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Sustainable warehouse evaluation with AHPSort traffic light visualization and post-optimal analysis method

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Abstract – Sustainable warehousing is essential for organizations to achieve overall supply chain sustainability. Warehousing facilities have the greatest potential for reducing socio-environmental impact. Yet, both research and practice have given relatively less attention to considering all aspects of sustainability in warehouses. In order to address this gap, this study proposes combining both input from professionals and from a literature survey of triple-bottom-line theory in order to develop a sustainable warehouse criteria framework, thus contributing to sustainable organizational warehouse evaluation. The method supporting the evaluation of this framework is based on the integration of a multicriteria AHPSort-traffic light visualization technique and novel post-optimal analysis. Furthermore, the authors deployed this framework and integrated methodology in an Indian manufacturing company to evaluate and classify seven of their warehouses for decision making. The traffic light visualization technique presents and conveys the results better than numbers. Finally, the post-optimal analysis provides recommendations for efficient improvements. The findings of this study present valuable insights and guidelines for industrial managers and practitioners, especially those from the Indian manufacturing industry, for sustainable warehouse decision-making, and for improving their overall corporate sustainability performance.

***Keywords*:** Decision analysis; Multi-criteria; Supply chain, Sustainability, AHPSort, Post-optimal analysis

1. Introduction

Sustainability, social network research and SC integration research has been evolved over the last ten years (Stolze et al. 2018; Fragoso & Figueira, 2020). Due to increasing pressure from diverse stakeholder groups, including governmental and non-governmental agencies, customers, and employees of organizations, forcing firms to become more sustainable (Govindan et al., 2019; Sarkis, 2018, Kusi-Sarpong and Sarkis, 2019; Gunasekaran et al., 2014; Hosseini-Motlagh et al., 2019), many organizations have started to explicitly consider the triple dimension of sustainability (economic, social, and ecological) in their overall supply chain decisions (Bai, Kusi-Sarpong, Badri Ahmadi, & Sarkis, 2019; Carter & Rogers, 2008; Garetti & Taisch, 2012; P. Rao, 2002; Raut, Narkhede, Gardas, & Raut, 2017). Assessing the potential benefits of environmentally sustainable performance is challenging due to the difficulty of measuring its return on investment (García-Dastugue & Eroglu, 2019). However, it is evident from the literature that sustainable supply chain investment can increase economic performance (Kirchoff, Omar & Fugate, 2016; Hosseini-Motlagh et al., 2019). Organizations that want to achieve sustainability need to minimize tension between different conflicting factors such as short-term profitability and long-term environmental integrity (Xiao et al. 2019). Organizations are eager to fulfil customer demand in a much more effective manner. One way of achieving this goal is to have enough warehouses to hold some amount of inventory to satisfy customer demand. A very important question that confronts managers is how to identify the right warehouse operations which may represent considerable savings for the organizations, both in the medium- and the long-term (Conceição, Pedrosa, Neto, Vinagre, & Wolff, 2012). More precisely, warehouse operational decision making is one of the most important strategic decisions having a direct impact on overall organizational supply chains (Foroozesh, Tavakkoli-Moghaddam, & Mousavi, 2018). Warehousing is one of the most critical functions in supply chains as it accounts for about 24 percent of logistical costs (European Logistics Association and Kearney, 2004).

Just as the literature on warehouse operational decisions has paid relatively less attention to environmental and social aspects in general (e.g. Xu et al., 2020; Wruck et al., 2013), organizations are also reluctant to do so in their warehousing. These organizations consider mostly economics-focused factors such as cost effectiveness and customer satisfaction as the main performance drivers (Neto, Bloemhof-Ruwaard, van Nunen, & van Heck, 2008; Linton, Klassen, & Jayaraman, 2007; Xu et al., 2020; Wruck et al., 2013). It is imperative that these organizations recognize the importance of transitioning from their current economics-based business models to sustainability-based business models (Fahimnia et al., 2015), since considering all aspects of sustainability within their warehouse operations will enhance their competitiveness (Zailani, Jeyaraman, Vengadasan, & Premkumar, 2012). Sustainable warehousing *"is about integrating, balancing and managing the economic, environmental and social inputs and outputs of the warehouse operations"* (Tan, Ahmed, & Sundaram, 2010). Sustainable warehouse management plays a significant part in achieving carbon efficient supply chains (Wu, Jin, Shi, & Shyu, 2017). Even though the basic function of warehouse operations is for the storage and management of goods or raw materials, yet, organizations have to comply with huge numbers of regulations and standards – ranging from the health and safety of employees, to hazardous material handling, to employees' rights – all of which have sustainability implications and consequences for the organizations (Badri Ahmadi, Kusi-Sarpong, & Rezaei, 2017). Ideally, organizations should have an effective checks and balances system in place to enable them adhere to these sustainability standards, and they should have an experienced workforce in place to implement and control such standards (Bai et al., 2019).

