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Sustainable Management of Pharmaceutical Waste Using The Quality Function Deployment Methods at PT Bio Farma

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Abstract
Waste management is a critical factor influencing corporate sustainability , particularly in the pharmaceutical industry where production growth parallels rapid population increase . This study aims to evaluate the effectiveness of waste management practices at PT Bio Farma using the Quality Function Deployment (QFD) method. Employing a mixed method approach with a case study design, the research identifying the environmental dimension as the most critical factor, emphasizing corporate commitment to waste management, the efficiency of waste segregation and collection systems, and the availability of recycling facilities. QFD provides a structured framework to translate stakeholder's needs into technical responses, offerings strategic recommendations to enhance both operational efficiency and environmental sustainability.

INTRODUCTION

Improper waste disposal can release various toxic materials into the environment, polluting air, water and soil (Sharma et al., 2022). This can trigger various health problems, ranging from respiratory disorders to chronic diseases such as cancer, as well as contribute to antibiotic resistance (Azzahra and Saptarini, 2021; Adar et al., 2022). Therefore, responsible and effective waste management is crucial for the pharmaceutical industry to maintain ecosystem balance, protect health, and ensure operational sustainability (Jamilah et et al., 2023).

One industry that produces hazardous waste is the pharmaceutical industry. The pharmaceutical industry, which is responsible for the production of medicines and other health products, plays a vital role in maintaining public health (Milanesi et al., 2020). However, behind this positive contribution, there is a negative side that is often overlooked, namely the production of hazardous and toxic waste. Table 1.1 compares several commonly used pharmaceutical waste disposal methods, along with their advantages and disadvantages.

Table 1.1
Waste Management Methods

Waste Management Methods	Advantages	Disadvantages

Incineration (High Temperature Combustion)	Reduces waste volume; Destroys pathogens and harmful compounds; Produces energy (if equipped).	High investment costs; Potential for hazardous gas emissions if not managed properly; Requires handling of combustion ash residue.
Landfill (Controlled Disposal)	Operating costs are relatively low; Common and easy method implemented.	Requires large areas of land; Potential for soil and groundwater pollution (leachate); Production of methane gas (GHG); Does not significantly reduce waste volume.
Encapsulation (Packaging)	Isolate hazardous waste so that it does not pollute the environment; Relatively safe for transportation and storage.	Does not reduce waste volume; Requires special packaging materials; Still requires safe final disposal.
Chemical Decomposition	Neutralizing or changing the properties of hazardous waste to make it less toxic.	Requires additional chemicals; Process can be complex and require specialized expertise; By-products may still require further handling.
Direct Disposal (Not Recommended)	(No excess is recommended due to negative effects)	Directly pollutes the environment (water, soil); Harms human health and ecosystems; Violates environmental regulations.

This problem is further complicated by the diverse nature of pharmaceutical waste, ranging from liquids and solids to gases, and containing hazardous compounds such as antibiotics and hormones that are difficult to decompose. In fact, a 2022 study by the Center for Information and Communication Technology (PUSAKOM) and the National Research and Innovation Agency (BRIN) identified five types of pollutants found in inland waters and several Pharmaceutical Industry Wastewater Treatment Plants (WWTPs) in West Java, Greater Jakarta, and Banten (Pusakom, 2022). Water-soluble compounds can spread through groundwater and contaminate drinking water sources.

According to Bio Farma's Sustainability Report (2023), all environmental management activities within Bio Farma are continuously monitored and reported to relevant government agencies on a regular basis. With this management approach, environmental quality measurements are below the quality standards set by laws and regulations. These optimal results are inseparable from Bio Farma's commitment to implementing standard Excellent compliance, which ensures that the Company does not receive any sanctions or penalties for non-compliance with applicable laws and regulations in the reporting year. On the other hand, as an implementation of the 4R principle (reduce, reuse, recycle, and recovery), one of them is by sorting waste into five categories to facilitate processing at the final disposal site, Bio Farma recorded results, including a reduction in the volume of non-B3 waste and water withdrawal volume. Specifically, energy use, which directly impacts greenhouse gas emissions, recorded a total energy use of 187,641 Gigajoules with total emissions of 16,143 tons of CO2 eq. Total energy use in 2023 increased by 4.28% compared to the previous year, which resulted in increased emissions in 2023 compared to 2022. Behind all of this management, the level of consumer satisfaction with Bio Farma's products and services was recorded at 89.36%, down from the 2022 score of 89.61%. When waste is recycled, process, and manage well, thing This can give mark plus services, which refer to activities distinctive created company for increase efficiency and effectiveness of operational they (Sidik et al., 2024). Company performance can be shaped by the business environment, environment business described as factor external to the organization business (Sagita et al., 2024).

