SUSTAINABLE
FACILITY LOCATION & FACILITY DESIGN

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A Review of Facility Location and Design Literature in the Context of Sustainability

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Abstract:

Facility location and facility design are crucial aspects of supply chain management, playing a significant role in the overall success and sustainability of supply chain operations. Selecting the location for industrial facilities is a significant decision. Traditionally, it focused on factors like production efficiency, cost-effectiveness, and profit maximization. However, in the present context, beyond these considerations, the choice of an optimal location for industrial units must also incorporate sustainable development criteria. Sustainable development comprises three pillars: social, economic, and environmental. This implies not only assessing the impact on employment and economic aspects but also ensuring environmental responsibility. Striking a balance among these factors is essential for a location that promotes long-term positive outcomes. This research aims to equip decision-makers with the necessary tools to make informed choices aligning with broader environmental and social goals by providing a structured framework, comprehensive insights into sustainable facility location, and practical examples of eco-friendly facility design. Visual aids, such as two figures highlighting key criteria for sustainable locations and principles for eco-friendly facilities, act as practical guides, simplifying the decision-making for creating more sustainable facilities.

Keywords:

Facility location, Facility design, sustainability

1. Introduction

The Council of Logistics Management described logistics management as the efficient handling of moving things from where they start to where they are needed, all to meet customer demand. A key focus within logistics is Supply Chain Management (SCM), which is about planning, doing, and overseeing everything related to moving and storing materials, making products, and delivering them from the supplier to the customer (Simchi-Levi et al., 2008)[i]. To optimize the supply chain, strategic facility location is a pivotal factor. The challenge of facility location has a longstanding history and generally revolves around determining the geographic placement of facilities for a particular organizational entity, like a company (Lujie Chen et al., 2013)[ii]. By strategically positioning key facilities such as manufacturing plants, warehouses, and distribution centers, businesses can achieve significant improvements in overall supply chain efficiency. Once the location of a facility has been determined, the subsequent crucial decision revolves around designing the optimal physical layout. This process entails evaluating the available space and organizing workstations, equipment, and storage to establish the most effective workflow [iii].on the other hand, the success of any project, in addition to time, cost and quality, requires attention to the fourth dimension, namely sustainability. Sustainable development is the type of development that meets the needs of the present generation with out undermining the ability of upcoming generations to fulfil their own needs. (Cowell & Parkinson, 2003) [iv].This paper explores the intricate relationship between facility location and sustainability, investigating criteria for facility location that should be considered to enhance sustainability. The study aims to answer the question: "Which influence does facility location have on sustainability?" Additionally, it delves into how facility design principles can positively contribute to sustainability.

2.Facility Location

A common facility location issue revolves around strategic positioning facilities to either minimize the associated costs or maximize the desirability achieved through their placement. Planners acknowledge the contributions of the geographical economist Thunen in 1826 at the start of the nineteenth century as the initiation of location theory. From the perspective of operations researchers, the origins of location theory trace back to 1929 with the publication of Alfred Weber's book titled""Theory of the Location of Industries" (Weber, 1929) [v] . These efforts laid the groundwork for both descriptive and normative location theories. Over time, numerous researchers and writers have expanded on this subject, resulting in the publication of various handbooks and scientific papers. Descriptive models focus on identifying spatial socio-economic patterns associated with each placement, while normative location theories aim to establish decision-making mathematical models for this objective. The distinctions between normative and descriptive approaches to location theory have persisted, as their objectives continue to differ (Terouhid S.A, et al., 2012) [vi].

One popular area of location problems involves deciding where to place facilities in the context of supply chains. For instance, D.G. Mogale et al., (2018) [vii], presented a novel mathematical model for optimizing the grain silo location-allocation problem in India's food grain supply chain network. The model considered multiple objectives of minimizing total supply chain cost and lead time. It considered various aspects of the supply chain including dwell time, multi-period operations, heterogeneous vehicles, and capacitated silos. Sanggyun Kang (2020) [viii], explored changes in warehouse locations in the Los Angeles area from 1951 to 2016. The study was based on data from over 5,000 warehouses, reveals a decentralization trend, with larger warehouses concentrating in places like San Bernardino. The researcher used discrete choice models to analyze how factors like land prices, market access, and trade node proximity affect location choices based on facility size and construction period. Houtian

Ge et al., (2022) [ix]investigated the challenge of determining optimal locations for facilities in the fresh produce supply chain within the United States. The primary objective of the model was to minimize expenses while adhering to a reliability standard. The model determined facility locations internally by considering production, import, export, and demand data. These efforts highlight a commitment to efficiency and cost reduction in facility placement within supply chains. As researchers continue to tackle challenges, location theory remains a dynamic and crucial aspect of operations research and urban planning.