Several studies have investigated warehouse or facility operational decision problems considering the traditional business and economic criteria frameworks (Büyüközkan & Uztürk, 2017; Demirel, Demirel, & Kahraman, 2010; Dey, Bairagi, Sarkar, & Sanyal, 2017; Roh, Jang, & Han, 2013; Wutthisirisart, Sir, & Noble, 2015; Drezner & Drezner, 2012). A few other studies have attempted to integrate sustainability into their decisions, (see see Jha, Raut, Gardas, & Raut, 2018; He, Wang, Lin, Zhou, & Zhou, 2017; Ishtiaq, Khan, & Haq, 2018; Jain & Khan, 2017; Khan, Kusi-Sarpong, Arhin, & Kusi-Sarpong, 2018; Rao, Goh, Zhao, & Zheng, 2015; Raut et al., 2017; Uysal & Tosun, 2015). Yet, none of these studies until now, have specifically considered all aspects of sustainability in their decisions and conducted investigations to aid in the classification and improvement of warehouses based on the levels of involvement in sustainability. Tools to support such decisions have also heavily relied on the analytical hierarchal process (AHP), which was developed by Saaty in 1980 (Saaty, 1980), and has since become the most widely used multi-criteria decision-making (MCDM) method. AHP takes both qualitative and quantitative inputs and breaks down complex problems in terms of different levels of hierarchy (Dweiri et al. 2016; Saaty, 1980). In the literature, several applications of AHP can be found, such as supplier selection and procurement planning (Khan, Dweiri, and Jain, 2016; Cheaitou and Khan, 2015); supply chain performance evaluation and knowledge based system development (Rehman et al. 2018; Khan, Chaabane, and Dweiri, 2019); contractor selection (Khan and Hosany , 2016); web based casting supplier assessment (Akarte et al., 2001); and forecasting method selection (Dweiri, Khan, and Jain, 2015). Similarly, it has been applied in many sustainability applications such as in hospital waste management (Ishtiaq, Khan, and Haq, 2018), supplier sustainability performance evaluation (Khan et al. 2018), reverse logistic supplier selection (Jain and Khan, 2017), and sustainable criteria selection for desalination plants (Dweiri, Khan, and Almulla, 2018). To address the current literature and practice gaps, this study proposes a comprehensive sustainable criteria framework based on a combination of literature survey and industrial manager input from a triple-bottom-line perspective supporting sustainable warehouse classification decisions. This study further investigates this framework within manufacturing industry context in India, providing theoretical, practical, and managerial insights to support the decision-making process. The AHPSort-traffic light visualization model is utilized to support the analysis of the framework within the Indian manufacturing industry. A post-optimal analysis follows providing recommendations for improvement. Post-optimal analysis is a new technique, more advanced than traditional sensitivity analysis. Contrary to sensitivity analysis, it does not only vary the scores of alternatives to assess the robustness of the classification, but it also searches for the cost-efficient variation of the scores to upgrade by one level.

This study targets India and its manufacturing industry for some key reasons, some of which are discussed as follows. The country is part of BRICS nations (part of the major emerging economy nations), which are known to have significant influence on regional affairs and are part of the G20 (BBVA Annual Report, 2012). The manufacturing industry happens to be one of the fastest growing industries in India with potential growth/revenue hitting some US$1 trillion in 2025 (Mehta & Rajan, 2017). Unfortunately, this industry's increasing growth does not match that of technological improvement and organizational practice, hence investment has been limited. There is also a need to improve sustainable performance in the Indian manufacturing industry, as growth will be hampered unless considering all aspects of sustainability. An important starting point to achieve this goal is to ensure that warehouse operations are sustainable by introducing sustainable criteria and practices into warehouse decision making. This study aims to help such initiatives.

The objectives of this paper are to:

a) Propose a sustainable criteria framework based on a combination of literature survey and industrial manager inputs and from a triple-bottom-line perspective.

b) Introduce the AHPSort method coupled with a traffic light visualization technique and post-optimal analysis to aid in the evaluation and classification of sustainable warehouses and propose improvements.
c) Evaluate and classify, from an Indian manufacturing company context, levels of sustainability involvement in selected warehouses using the sustainability criteria framework and the integrated method.
d) Provide recommendations on how to improve sustainability from a cost-efficient approach.

The paper makes the following four contributions:

(1) It identifies and develops a multi-level sustainable criteria framework as a theoretical basis and decision-making reference for manufacturing sector sustainable warehouse classification decisions;

(2) It proposes AHPSort method coupled with a traffic light visualization technique as a decision support tool for aiding the evaluation and classification of sustainable warehouses and other facilities;

(3) It develops a novel post-optimal analysis method for recommending cost-efficient improvements.

(4) It applies this methodology using empirical data in the context of the Indian manufacturing sector.

The remainder of the paper is organized as follows: Section 2 provides a brief literature survey of sustainable organizations, warehousing, warehousing sustainability criteria, and MCDM tools for supporting sustainable warehousing decisions. Section 3 describes the methodology composed of the AHPSort-traffic light visualization method and post-optimal analysis. Section 4 presents the case study. Section 5 discusses the results, and finally Section 6 presents the conclusion and some future directions.