In 1999, the World Health Organization (WHO) published an important guideline entitled " Guidelines for safe disposal of unwanted pharmaceuticals in and after emergencies ". In it, WHO pays special attention to various methods of pharmaceutical waste disposal, including incineration (burning at high temperatures), landfill (accumulation in a controlled location), encapsulation (packaging), disposal, and chemical decomposition. This guideline is not just a list of methods, but rather a comprehensive guide that outlines various strategies to ensure the safe and responsible disposal of medicines (Bungau et et al., 2018).

In March 2020, the Minister of Environment and Forestry issued Circular Letter No. SE.2/MENLHK/PLB.3/3/2020, which mandates the use of incinerators for waste processing. In emergency situations, a permit for incinerator use is not required. Ash or residue from incinerators must be safely packaged and transported to a licensed landfill, or buried in accordance with applicable regulations if this is not possible (Ministry of Environment and Forestry, 2020).

In designing an effective and sustainable waste management strategy, a systematic approach is required to identify and meet stakeholder needs. One methodology that has proven effective in translating the "voice of the customer" into technical and operational requirements is Quality Assurance. Function Deployment (QFD). QFD is a customer-centered quality planning tool that helps organizations systematically integrate consumer desires and expectations. Thus, QFD enables companies to identify priorities, align internal goals with external expectations, and ultimately improve overall operational quality and efficiency. The public will certainly be a customer of the pharmaceutical industry, one of which is PT Bio Farma. This study also aims to design an effective and sustainable waste management strategy by implementing the Quality Assurance (QFD) method. Function Deployment (QFD).

The most well-known QFD model is the House of Quality (HoQ). This matrix describes the relationship between customer needs and the technical characteristics of a product or service (Ginting et al., 2020). Previous research also explains that the use of QFD analysis is to create high-quality products and services that meet customer needs and expectations (Rafidah, G., Hendayani, R., Hidayah RT, 2024). By integrating customer needs into every stage of development, QFD helps companies achieve overall operational excellence. In addition, Ginting, R., Ishak, A., Malik, AF, and Satrio, M. R (2020) stated that the Quality Assurance (QFD) method Function Deployment (QFD), can help plan a strategy effectively in solving a problem.

Based on previous research, waste management in industry is still ineffective, requiring more specific techniques for purification and recycling (Khoshsepehr, Z., Alinejad, S., & Alimohammadlou, M., 2023). Previous research revealed that the application of QFD allows the selection of key activities to meet the needs of the healthcare waste management sector.

PT Bio Farma has made efforts to improve its waste management, one of which is by obtaining environmental management system certification such as ISO 14001:2015. According to Pusfaster (2017), this standard encourages the integration of environmental aspects into business processes, including considering risks and opportunities related to the organization's activities, products, and services. However, in addition to waste management, it is also important for pharmaceutical companies to ensure that PT Bio Farma's waste management is carried out effectively and sustainably. Development that only targets economic growth has proven to fail to create a national economy that grows stably, inclusively, and sustainably. Reflecting on these factual conditions, a new paradigm has developed, namely sustainable development, which prioritizes the harmony of economic, social, and environmental aspects (Biofarma , 2023). As regulated in Law Number 32 of 2009 concerning Environmental Protection and Management, sustainable development is defined as a conscious and planned effort.