2.1 Classification of Facility Location Problems

Facility location problems and models can be classified into different methods. There are various types of facility location problems, and some important categories include: Single Facility Location Problem (SFLP): This involves determining the optimal location for a single facility, such as a warehouse or factory. (Sanggyun Kang, 2020) [x]Multi-Facility Location Problem (MFLP): This problem involves determining the optimal locations for multiple facilities within a supply chain network. Fixed Costs Capacitated Facility Location Problem (FC-CFLP): This problem involves determining the optimal locations for facilities considering both the fixed costs associated with each potential location and the capacity constraints of the facilities. Capacitated p-Median Facility Location Problem (CpMFLP): This problem involves determining the optimal locations for facilities to minimize the total distance or cost to serve a given set of customers, subject to capacity constraints. Covering Location Problems (CLP): These problems involve determining the optimal locations for facilities to maximize the coverage of demand within a certain distance or time. Examples include the Symmetrical Total Covering Problem (STCP) and the Maximum Covering Location Problem (MCLP). Undesirable Facility Location Problem (UFLP): This problem involves determining the optimal locations for facilities that are undesirable, such as waste treatment plants or power stations, to minimize their impact on the surrounding areas.[xi]

2.2 Objectives of Facility Location Problems:

In a classification of facility location objectives, with a focus on mathematical programming and based on types of objective functions, three main categories can be highlighted: Drezner. Zvi, (1995-) [xii]Pull objectives: Focus on bringing facilities closer to customers, minimizing distances. Push Objectives: Address undesired facility location problems (UFLP) by maximizing distances between facilities. For example, due to the health and environmental consequences, it may be undesirable to place landfill facilities near waste collection points. Balancing Objectives: Strive for an even distribution of distances between facilities and customers, promoting fairness in service provision.

2.3 Methods for Resolving FLP

Each optimization algorithm strives to acquire the optimal solution within the feasible solution space. Various techniques have been suggested in diverse literature to achieve optimal solutions for Facility Location Problems

(FLP). Here are some commonly employed methods for addressing problems related to facility location:

Table 1: Methods for Resolving FLP

Techniques	references
Branch-and-Bound	Vladimir Beresnev (2013)[xiii], Lionel Dupont (2008) [xiv]
Lagrangian Relaxation Heuristic	Anis Kadri et al (2022) [xv], Igor Litvinchev et al (2013) [xvi], Ali Diabat et al (2015) [xvii]
Constructive and Local Search	Burke et al, (2005) [xviii]
Tabu Search	Abyasi-Sani et al, (2016) [xix]
Particle Swarm Optimization	Burke et al, (2005) [xx]
Large Neighborhood Search	Stefan Voigt et al (2022) [xxi]Yuehui (2022) [xxii], Ozge S (2021) [xxiii]
Ant Colony Optimization and Variants	Merkle, D et al (2005) [xxiv]
Simulated Annealing	Bertimas, D (1993) [xxv]
Genetic Algorithm	Diogo R, et al (2014) [xxvi], A. Rahmani (2014) [xxvii], Mohammad Mahdi Nasiria et al,. (2018) [xxviii]