2. Literature Background

2.1. Sustainable organization

Over the last decade, the concept of sustainability has gained much attention from both supply chain researchers and practitioners (Badri Ahmadi et al., 2017; Bai, Kusi-Sarpong, & Sarkis, 2017; S Kusi-Sarpong, Varela, Putnik, Ávila, & Agyemang, 2018; Song & Li, 2019). This wave of interest in sustainability by practitioners is a result of the growing awareness of businesses and communities at large of the need to transition their business operations to sustainable business operations (Perrott, 2014; Xing & Dangerfield, 2011). This initiative, however, can be advance through the integration of sustainability concerns into organizational and business operations (Mežinska et al., 2015; Sarkis, 2018). Sustainability has been defined in terms of its economic, social, and environmental dimensions (Carter and Rogers 2008). Therefore, organizations must balance economic activities with social and environmental concerns to achieve sustainability (Badri Ahmadi et al., 2017; Bilbao-Terol et al., 2018). In this way, organizations must manage their operational activities to maximize *economic gains*, improve *stakeholders' wellbeing* and reduce *negative environmental impact* in order to achieve a truly sustainable organization (Gupta et al., 2020).

Yet, organizations will need to demonstrate innovativeness (Orji et al., 2019; Gupta et al., 2020; Ji, & Gunasekaran, 2014) in order to integrate sustainability in their business operations. The organizations pursuing innovation initiatives to enhance sustainability need to introduce new processes, or modify organizational practices, systems, and techniques, to minimize environmental and social impact, and thereby increase competitive advantage (Beise & Rennings, 2005). For example, organizations can develop innovative strategies such as using renewable energy sources to power their warehouses to deal with and enhance sustainability performance in their warehouses (Orji et al., 2019; Cai and Zhou, 2014). Sustainable innovations thus can benefit organizations in several ways, including by reducing costs, and improving the image and profit of the organizations (Aguado et al., 2013). The importance of sustainable innovation in moving to organizational sustainability cannot be underestimated (Kusi-Sarpong at al., 2019). By extension, organizations need to innovate for sustainability in order to enhance their operations performance (Varadarajan, 2017).

2.2. Sustainable Warehousing

Warehousing includes storage, retrieval operations, organizing, material handling equipment, media for the storage of materials, and the necessary building facilities to protect goods (Gunasekaran et al., 1999). A warehouse is therefore an important part of organizational operations (da Silva et al., 2015). This is because it connects the production lines to the customers and plays an important role in delivery performance (Gunasekaran et al., 2001). Therefore, improving the effectiveness of warehouse operations can lead to increased overall organizational performance (Gunasekaran et al., 1999). However, warehouse operations are confronted with numerous sustainability issues and organizations have to make certain critical decisions to address these concerns. Unfortunately, most warehouse decisions have predominately been focused on economic sustainability, such as minimizing costs or maximizing customer service level (Rao et al., 2015). Thus, limited studies have attempted to investigate the sustainability of warehouse operations. With the emphasis on corporate social responsibility and environmental awareness, this goal has grown to include the consideration of other criteria to help address the challenge of current sustainability requirements of warehousing decisions. A wrong sustainable warehouse decision may result in additional costs for the organization, such as fines, while making no impact on the level of customer service (Conceição et al., 2012). Therefore, organizations must not only consider the economic factors, but also social and environmental factors, when ensuring that their warehouse operations and operational environments are not negatively affecting their sustainable supply chain performance (Tan et al., 2010).

While considering sustainability issues in supply chains, previous studies have paid more attention to the investigation of issues such as procurement (Walker and Brammer, 2012), transportation (Schneider, 2013), and manufacturing (Garetti & Taisch, 2012) . Studies that focus explicitly on sustainable warehousing are limited. Supply chain activities in warehouse operations may have severe environmental and social problems with serious economic consequences (Kusi-Sarpong, Sarkis, & Wang, 2016). The negative impact of warehouse facilities and activities has grown exponentially, threatening and increasing the burden on local communities (Yuan, 2018). Organizations must therefore lead in this transition towards sustainable technologies and practices by implementing environmentally sound and socially responsible warehousing operational practices (Abdallah, Diabat, & Simchi-Levi, 2012). Given the importance of addressing a host of environmental and social problems inherent in warehousing operations (Pagell & Shevchenko, 2014), sustainable warehousing is key solution for alleviating the negative sustainability impact and creating beneficial consequences (Zailani et al., 2012).

In addition to traditional economic and business issues, sustainable warehousing decisions consider environmental and social issues when aiming to achieve higher sustainable performance. Indeed, many organizations have focused on the use of energy-efficient systems in their warehouse operations (Meneghetti & Monti, 2013). Marchant, (2010) proposed a three-stage sustainable warehouse model that deals with the business, economic, environmental, and social aspects of warehousing, and attempted to capture a wider range of criteria to aid organizations in achieving minimum negative sustainability impact. In another study, Tan et al., (2010) presented a discussion on the concept of sustainable enterprise simulation models from the perspective of a warehousing and distribution company, explaining the interconnectivity among the various sustainability dimensions in practice. Similarly, Żuchowski, (2015) argued that strategic implementation of sustainable solutions for warehouse management minimizes greenhouse gas emissions and resource consumption and, in the long term, leads to sustainable warehousing.

Overall, most companies' sustainable warehousing decisions contributing to such a transition are principally driven by compliance with regulation. Yet, the lack of understanding of sustainable regulations and its implications on the operations of warehousing could be challenging to achieve the sustainability goal within the warehouse sector.