There are many ways to research waste problems management, one of which is Theory of Planned Behavior (TPB) which suggests that an individual's intention to engage in a specific behavior, such as waste management practices, is influenced by their attitude toward that behavior, subjective norms (perceived social pressure), and perceived behavioral control (Sapawi et al., 2024). TPB can be extensively utilized in transportation studies to investigate the impact of various disruptions on changes in travel behavior (Kafi et al., 2024). However, in this study, the way to achieve this is by applying the Quality Assurance method. Function Deployment (QFD).

Therefore, this study aims to explore how QFD can be applied in the pharmaceutical industry to improve operational efficiency and reduce negative environmental impacts. Furthermore, this study will evaluate how QFD implementation can contribute to improvements in environmental impact reduction.

Waste Management

Waste management describes system management waste with collection, transportation, recycling repeat, or disposal waste (Al Rawahi et al, 2020). This matter concludes If management waste aim for minimize impact environment at a time maximize recovery and utilization source power. Management rubbish involving three Beneficiaries: government, industry and society.

Facility storage B3 waste for B3 waste and/ or place hoarding B3 waste for a maximum of 90 days since B3 waste is produced (Rajagukguk , JR, 2020). There are 4 dimensions in management waste That themselves, including (Krishna and Sharma, 2023):

1. Technology: Technology that is help in management waste, such as sorting, processing, and disposal.
2. Economics: Costs incurred in the management process waste, starting from transportation until disposal end.
3. Environment: Management process waste that must be confirmed in a way safe and secure If waste No polluted.
4. Social: Impact on the environment related health, safety and rights worker.

Quality Function Deployment

Quality Function Deployment was introduced in Japan in 1972 by Yoji Akao (Ginting et al., 2020). This method used for determining request or need consumer Then elaborate request This in a way accurate to in condition technical, system manufacturing and planning proper production (Ishak et al., 2020). The application of QFD itself Already studied in a way wide and has tested on various real -world fields (Zhou, et al, 2022). The planning process used is Quality Function Deployment (QFD), one of which using House of Quality.

The process of making the HOQ started with determine connection between need with characteristics quality That itself. HOQ is used for elaborate hope customer to in need technical. Simple technique from QFD implementation in seven areas within the HOQ: (1) desires and expectations customer, (2) matrix planning, (3) requirements technical, (4) target of condition technical , (5) matrix relationship , (6) matrix correlation technical , and (7) evaluation customers (Himawan , 2023).

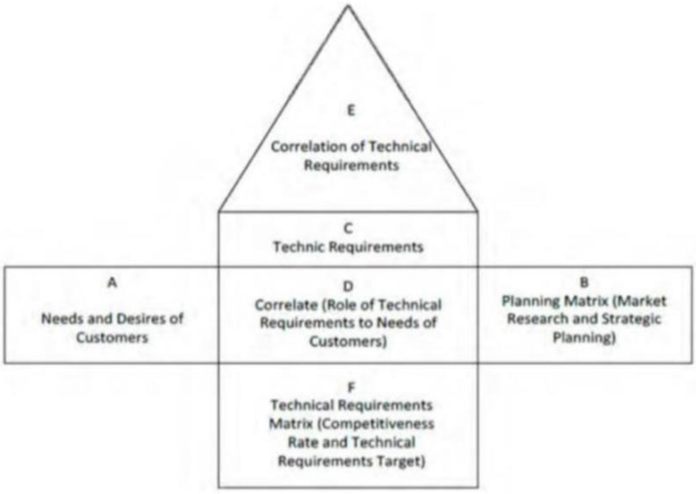


Figure 2.1 House of Quality
source : Himawan (2023)

Pharmaceutical Waste

Industrial waste management, including pharmaceutical waste, has become a major concern in various industrial areas. Khoshsepehr et et al. (2023) noted that most industrial areas face significant challenges in determining appropriate waste disposal practices. Large cities, which consume significant amounts of resources, generate large amounts of solid waste that has the potential to permanently damage the environment. Several methods used to manage industrial waste, such as sanitary waste disposal, incineration, thermal decomposition, and recycling, each have their own advantages and disadvantages (Raj and Samuel, 2023).