2.4 Sustainable Facility Location

The scholarly literature exploring the integration of facility location and sustainability is in its early stages but is expanding. (Terouhid et al. (2012) [xxix]. Treitl & Jammernegg (2014) [xxx]assert that the primary catalyst for incorporating environmental sustainability into business operations is the escalating regulations imposed by governments and the increasing environmental consciousness among customers favoring eco-friendly practices. This implies that companies must factor in these considerations when making strategic decisions, such as facility location choices, to remain competitive. Abdul-Rashid, et al., (2017) [xxxi]argue that manufacturing industries should prioritize decisions aimed at enhancing environmental sustainability, including the reduction of CO_2 emissions. Such emissions have detrimental effects on the environment, leading to global warming, alterations in weather patterns, air pollution, and the formation of acidic rain. These effects not only impact human health but also disrupt the balance of ecosystems (International Energy Agency, 2009). Wang, Lai, & Shi (2011) [xxxii]developed a multi-objective optimization model with the goal of addressing environmental issues related to CO_2 emissions from production and distribution services within the supply chain (SC). In 2020, Keivan Tafakkori [xxxiii]introduced an innovative mathematical model for placing sustainable refueling stations in city transportation networks. The model considers various station types and aims to minimize costs, environmental impact, and maximize social welfare. In 2022, S. Umar Sherif [xxxiv]proposed a three-stage method to choose a sustainable location for a battery recycling plant. First, interpretive structural modeling (ISM) identified key sustainability and technical criteria. Second, fuzzy analytic hierarchy process (AHP) determined weights for these criteria. Lastly, fuzzy COMPRAS (COmplex PRoportional ASsessment) was used to assess and pick the best location. This approach was applied to a case study in India, where 18 sub-criteria were identified, with environmental criteria carrying the highest weight. The paper by Ahmadi and Ghezavati (2020) [xxxv]addresses a competitive facility location problem for a new company establishing chain stores in a region with existing competitors. The proposed model integrates sustainability aspects, aiming to maximize profit by capturing market share while considering costs such as location, emissions-related taxes, and customer dissatisfaction. Ali ala and his colleagues [xxxvi]in 2023 proposed a solution approach for the dynamic capacitated facility location problem in mobile renewable energy charging stations (MRECS) with the goal of minimizing costs and environmental emissions. After a comprehensive review of the mentioned articles along with others, it becomes evident that when selecting a facility location with sustainability in mind, certain criteria must be considered. In this regard, the compiled criteria from various literature sources are presented in Figure 1.