2.3. Warehousing sustainability criteria

In order to evaluate warehousing operations, many criteria must be taken into consideration. A number of studies have considered different qualitative and quantitative criteria, such as governmental policies and regulations (Dashore & Sohani, 2013; Demirel et al., 2010; Ketikidis, Hayes, Lazuras, Gunasekaran, & Koh, 2012; Luthra, Kumar, Kumar, & Haleem, 2011); climatic conditions (Ashrafzadeh, Rafiei, Isfahani, & Zare, 2012; Dey et al., 2013); technology availability (Amjed & Harrison, 2013; Ashrafzadeh et al., 2012; Karmaker & Saha, 2015); availability of a sustainable skilled workforce (Amjed & Harrison, 2013; Karmaker & Saha, 2015; Luthra et al., 2011; Luthra, Qadri, Garg, & Haleem, 2014); provisions for energy saving (Amjed & Harrison, 2013; Diabat & Govindan, 2011; Dubey, Bag, Ali, & Venkatesh, 2013; González, Sarkis, & Adenso-Díaz, 2008). From the above literature, it is clear that many frameworks for warehouse evaluation have been proposed, but are mostly limited to economic and business criteria, with a few focusing on environmental sustainability. While broader sustainability consideration has begun to emerge (see e.g. Uysal & Tosun, 2015), these frameworks do not examine sustainability concerns. Taking the triple-bottom-line theoretical view, this study introduces a unified and more comprehensive sustainable criteria framework for helping organizations evaluate sustainable warehousing operations.

In this study, through an initial literature survey, we collected and tabulated various criteria pertaining to sustainable warehousing decisions. We then sent this to seven experts (listed in Table 2, in Section 4) for review, validation, and categorization, as either social, economic, or environmental factors, and integration into a single and unified framework to aid the evaluation and classification of sustainable warehousing. This process was reviewed and completed in a group and facilitated by one of the authors via videoconferencing. Table 1 depicts the final list of criteria and their triple-bottom-line categorization as being either social, environmental, or economic, along with a brief description of each criterion according to the expert review group.

Table 1: Sustainability Criteria for Warehouse Evaluation and Classification Decisions

No.	Dimension	Criteria	Brief Description	References
1	Economic	Inventory Costs (IC)	Includes the cost required to hold and maintain the inventory in physical terms, the ordering cost needed to prepare and process the order, and associated labour cost for arranging inspection of the goods.	(Cagliano, Demarco, Rafele, & Volpe, 2011; Gallmann & Belvedere, 2011; Rimiene, 2008)
		Labor Costs (LC)	Cost incurred towards salary or wages of the manpower mobilized for the related work. May be on a daily, weekly, monthly basis, or on the basis of the number of jobs performed. Also includes other benefits and taxes as applicable.	(Cagliano et al., 2011)
		Costs as a % of Sales (CAS)	Direct expense cost involved to generate finished goods. Includes the cost of raw materials, processing, and manpower costs, etc. which are required for the production of goods.	(A, N. Subramanya, & M. Rangaswamy, 2012)
		Maintenance Costs (MC)	Cost required to keep the infrastructure of a factory operational.	(de Marco & Mangano, 2011; Andrew Johnson & McGinnis, 2011; Andy Johnson, Chen, & McGinnis, 2010; E. Johnson, 2008)
		Cost of Land (CoL)	Cost incurred by any company in acquiring the land on which its entire factory is to be established, as well as cost required to ready it for use.	(Ashrafzadeh et al., 2012; Demirel et al., 2010; Glasmeier, 1996; Sivitanidou, 1996;

				Turğut, Taş, Herekoğlu, Tozan, & Vayvay, 2011)
		Overhead Costs (OHC)	Indirect and fixed costs not related to direct manufacturing costs. Includes expenditures incurred on travel, insurance, legal fees, rents, utilities, etc.	(Lambert, Stock, & Ellram, 1998; Tompkins & Smith, 1998)
		Construction Costs (CC)	Cost to company for an entire project involved in construction work for capital improvement.	(Lambert et al., 1998; Tompkins & Smith, 1998)
2	Environmental	Renewable Energy Sources (RES)	Natural sources of energy, such as solar energy. It signifies the quantum of natural sources of energy used by the company	(Marchant, 2010)
		Daylight Usage (DU)	Suggests the utilization of daylight freely available in daytime.	CarbonTrust. (2007)
		Noise pollution (NP)	Noise generated by running of machinery in plants and propagated in the environment. A high level of noise is harmful and treated as noise pollution.	(Gazeley, 2004)
		Recycling Facility (RF)	It refers to the company's available facilities for reusing abandoned material or generated waste.	(NZBCSD, 2003)
		Material Handling Equipment Power Sources (MHEPS)	Defines the company's available equipment or facilities for handling of material and power sources, such as a tipper, forklift, etc.	(Buckley, H. 2006; Department for Transport (DfT), 2006)
		Artificial Lighting Scheme (ALS)	The arrangement for illumination which consumes electricity.	(Carbon Trust, 2007; Marchant, 2010)
		Temperature Control (TC)	The arrangement provided to maintain and control the temperature of concerned space.	(Marchant, 2010)
3	Social	Aisle Design (AD)	Indicates the design and width of walkways in production blocks and other storage areas of the factory.	(Hassan, 2002)
		Work-Life Balance (WLB)	The equilibrium required to balance professional and personal lives.	(Hudson, 2005)
		Shift Roster (SR)	A written message which shows the timing of daily work for a particular working group.	(New Zealand Department of Labor (NZDoL), 2007)
		Driver or Operator Training (DT)	A focused and dedicated training program for operators, drivers, or any other worker for their specific	(Ward *et al.* 2004)