Waste pharmacy, as one of the types of waste industry, has characteristics unique that requires attention special. Waste This often contains substance active pharmaceutical active ingredients (PAIs) that are difficult decompose in a way natural and can pollute water bodies if no managed with good. Substances like antibiotics, hormones, and other materials chemistry other in waste pharmacy not only dangerous for ecosystem waters but can also influence health man through exposure term long. Waste pharmacy that does not managed with that's right to trigger resistance antibiotics, which become threat Serious for global health (Adar et al., 2022).

This study emphasizes that pharmaceutical waste management requires a more integrated and innovative approach. This includes the implementation of environmentally friendly waste treatment technologies, stricter regulations, and education for the public and stakeholders regarding the dangers of pharmaceutical waste.

RESEARCH METHODS

This research uses a mixed method (qualitative and quantitative). Creswell & Creswell (2023) in their book entitled " *Research design : Qualitative , quantitative , and mixed methods approaches* " explains that mixed methods Research is a methodological approach that systematically combines quantitative and qualitative data in a single study or series of studies, with the aim of leveraging the strengths and addressing the weaknesses of each method to gain a more comprehensive and in-depth understanding of the research phenomenon. This approach is based on a pragmatic paradigm that rejects the dichotomy between positivism (quantitative) and constructivism (qualitative), thus allowing for richer data integration and interpretation.

Qualitative research methods, as explained by Ilyas and Ismail (2023), aim to describe, explore, and understand social phenomena in depth. This approach allows researchers to explore the experiences, attitudes, and opinions of individuals and groups, focusing on the interpretation and meaning of social interactions that occur (Indrawati, 2018). Meanwhile, quantitative research is a method based on positivism used to test samples or populations of people who have a good understanding of data processing with instructions and analyze quantitative statistics (Sugiyono, 2023). Quantitative studies are defined as a research approach that emphasizes the collection and analysis of numerical data to identify patterns, relationships, or causal effects (Zamudio-Rodriguez et et al. , 2021).

QFD process

The QFD method is divided into three phrases: quality design, comprehensive design and process implementation (Razik , 2015; Himawan, et al., 2023). The QFD process begins with the desires and needs of consumers and themselves, which are often referred to as the "voice of the consumer" of " customer voice." There are various ways to obtain this " voice" such as surveys and interviews. This voice is logically classified and then interpreted to generate customer desires. By focusing on key aspects of the product being developed, it can be built with a planning matrix (Indriya, 2018).

House of Quality

House of Quality is a tool for developing Quality projects Function Deployment (Himawan, et al., 2023). House of the house-shaped Quality matrix will provide a connection between the existing matrices. Design priorities can be changed according to research needs to achieve the desired solution. Customer needs are identified and defined qualitatively. Then, the House of Quality section is created. Quality, known as " what " is a combination of customer voices that are tailored to expectations and needs, then categorized and prioritized (Dale et al., 1998; Himawan, et al., 2023). To proceed to the next, more comprehensive step, the "what" section will be completed by creating a list of "how" questions. Then, the relationship between "what" and "how" is determined. There is a section known as the "Relationship Matrix" to address this issue.

The strength of the relationship can be categorized as strong, moderate, or weak, into three categories. Next, a correlation matrix is created. Correlations are classified as positive, very positive, negative, very negative, and so on. Finally, the final step is taking action, where the goal is to identify the most critical issues in improving overall customer satisfaction with products and services based on the organized data (Himawan et al., 2023).

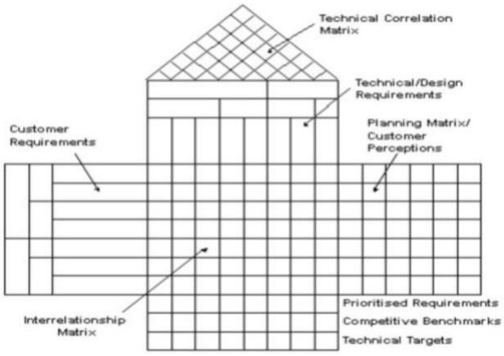


Figure 3.4 QFD Structure

source: Himawan (2023)

RESULTS AND DISCUSSION

Relationship Matrix

At this stage, every attribute in What's associated matrix with response technical is listed in How's matrix. Through this relationship matrix, we can see the connection between the need for customers and technical responses, as well as the level of strength of the connection. The Relationship Matrix can be seen in the table below.