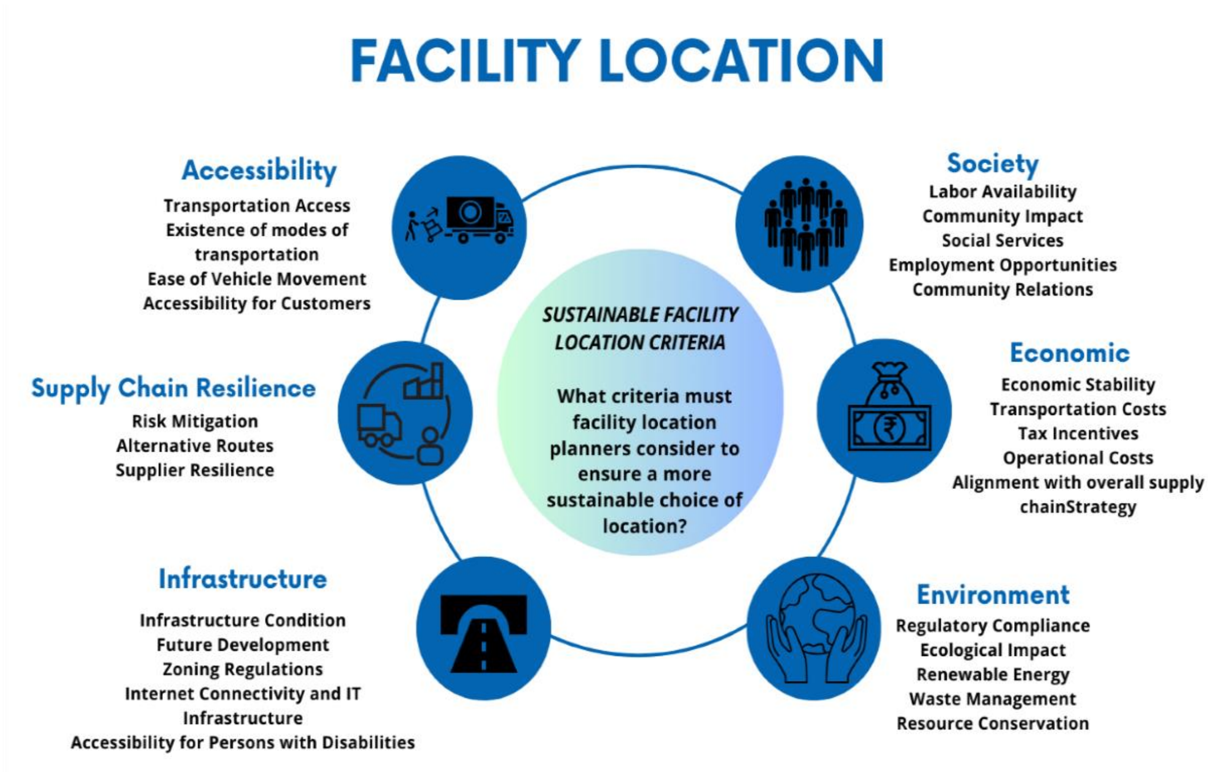

Figure 1. Sustainable Facility Location Criteria

3.Sustainable Facility Design

Sustainable facility design is a comprehensive approach aiming to reduce environmental impact and enhance building performance throughout its life cycle. It prioritizes efficient material use, balancing costs with environmental, societal, and human benefits. J. Paul Guyer (2009) [xxxvii]outlines the following six principles for sustainable design, which encompass maximizing site potential, minimizing non-renewable energy use and waste, selecting environmentally friendly products, conserving water, enhancing indoor air quality, optimizing operational practices, and promoting healthy and productive environments. in 2023 Olakunle Oloruntobi [xxxviii]assessed strategies and technologies that warehouses can implement to reduce pollution and improve sustainability. It analyzed 75 recent research papers on topics like renewable energy usage, smart consumption, and green practices. The review found that warehouse expansion is increasing pollution from construction waste and energy usage. Packaging waste from warehouses accounted for 12% of US municipal solid waste in 2018. The article recommends green certification standards, legislation promoting energy efficiency, sustainable packaging/waste management, and energy-efficient equipment/processes to mitigate environmental impacts.

3.1 Examples of sustainable facility design

As an illustration of sustainable design principles, the Audi factory has implemented various environmentally conscious practices [xxxix]. For example, they have a big man-made lagoon at a high elevation, acting as a water reservoir filled during the six-month rainy season. This water is then treated and used for various processes, helping to save water. The factory also uses renewable energy sources, with solar panels on the roofs of their logistics centers and a geothermal plant providing a significant portion of their heating needs. This geothermal system even helps heat the nearby city of Győr. In addition, the Audi factory in Neckarsulm is careful about recycling. They collect and process aluminum scraps with a focus on keeping the material pure. This ensures that only clean aluminum, without any magnetic metals or foreign substances, is recycled, preventing any loss of quality. Currently, the Neckarsulm plant recycles around 11,500 tons of aluminum scrap each year. As another example IKEA [xl]has introduced its most sustainable warehouse ever built in Kaarst, Germany, with the assistance of Henning Larsen. The store features energy-efficient technologies, natural materials, exterior spaces, and varying daylight, creating a more comfortable and attractive environment for both visitors and employees. These efforts show how factories are working to be environmentally responsible and follow sustainable design principles.

In Figure 2, key principles are outlined that should be taken into consideration to design facilities in a more sustainable manner. These principles serve as essential guidelines for creating facilities that prioritize environmental responsibility, economic efficiency, and social well-being.

