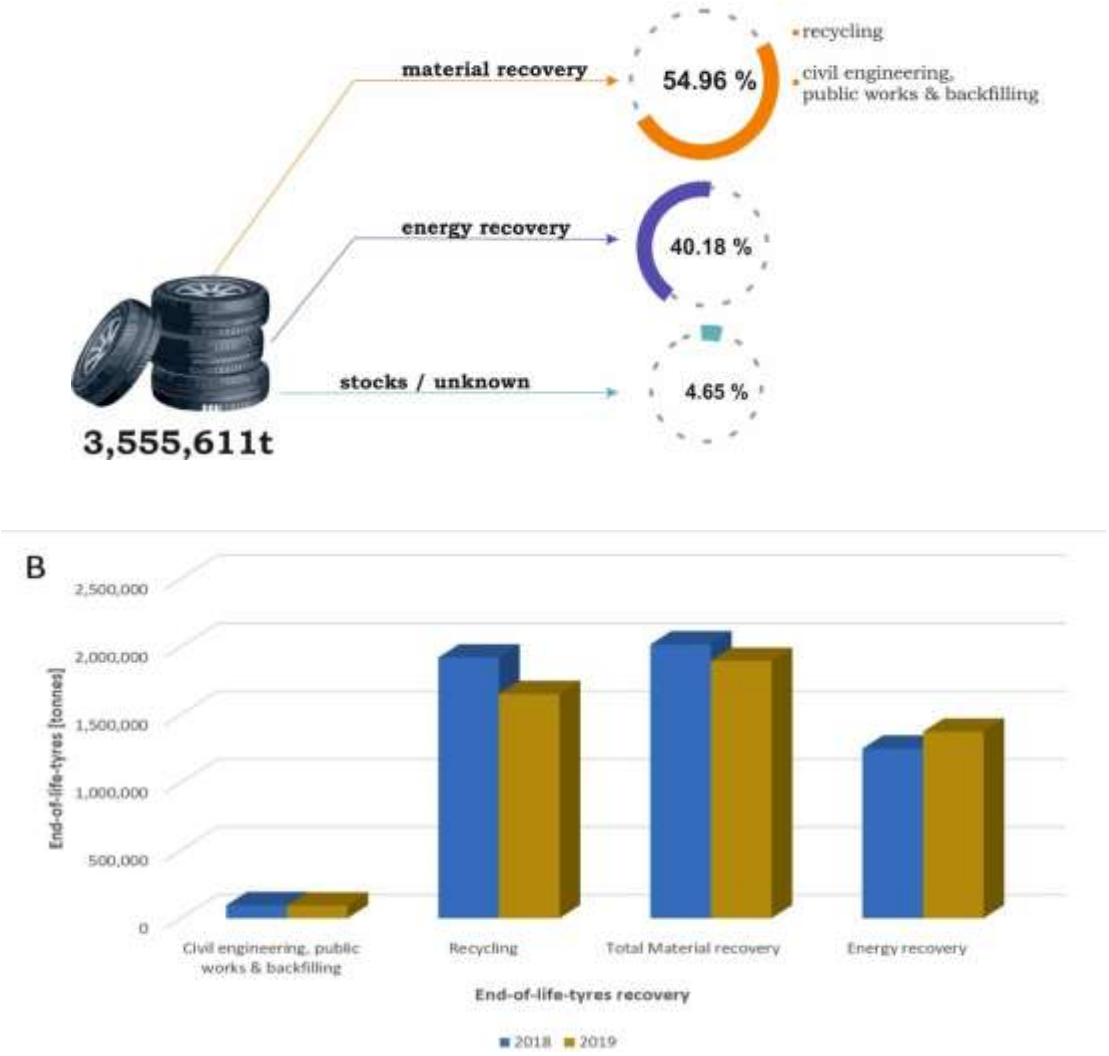


Fig 4. End-of-life tires (ELTs) recovery in Europe [21]