Technical Requirements / Customer Requirements (Explicit and Implicit)	Tempat pembuangan limbah terpisah	Dukungan Board of Directors	Fasilitas insinerasi	Kebijakan pemerintah	Alat penanganan dampak lingkungan	Adopsi teknologi baru	Koordinasi pemerintah kota	Daur ulang internal
Sistem pemisahan dan pengumpulan limbah yang efisien	●	○	○	○	○	●	○	●
Biaya pembuangan limbah yang rendah	○	●	●	●	○	●	○	●
Tidak ada dampak berbahaya dari limbah	○	○	●	●	●	○	○	○
Solusi daur ulang limbah	○	○	○	○	○	●	○	●
Kerapihan dan kebersihan lingkungan	●	○	○	○	○	○	●	○
Kesadaran karyawan	○	●	▽	○	○	○	▽	○
Pengurangan jumlah limbah	○	○	○	○	○	●	○	●

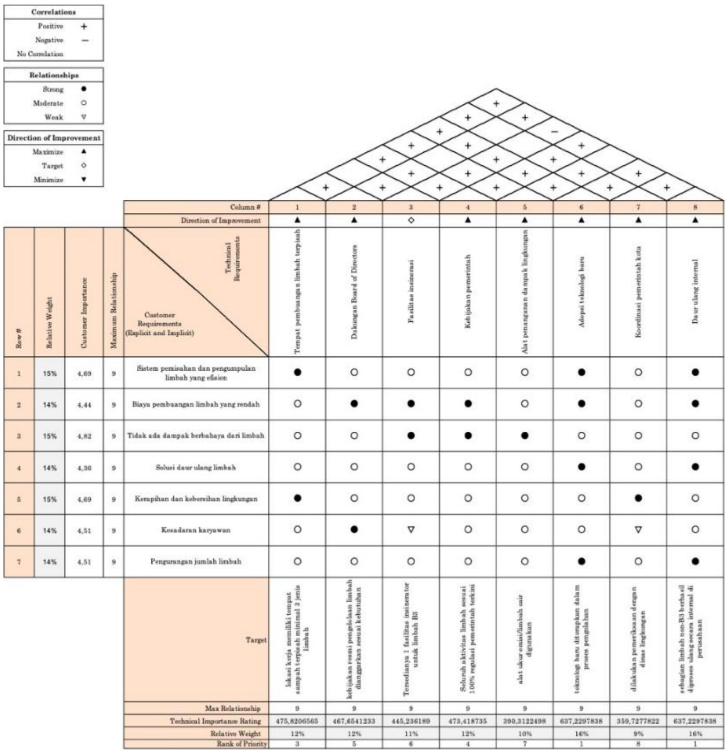
Source: data processed writer (2025)

Relationships	
Strong	●
Moderate	○
Weak	▽

Technical Correlation Matrix

Function of technical correlation is used to identify the degree and direction of the relationship between technical responses. This correlation indicates how closely two technical response variables move together (positive correlation), oppositely (negative correlation), or are uncorrelated. If the correlation value between technical characteristics is positive, then the improvement or increase in one technical characteristic will be positively correlated with the other technical characteristics. In other words, an improvement in one technical aspect tends to be followed by an improvement in the technical aspect that is positively correlated with it. Conversely, if the correlation value between technical characteristics is negative, then the improvement or increase in one technical characteristic will be negatively correlated with the other technical characteristics. This implies that an improvement in one technical aspect tends to be followed by a decrease in the technical aspect that is negatively correlated with it.

House of Quality



In this HOQ, there are seven main customer needs (Customer Requirements), such as an efficient waste separation system, low costs, minimal harmful impacts, and increased environmental awareness and cleanliness. Each requirement is then mapped against eight technical specifications (Technical Requirements), for example, separate waste disposal, the use of new technologies, and internal recycling. The relationship between customer needs and technical specifications is assessed based on its strength level (strong, medium, weak) and produces a technical priority weight through Technical Importance Rating and Relative Weight.