			job, to enhance their knowledge and enable them to perform their work effectively.	
		Occupational Health and Safety (OHS)	The system by which the company monitors employee health and ensures their safety in the workplace. Generally, a dedicated company group or department carries out all the activities related to OHS.	(Kuorinka, Lortie, & Gautreau, 1994; Larsson & Rechnitzer, 1994)
		Picking Processes (PP)	The company's system for finding or extracting products.	(Tomkins 1996)
		Welfare Facilities (WF)	The basic facilities offered to employees, like clean drinking water, meals, toilets, protective equipment, etc., essential in the workplace.	(Australia, S., 2011)
		Emergency Room (ER)	A dedicated space in a particular building or department for employees' case of any emergency.	(Victoria, W, 2008)

This framework was then used in a case study setting to evaluate and classify sustainable warehousing in section 4.

2.4. MCDM methods for supporting Warehouse Decisions

Warehouse sustainability evaluation is a multi-criteria decision-making (MCDM) involving several conflicting criteria and choices requiring adequate methods (Kusi-Sarpong, Sarkis, & Wang, 2016; Aguezzoul, 2014; Orji et al., 2020). Such criteria may be both qualitative and quantitative (Khumawala & Clay Whybark, 2008; Magee et al., 1985). In the literature, several studies have used different MCDM methods for warehouse operations evaluation, such as integrated fuzzy and TOPSIS-SAW-MOORA (Dey, Bairagi, Sarkar, & Sanyal, 2016) AHP –TOPSIS (Özcan, Elebi, & Esnaf, 2011); FAHP (Khan, Dweiri, & Chaabane, 2016); hybrid fuzzy MCDM approach (Dey, Bairagi, Sarkar, & Sanyal, 2013); AHP with hybrid fuzzy and TOPSIS (Karmaker & Saha, 2015); AHP (García et al., 2014; Korpela & Tuominen, 1996). The MCDM methods employed in those studies aid in the evaluation and selection of sustainable warehouses but are unable to assist in classifying sustainable warehouses. For the first time, therefore, this study introduces AHPSort-

Visualization and post-optimal analysis method – an MCDM model for sustainable warehouse evaluation enabling evaluation, classification, and recommendations for improvement.

3. Methodology

3.1. AHPSort-based Traffic Light Visualization method

AHPSort is an extension of AHP (Saaty, 1977) for sorting problems. It was invented in 2012 (Ishizaka, Pearman, & Nemery, 2012), and has since been applied to several case studies (Krejčí & Ishizaka, 2018; Lolli, Ishizaka, & Gamberini, 2014; López & Ishizaka, 2017; Miccoli & Ishizaka, 2017). This section describes the main steps of AHPSort.

First, the problem needs to be structured. In the previous papers, the problem was defined with the goal of the problem, the criteria c_j, j = 1,..., m, and the alternatives a_k k = 1,..., l. In this paper, we structure the problem as a hierarchy, where sub-criteria are added. This allows to be more precise and to identify better the fine performance of the alternatives. As it is a sorting problem, we need also to define the classes $C_i, i=1,...,n$, where n is the number of classes. The classes are ordered and have a label (e.g., excellent, good, medium, bad). These classes need to be defined. This is done generally with local limiting profiles lp_{ij}, which indicate the minimum performance needed for each criterion j to belong to a class C_i. The classification is then performed as described in (Ishizaka, Pearman, & Nemery, 2012).

AHPSort has many advantages, especially from the practical point of view. The decision-maker is asked to conduct pairwise comparisons. This means that the decision-maker focuses on only two elements at the time, which is more precise and less confusing than directly evaluating elements (Millet, 1997; Por and Budescu, 2017). It does not require difficult inputs to elicit on like preference and indifference threshold or technical parameters as in Electre-Tri and ELECTRE-SORT (Almeida-Dias et al., 2010; Ishizaka and Nemery, 2014) and FlowSort (Nemery and Lamboray, 2008).

Moreover, AHPSort requests a redundancy of information which allows to check the consistency of the responses. If the decision-maker is not consistent with the responses to pairwise comparisons, the decision-maker is asked to revise those inputs/responses until consistency is achieved.

To better illustrate the results, this study introduces and integrates the traffic light visualization approach with the AHPSort method. The traffic light method is a visual method to display the classification of the alternatives in relation to the goal, criteria and sub-criteria. It is an effective way to communicate performance information. The indication of performances is done using the three colours of the real traffic lights (red, orange and green). The number of variation of colours can be extended with the number of classes. Good and poor performances can easily be identified, and appropriate action can be taken to improve performances. The traffic light visualization approach is an extension of the AHPSort method and offers a finer understanding of the classification of the alternatives, in this case, the warehouses.