Heba El Mehelmi conducted an investigation into the application of QFD in the context of the Egyptian public sector. This study sought to enhance understanding regarding the selection of suitable TQM tools for the Egyptian PSOs. This study utilizes two distinct data collection methods: semi-structured interviews with customers, which were subjected to content analysis, and focus groups with managers aimed at developing the QFD model. [52]

The research conducted by Khaerul Fahmi et al. (2021) aims to examine the practical and strategic impacts of Six Sigma implementation on innovation capabilities, work productivity, and customer quality, as components of the comparative and competitive advantages for companies in the tire industry. The population of this study comprises all employees within the tire industry. The total count of received and valid questionnaires was 443 samples. Data analysis employing the SEM technique utilizing Smart PLS 3.0 software. This study presents a model aimed at enhancing the quality of the tyre industry by augmenting and reinforcing the implementation of the Six Sigma methodology, utilizing innovation capabilities and work productivity as mediators. [53]

An estimated 19.3 million tonnes of used tires are produced annually worldwide, according to a study by Svetlana Dabi Ostoji et al. Used tires are a type of waste whose complicated structure and diverse composition make processing them particularly challenging. [54]

The long-term benefits of tire reuse are discussed by Walid Abdul-Kader and Muhammad S. Haque. Tire, collector, recycler, and remanufacturer are the agents identified by an agent-based simulation approach used to address this research problem. Retreaded tires can make up almost 25% of the replacement (sales) market, according to the findings; it will drastically reduce the amount of raw materials and scrap tires used.

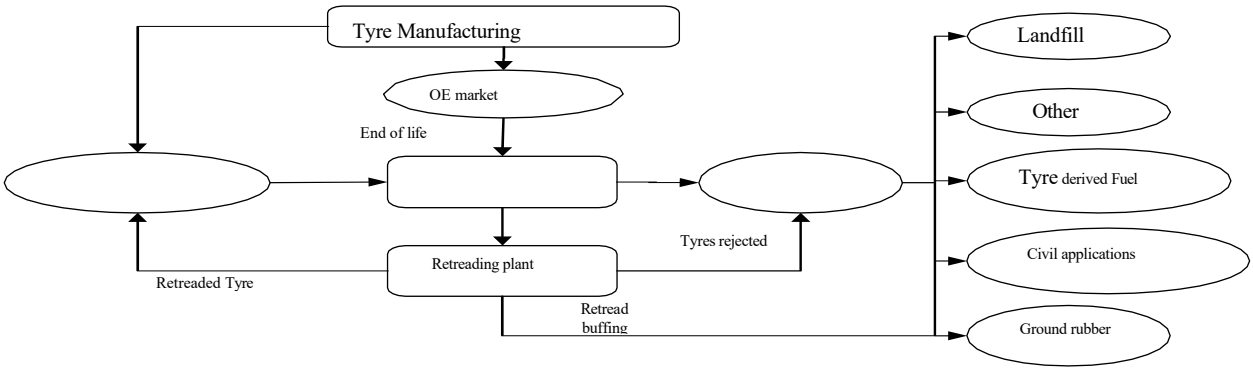


Fig 5. Overview of Tyre Industry [52]