Additional information within the HOQ roof reveals correlations between technical elements, both positive and negative. For example, the use of new technology has a strong positive correlation with segregated waste disposal and inter-agency coordination. This is important because it demonstrates that the implementation of one technical aspect can strengthen or weaken another. Specific, realistic targets are also set for each technical element, such as "worksites must have separate bins for at least three types of waste" or "all waste activities must be 100% in accordance with current government regulations," providing concrete direction for decision-making.

The QFD results show that the highest weighting of elements is related to the environment, namely internal recycling (16%), followed by government policies (12%) and environmental impact reduction tools (10%). These three aspects contribute significantly to addressing customer needs comprehensively. Therefore, the QFD approach not only produces a list of technical specifications but also helps determine priorities for developing a sustainable pharmaceutical waste management system. This will be described in more detail and structured based on the four main dimensions of sustainability: environmental, social, economic, and technological.

These results were obtained from:

1. Customer Importance: ∑ (Total Score / Number of Respondents)
2. Relative Weight: (Technical Characteristic Value / Total Technical Characteristics) x100%

Environmental Dimension

The environmental dimension of pharmaceutical waste management is a primary focus because pharmaceutical waste contains active chemical compounds that can pollute water, soil, and air if not handled properly. Within this HOQ, several customer requirements, such as "no harmful impacts from waste" and "reduction in the amount of waste," are closely linked to technical specifications such as the use of environmental impact reduction tools and internal recycling. Strong relationships are indicated by the symbol "●," for example, the relationship between "no harmful impacts" and "environmental impact reduction tools," indicating that implementing these tools is crucial to achieving environmental goals. Internal recycling also receives the highest relative weight (16%) due to its contribution to reducing pharmaceutical waste entering the ecosystem.

The results of this study, which found that prioritizing waste management is crucial, align with previous research by Derhab & Elkhwesky (2022), which stated that waste management offers numerous benefits, including improved financial performance, economic growth, competitive advantage, and sustainable development. PT Bio Farma has also implemented waste management *beyond its intended scope. compliance* thus receiving the PROPER Gold category award from the Indonesian Ministry of Environment and Forestry.

On the other hand, the "use of new technology" also contributes to environmental sustainability by using IPAL (Wastewater Treatment Plant) which uses MBBR (Moving Bed Biofilm Reactor). The positive correlation between technical elements on the HOQ roof indicates that synergies between components, such as between separate waste disposal sites and new technology analysis, can strengthen overall environmental performance. Technical targets such as "emission/effluent measurement tools used" are indicators of success in this dimension. From a technical assessment perspective, the environmental contribution is very clear in driving system development priorities, as most strong customer needs stem from environmental concerns.

Therefore, the success of sustainable pharmaceutical waste management must be based on the principle of pollution mitigation at source, through waste separation, recycling, and the application of environmentally friendly processing technologies. QFD demonstrates that technical interventions in the environmental dimension have broad and sustainable effects not only on the environment but also on the quality of life of communities surrounding healthcare facilities.

Technology Dimension

The technological dimension in sustainable pharmaceutical waste management plays a crucial role because it directly relates to the effectiveness, efficiency, and sustainability of technical processes in handling complex and potentially hazardous waste. In this HOQ matrix, the technological dimension is represented by several technical elements such as "use of new technology," "environmental impact reduction tools," and "internal recycling." These three elements contribute significantly to meeting customer needs, particularly in the aspects of waste reduction, separation efficiency, and elimination of hazardous impacts. It can be seen that "internal recycling" and "use of new technology" have the highest relative weights (16% and 16%, respectively), indicating that focusing on technological development is a strategic priority in pharmaceutical waste management.

"New technology analysis" has a strong relationship (●) with customer needs such as "no harmful impacts from waste," "recycling solutions," and "reduction in the amount of waste." This shows that the selection and implementation of the latest technology such as the use of MBBR (Moving Bed Biofilm Reactor), STP (Sewage Treatment Plant) is essential for addressing the complexity of active chemical compounds in pharmaceutical waste. Furthermore, "environmental impact reduction tools" also support technical performance by providing safer and more environmentally friendly filtering, shredding, and destruction infrastructure. The strong connection between these tools and diverse customer needs reinforces technology's position as a key foundation in a holistic waste management system.