3.2. Post-optimal analysis

Researchers have long recommended using sensitivity analysis after applying MCDM method in order to integrate uncertainties (Saaty, 1980). The aim of the exercise is to determine the stability of the ranking. Barron and Schmidt (1988) proposed a new type of sensitivity analysis, where they determined the minimum weight modification in order that an alternative become equal to or be exceeded by Δ for a specific alternative. They applied it to the additive multi-attribute value method. Wolters and Mareschal (1995) proposed the same analysis for PROMETHEE. Triantaphyllou and Sánchez (1997) searched for the most critical criteria and alternative performances where the smallest change altered the existing ranking for the weighted sum model, the weighted product model, and the analytic hierarchy process. Later, the minimum performance modification for improving the score of an alternative, in order that it be weakly preferred over another, was applied to PROMETHEE and the weighted sum method (Hyde and Maier, 2006; Hyde et al., 2005). Recently, Ciomek et al. (2018) and Kadziński et al. (2016) have proposed a post-factum analysis. It assesses the consequences of different variations for the additive value model. In particular, it quantifies the possible and necessary improvements that need to be made to reach a certain target. Both studies also estimated the potential deterioration that could be afforded, whilst keeping the same target. The same analysis has also been proposed for TOPSIS (Dutta et al., 2019). However, it should be noted that the cost of improving one alternative is not necessarily the same as for another alternative. In this paper, we propose a post-optimal analysis, where the improvement costs of each alternative are taken into account. Our approach is applied on AHPSort, but could also use other sorting or ranking techniques.

The aim of the post-optimal analysis is to identify the minimal improvements on the performances that could upgrade the performance of action a_i, to a higher level. This recommendation should be formulated in order to minimize costs.

Formally, suppose an action a_i is assigned to a class C_j, and action a_i is denoted a_i^+ after the improvement of its performances have been operated, such that:

$$f_j(a_i^+) = f_j(a_i) + \Delta_j^i \quad \forall j \tag{5}$$

where $\Delta_j^i \geq 0$ represents the increase in performance of action a_i on criterion f_j.

In order to be assigned to a better category C_{j-1}, we need to achieve the following condition (2):

$$lp_{j-1} > f(a_i^+) \geq lp_{j-2} \tag{6}$$

In addition, the improvements on the performances of action a_i must generally meet the following two constraints of (3) and (4).

- Performances cannot be decreased:

$$\boldsymbol{f_j(a_i^+) \geq f_j(a_i)} \ \boldsymbol{or}\ \Delta_j^i \geq \boldsymbol{0} \quad \forall \boldsymbol{i, j} \tag{7}$$

- Improvements on performances have an upper limit:

$$\boldsymbol{U_j} \;\geq\; \boldsymbol{f_j(a_i^+)} \;\; \boldsymbol{or} \; \boldsymbol{U_j - f_j(a_i)} \geq \Delta_j^i \geq \mathbf{0} \quad \forall \boldsymbol{i, j} \tag{8}$$

where, U_j is the upper limit on criteria j

Additional feasibility constraints may be added to the model: for example, that some improvements on a precise criterion are not possible.

We are thus searching for the values Δ_j^i such that the generated costs $C(\Delta_j^i)$ are minimum, whilst satisfying the constraints (6), (7), and (8). This problem can be solved with the following mathematical program:

$$\text{Min } \sum_{j=1}^{n} \mathbf{C}(\Delta_j^i) \tag{9}$$

s.t.

$f(a_i^+) \geq lp_{j-2}$

$\Delta_j^i \geq 0$

$U_j \;\geq\; f_j(a_i^+)$

4. Case study

A case study is used to aid in the investigation and classification of the sustainable warehouse. The study uses industrial managers from an Indian manufacturing company. These managers were involved in the evaluation and classification processes of the warehouses based on their involvement levels in all aspects of sustainability. We followed a combination of purposeful and self-selection sampling approaches to choose these companies' respondent managers. We present the details of the Case Study Company and warehouses in sub-section 4.1, and the respondent managers involved in the decision in Table 2**.**

Table 2: Case Company's Respondent Managers involved in the decision

Expert #	Position	Working Experience (in years)
1	Assistant General Manager	33
2	Assistant Engineer	13
3	Senior Engineer	7
4	Assistant Engineer	9
5	Assistant Engineer	3
6	Engineer	6
7	Assistant Engineer	15

4.1 Case problem description – XYZ Company Ltd.

India, the case country for this study, is one of the BRICS nations and is at a relatively immature stage in terms of sustainable development implementation (Mani et al., 2016). The manufacturing sector is especially young with respect to sustainable development (Kusi-Sarpong, Gupta, & Sarkis, 2019; Kusi-Sarpong et. al, 2019).

We now provide an overview of the case company under consideration. The case company, henceforth referred to as XYZ Company Ltd., is an industrial organization dealing in power plant components. XYZ Company Ltd. is a manufacturer of large-size casting and forging components of various types of steel, such as alloy, creep-resistant, and supercritical grade steels. XYZ Company Ltd. is a pioneer company forging ahead to make the heaviest castings and forgings in India. XYZ Company Ltd. produces steel products in the order of 10,000 metric tons (MT) per year. The manpower of XYZ Company Ltd. is around 1500, including top management, working executives and other elements of the workforce. XYZ Company Ltd.'s operational processes starts from engineering to design, manufacture and supply through its labor and well versed with all engineering equipment. It also has strong vendor base throughout the country and ancillary units nearby to its location.