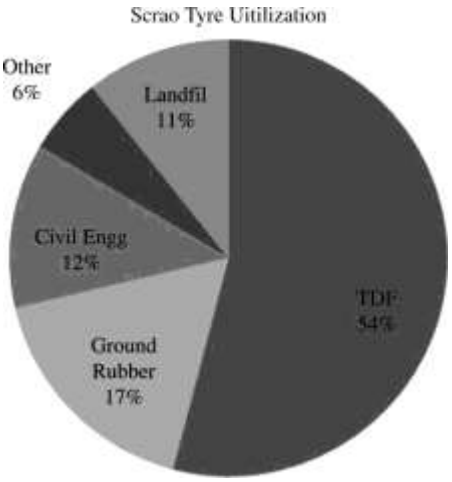
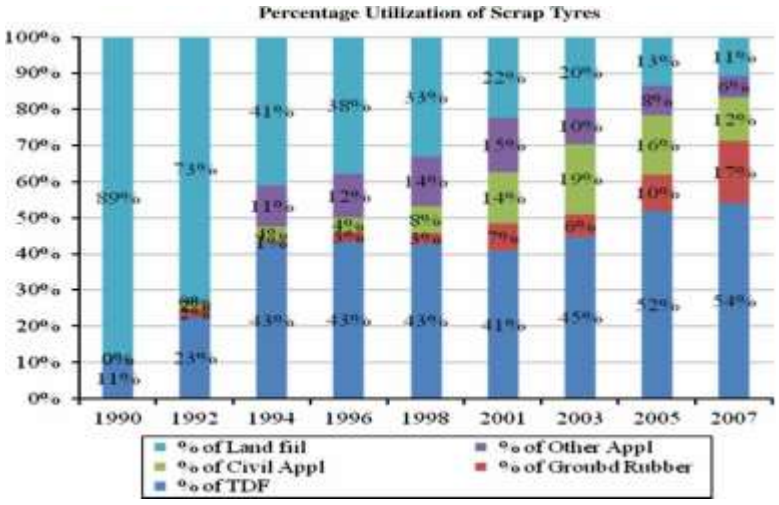
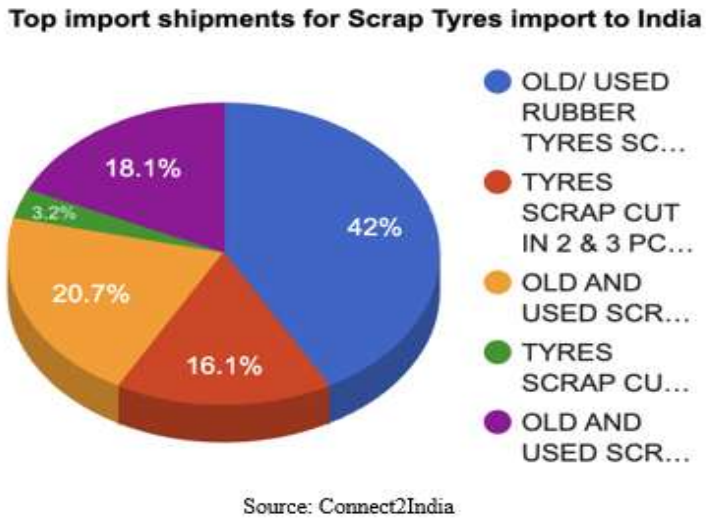


Fig 6: Scrap Tyre Market



Retreading is the process of taking out the old thread and replacing it with a new one in order to prolong the tire's life, according to Muhammad Haikal Sitepu et al., Retreaded tires can be used if they passed a wear and tear inspection and have been found to be completely intact. Either a hot or cold method can be used for rethreading. According to the TRIB, retreading can prolong the life of new tires by 75% to 100%, while only 30% of energy and 25% of raw materials are needed for the process. [56]

Bahmankhah Behnam and Helena Alvelos have detailed how to use high-quality tools in tire retreading, a unique industrial setting. The specific objectives are to better understand the underlying causes of the primary quality issues that arise from the production process, rank those causes according to the significance of their occurrence, determine the critical step in the production process in light of the identified main issue, and investigate the possible causes of issues in that step. The Pareto chart, brainstorming, fishbone diagram, and matrix diagram were the tools utilized. [57]



Source: Connect2India

As the automobile industry has grown, a significant amount of scrap tires have been produced, according to Dr. Seema Laddha. Technology's arrival has opened the door for the retreading sector. However, systematic research in technology theory, craft, detection, etc. is lacking in Indian re-treaded tires, which enables them to fall short of quality standards. The most frequent issues with re-traded tires are tread, sidewall, ply, buffer layer, and bead delamination and cracking failure. [58]

Mehta Divyesh et al. conducted a study on the ST Bus tire retreading procedure. ST buses' old, worn-out tires are retread using various techniques, and they are used rather than new ones. The life cycle of this retreaded tire from ST Government buses is also examined in this paper. By reusing old tires, this bus tire retreading reduces tire waste and benefits the government financially. Using retread tires in public transportation is quite simple. Public transportation in Gujarat uses tires that are no more than four or six years old. [59]