The correlation between technical elements at the top of the HOQ shows a positive relationship between "use of new technology" and other elements such as "separate waste disposal sites" and "inter-agency coordination." This demonstrates that technology cannot stand alone but must be supported by a coordinated operational and regulatory system. Technical targets set in the technology column, such as "new technology implemented in the processing process" and "inspections conducted with the environmental agency," represent a form of quality control and adaptation to the ever-evolving dynamics of pharmaceutical waste.

Overall, the technological dimension serves as a key catalyst in ensuring optimal waste management systems. A technological approach involves more than just equipment procurement; it also involves research. With appropriate and sustainable technology, environmental, social, and economic efforts can be optimally synergized. Therefore, the primary recommendation from this HOQ analysis is to strengthen investment and integration of technological systems across all stages of pharmaceutical waste management, from separation and collection to processing and final recycling.

Economic Dimension

The economic dimension of a pharmaceutical waste management system aims to ensure cost efficiency and optimal resource utilization. In this QFD, the customer requirement of "low waste disposal costs" receives significant attention, with a high importance weight (4.44) and a strong correlation with technical aspects such as "incineration facilities" and "internal recycling." Recycling strategies reduce the volume of waste to be disposed of, thereby reducing recurring operational costs. Furthermore, efficient incineration can minimize the logistical burden and transportation of hazardous waste.

Technical elements such as "board support" also play a role in the allocation of funds and resources. This strong link between the need for low costs and technical elements underscores the importance of managerial support in implementing a sustainable economic system.

Through the QFD approach, the economic dimension is assessed not only in terms of savings but also in terms of efficiency, utility, and added value. The internal recycling strategy, which received the highest relative weighting (16%), demonstrates the effectiveness of this economic approach.

Social Dimension

The social dimension of pharmaceutical waste management highlights the importance of community and worker awareness, as well as environmental cleanliness around healthcare facilities.

In this QFD, needs such as "employee awareness" and " neatness and cleanliness of the environment" are important indicators of social perceptions of the waste management system. These two needs are strongly linked to technical elements such as "government policy," "board of directors' support," and "inter-agency coordination." This demonstrates that the social aspect is highly dependent on structural support and strong institutional coordination.

Government policies play a significant role in establishing operational standards and training programs for employees to foster awareness in handling hazardous waste. The "●" symbol in the "employee awareness" line indicates that active government and management involvement is crucial. Furthermore, inter-agency coordination plays a role in disseminating information and involving the wider community in the waste management process, including through outreach and public education.

Thus, the social approach in QFD reflects the need to build a participatory and transparent system. This will not only improve operational efficiency but also foster a sense of collective responsibility. In a social context, successful waste management is highly dependent on human behavior, and therefore, technical strategies that support increased awareness and collaboration will yield more significant long-term results. Expanding this social dimension will also strengthen the public legitimacy of implemented waste management policies.

CONCLUSION

The results of the House of Quality (HOQ) analysis show that management of waste pharmacy sustainability must be viewed as a system integrated involving aspects of environment, technology, economy, and social aspects simultaneously. From the side environment, needs customer for reducing the impact of dangerous waste can be achieved through the implementation of new technologies, such as MBBR and recycling strategies, and internal re-use, contributing directly to reducing waste volume. The approach technology currently strengthens the efficiency of the processing process, reducing operational costs, and supports the principal economy's sustainability. In addition, supporting managerial and policy government becomes key to investing in technology appropriate to use, executed in a way effective as well as in harmony with efficiency targets, costs, and compliance regulations.

On the other hand, success management waste is not only measured from the technical and economic, but also from the involvement of the community and employees involved in the active in-built system. Awareness social, education public, as well as coordination between agencies, has proven to strengthen the legitimacy management of waste pharmacy at a time to increase a sense of responsibility to answer collectively. Thus, synergy between control impact environment, utilization technology-friendly environment, efficiency economy, and support participatory social creates a holistic environment that not only guards the sustainability ecosystem but also ensures quality life for the public around as well as Power competition company in the long term.

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