XYZ Company Ltd. has planned to improve its sustainability performance at their warehouses due to series of strike actions both by its employees, because of poor work conditions, and local activists in respond to the negative health and environmental impacts. Since warehouses are mostly located away from the manufacturing points and are closer to customers (Schmitt et al., 2015), XYZ Company Ltd. is keen to identify warehouses with higher performance in all aspects of sustainability to enable them improve their lower-performing warehouses. In doing so, XYZ Company Ltd. has initiated the decision-making process by selecting those warehouses that have received huge complaints from both employees and customers or local activists. XYZ Company Ltd. wants to categorize its existing warehouses in terms of levels of involvement in sustainability. In order to do this, they established four categories, including excellent, good, medium, and bad, to help them identify the levels of involvement and how much effort would be required to improve upon low-performing warehouses.

4.2 Problem structuring

The list of collected criteria from the literature (Table 1) was presented to the company managers (Table 2). They approved all criteria, apart from "Costs as a % of sales" and "Temperature control". They deleted these two criteria because they were not related to them in exact terms: they did not measure costs in terms of sales percentages, and they did not have any mechanism for measuring temperature control. In order to measure cost, they proposed that "cost preorder" be added to the list, as this is their main parameter for measuring the economic viability of their warehouses. Similarly, they also added transportation costs for the same reason. We then asked them to define the limiting profile of the classes. After some discussion between the managers, they agreed on the values shown in Table 3.

Table 3: Limiting profiling

Sustainability Dimension	Criteria	Limiting Profile Excellent	Limiting Profile good	Limiting Profile Medium
Economical	Inventory Costs (IC)	10% of total costs	15% of total costs	20% of total costs

	Labor Costs (LC)	5% of gross sales	8% of gross sales	11% of gross sales
	Maintenance Costs (MC)	8% of manufacturing costs	12% of manufacturing costs	16% of manufacturing costs
	Cost of Land (CoL)	$10/sq ft	$13/sq ft	$16/sq ft
	Overhead Cost (OHC)	20% of COGS	25% of COGS	30% of COGS
	Construction Cost (CC) of reinforced cement concrete (RCC)	$15/sq ft	$17/sq ft	$19/sq ft
	Cost per order (C/O)	$12/pallet	$15/pallet	$18/pallet
	Transportation cost (TC)	7% of total revenue	9% of total revenue	11% of total revenue
Environmental	Renewable Energy Sources (RES)	50% of total energy usage	40% of total energy usage	30% of total energy usage
	Daylight Usage (DU)	90% of WH activities	85% of WH activities	80% of WH activities
	Noise pollution (NP)	55 dB (A)	65 dB (A)	80 dB (A)
	Recycling Facility (RF)	5 facility	4 facility	3 facility
	Material Handling Equipment Power Sources (MHEPS)	50% MHEPS on solar	35% MHEPS on solar	25% MHEPS on solar
	Artificial Lighting Scheme (ALS)	12 footcandles (fc)	18 footcandles (fc)	24 footcandles (fc)
Social	Aisle Design (AD)	Pallet per Sq metre ratio 1	Pallet per Sq metre ratio 1.1	Pallet per Sq metre ratio 1.2
	Work-Life Balance (WLB)	0 late sittings	1 late sitting	2 late sittings
	Shift Roster (SR)	1 night shift/month	2 night shifts/month	3 night shifts/month
	Driver or Operator Training (DT)	4	3	2
	Occupational Health and Safety (OHS)	4 accreditation certificates	3 accreditation certificates	2 accreditation certificates
	Picking Processes (PP)	55% automated processes	45% automated processes	35% automated processes
	Welfare Facilities (WF)	7	6	5
	Emergency Room (ER)	4 fully equipped rooms	3 fully equipped rooms	2 fully equipped rooms