Francesco Valentini and Alessandro Pegoretti proposed that the demand for enormous amounts of tires, which should be properly managed after their useful life, is caused by the growing rate of motorization around the world. Due to the relatively low cost of tires and the difficulty of recycling them, approximately 41% of all end-of-life tires are disposed of in landfills or stockpiles worldwide with no material or energy recovery. Furthermore, tires' chemical makeup renders them incredibly resilient to environmental deterioration, potentially making them permanent over time. [60]

The issue of waste treatment is crucial for the environment, and tires play a significant role in this regard, according to Svetlana Dabi´c-Ostoji´c et al. Analyzing retreading as an intriguing tire treatment method is

the goal. Data from a public passenger transportation company's tire exploitation database is analyzed, and the statistical findings are fed into the suggested model. [61]

According to Ping Fu et al., tire retreading is the process of repairing waste tires by polishing, gluing, pressing, and curing them to restore their usable value. The pre-vulcanization retreading technology is used in this article to renovate radial tires following additional research into related retreading theory. Tire carcass inspection, repair, polishing, brush glue, tread molding (including post pad, pre-vulcanized tread, and pressed), vulcanization, and final inspection are all included in the renovation process. Poor quality, short service life, and outdated technology were all resolved by this study. [62]

The tyre retreading process has developed quickly, as described by Nihal T. Tahikar et al. Numerous value-added procedures, such as inspection, tread application, enveloping, curing, etc., are part of the retreading process. More time and labor are needed for this wrapping process. The envelope expander is a new machine that was created to solve this issue. The total cost of retreaded tires is examined in this review study. [63]

According to S. Ajeeth Kumar, the tire is composed of either synthetic or natural rubber. The bark of the HEVEA BRASILIENSIS rubber tree contains natural rubber in the form of latex or milky liquid. At temperatures between 100 and 140 degrees Celsius, natural rubber undergoes a series of processes that combine it with carbon, oil, sulfur, and other chemicals. The new and safe technology that is being used today will make tire production easier and more affordable. More tires will be needed as the economy continues to grow because there will be more passenger cars and transportation vehicles. As a result, retread tires have a lot of potential as an original substitute. [64]

P. Fithri et al. noted that one of the crucial studies that need to be implemented in the organization is occupational health and safety. The purpose of this study is to ascertain the occupational hazard index for tire retreading operations at PT. Inti Vulkatama. By using the safety performance index (SPI) approach and assessing hazards, work behavior is directly observed. The analytical hierarchy process questionnaire (AHP) and the critical behavior checklist (CBC) were the tools utilized in this study for every workstation in the hot and cold process processing department. The scrape workstation with SPI 0.498, side cut workstation with SPI 0.496, and hot process workstation with SPI 0.492 are considered unsafe, according to the results of SPI calculations that were integrated between the results of questionnaires CBC and AHP. [65]

3. CONCLUSION

The literature review indicates that retreading is a well-established and regulated process for manufacturing excellent recycled tyres. The study's findings demonstrate that QFD serves as a versatile and viable framework for application. This study aims to examine the existing retreading processes of tyres, identify areas for improvement, and propose optimal methods to enhance these processes to achieve high-quality products at reduced costs. The study's findings suggest that organizations can enhance the use of worn-out tyres by identifying defects in tyre retreading and their underlying causes, as well as by implementing corrective measures at various stages of the tyre remanufacturing process. The expectations of customers purchasing and utilizing remanufactured products can be identified, and their requirements and expectations can be incorporated into the House of Quality (HOQ). The findings of the paper are:

- The retreading process involves multiple procedures. Each process can be executed more efficiently than retread tyres, which are considered safe.
- The traveling distance of retreaded tires decreases with an increasing number of retreads.
- The lifespan of a first-time retreaded tire is 70% that of a new tire, while the lifespan of a second-time retreaded tire is 40% compared to a new tire.
- The cost per kilometer of tire usage is decreased through the application of retreaded tires.

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