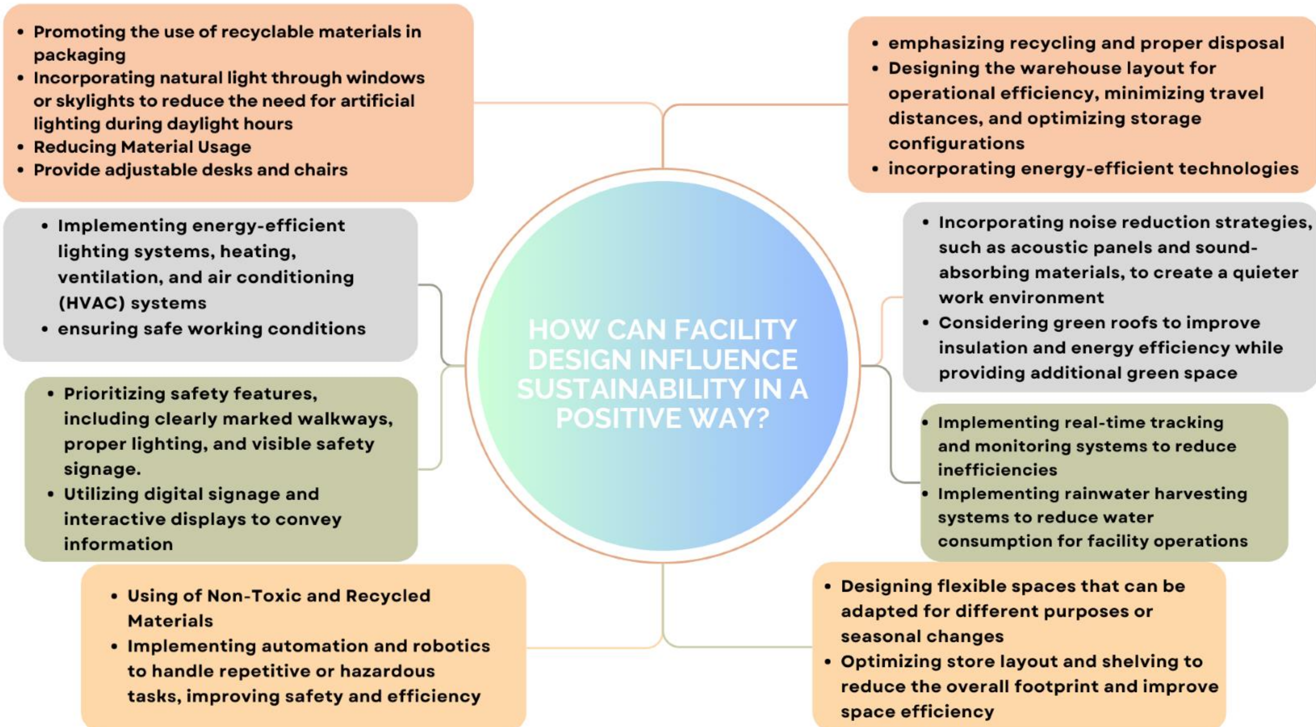

Figure 2. facility design principles

3.3 Essential Steps in Facility Design

The facility design process involves several steps to ensure the effective planning, layout, and construction of a facility that meets its intended purpose. Here are the key steps typically involved in facility design: Identify the Need: Understand the strategic, operational, or functional requirements driving the facility design, considering factors such as capacity, efficiency, safety, and compliance. Conduct a Feasibility Study: Assess the practicality and potential success of the facility design project, considering factors such as cost, technology, and market demand. Develop a Project Plan: Create a comprehensive plan that outlines the project's objectives, scope, performance indicators, evaluation methods, and change control procedures. Design the Facility: Apply engineering principles and standards to create the layout of the facility, including equipment, workstations, offices, and machinery. Construct the Facility: Execute the construction phase based on the approved design and plans, ensuring compliance with regulations and safety standards. Operate and Maintain the Facility: Once the facility is constructed, focus on its ongoing operation and maintenance to ensure its continued effectiveness and safety Additionally, the facility design process typically consists of four phases: conceptual design, preliminary design, detailed design, and final design. In each phase, best practices and standards should be applied, and design decisions, assumptions, calculations, drawings, models, and specifications should be documented in a clear and consistent manner. xli

4. Conclusion

In conclusion, facility location and design are integral components of business operations, with an emphasis on sustainability. While exploration in Chapter 2 provided comprehensive insights into location-related challenges, it is evident that there exists a noticeable gap in research concerning sustainable facility design, presenting a promising avenue for future investigation. Closing this research gap not only offers an opportunity for deeper exploration but also equips businesses with the knowledge to make eco-friendly decisions in shaping the design of their facilities. And future studies can provide valuable insights, tools, and best practices for businesses striving to create facilities that not only meet operational needs but also align with environmental and social sustainability goals.

The identified criteria and principles extracted from available resources emerge as invaluable tools for decision-makers navigating the complex landscape of facility location and design. These criteria and principles, when applied judiciously, empower decision-makers to pinpoint the most sustainable locations and craft eco-conscious designs for facilities, including warehouses, factories, and stores.

Term	Abbreviation
Supply Chain Management	SCM
Facility Location Problems	FLP
Single Facility Location Problem	SFLP
Multi-Facility Location Problem	MFLP
Fixed Costs Capacitated Facility Location Problem	FC-CFLP
Covering Location Problems	CLP
Symmetrical Total Covering Problem	STCP
Maximum Covering Location Problem	MCLP
Undesirable Facility Location Problem	UFLP
interpretive structural modeling	ISM
analytic hierarchy process	AHP
COmplex PRoportional ASsessment	COMPRAS
mobile renewable energy charging stations	MRECS
Capacitated p-Median Facility Location Problem	CpMFLP

Table 2. Abbreviation

Declaration of authorship

I declare that I have authored this thesis independently, that I have not used other than the declared sources / resources, and that I have explicitly marked all content, which has been quoted either literally or by content from the used sources.

Date & Signature

Zahra Alavi 08.01.2024

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