4.3 Criteria weighting.

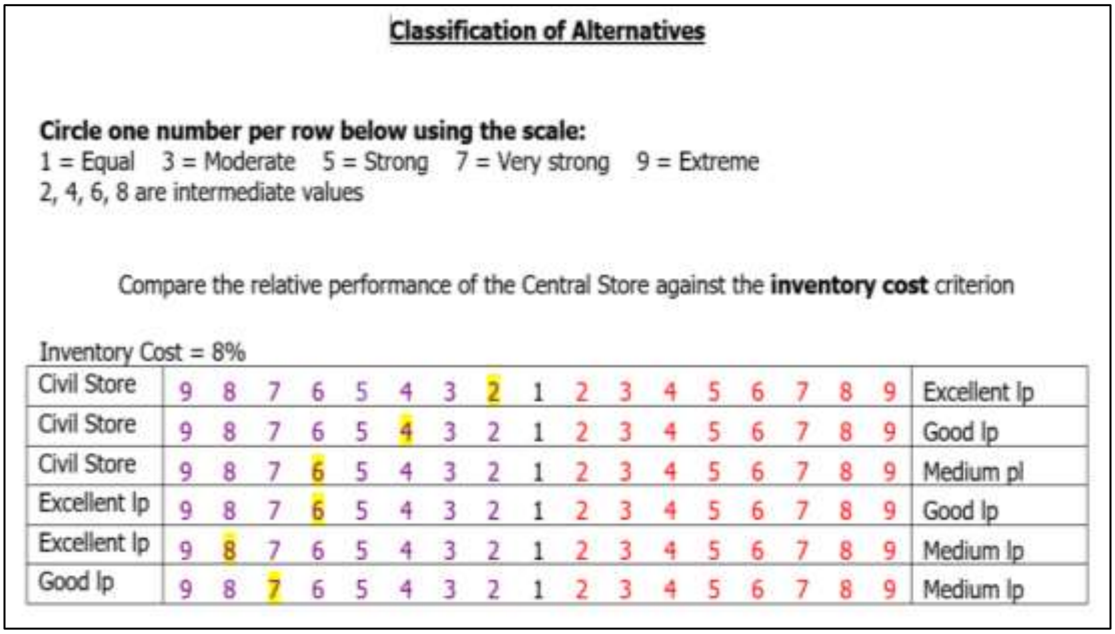
The mangers were asked to evaluate the criteria based on pairwise comparisons. As some matrices were quite large – as in 8x8, inconsistencies were inevitable. To decrease them, we used the Saaty's (2003) interactive method. The least consistent entry is highlighted and the decision-maker is invited to reassess it. This process is repeated with the next inconsistent entry, and so on, until the matrix consistency is below the acceptable consistency threshold of 0.1. The weightings resulting from these comparisons are given in Table 4. The social and environmental dimensions of sustainability seem the most important, with weights measuring more than 80% of total weight. However, the economic dimension contributes to only 16.8% of the overall weight of importance. This shows that the company's experts strongly believe that in order to achieve overall sustainability in their supply chain function, they have to pay more attention to the environmental and social aspects of their warehouse operational decisions.

Table 4: Weightings of the criteria

Sustainability Dimensions	Criteria	Weights
Economic (0.168)	Inventory costs (IC)	0.080
	Labor costs (LC)	0.166
	Maintenance costs (MC)	0.150
	Cost of Land (CoL)	0.090
	Overhead Costs (OHC)	0.123
	Construction Costs (CC)	0.082
	Cost per order (C/O)	0.083
	Transportation costs (TC)	0.225
Environmental (0.349)	Renewable Energy Sources (RES)	0.113
	Daylight Usage (DU)	0.079
	Noise pollution (NP)	0.321
	Recycling Facility (RF)	0.236
	Material Handling Equipment Power Sources (MHEPS)	0.150
	Artificial Lighting Scheme (ALS)	0.101
Social (0.484)	Aisle Design (AD)	0.035
	Work-Life Balance (WLB)	0.091
	Shift Roster (SR)	0.054
	Driver/Operator Training (DT)	0.340
	Occupational Health and Safety (OHS)	0.171
	Picking Processes (PP)	0.147
	Welfare Facilities (WF)	0.129
	Emergency Room (ER)	0.033

4.4 Classification

Each manager was asked to evaluate the warehouses against the limiting profiles (see Figure 1).


Classification of Alternatives

Circle one number per row below using the scale:
1 = Equal 3 = Moderate 5 = Strong 7 = Very strong 9 = Extreme
2, 4, 6, 8 are intermediate values

Compare the relative performance of the Central Store against the **inventory cost** criterion

Inventory Cost = 8%

Civil Store	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Excellent lp
Civil Store	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Good lp
Civil Store	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Medium pl
Excellent lp	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Good lp
Excellent lp	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Medium lp
Good lp	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Medium lp

Figure 1: Extract from the questionnaire

After calculating the priorities with Equation (1) and aggregating them with Equations (2) and (3), we found that most warehouses are classified as "good" with only two as "medium" and these can be found in Table 5.

Table 5: Classification of warehouses

Warehouse	Alternative	Excellent lp	Good lp	Medium lp	class
1	0.289	0.485	0.169	0.057	Good
2	0.216	0.470	0.212	0.101	Good
3	0.281	0.482	0.176	0.060	Good
4	0.284	0.452	0.192	0.071	Good
5	0.188	0.524	0.214	0.074	Medium
6	0.170	0.544	0.216	0.070	Medium
7	0.215	0.518	0.196	0.071	Good

To have a finer understanding of the classification of the warehouses, we used a traffic light approach (Figure 2). This visualization approach provides better feedback. For example, Warehouse 1's excellent economic sub-criteria qualifies as "maintenance cost" because it is well within the defined excellent limiting profile. Similarly, “aisle design” and “picking process” in the warehouse are the excellent social sub-criteria of Warehouse 1, and “artificial lightening system” is the excellent environmental sub-criteria of Warehouse 1. The bad sub-criteria of Warehouse 1 includes economic “cost per order”, social “occupational welfare and health and safety”, and environmental “renewable energy sources” and “recycling facilities”. The same analysis can be done for the other warehouses. This traffic light approach helps managers and decision-makers specifically evaluate the sustainability of each warehouse and put together the necessary improvement strategies and plans.

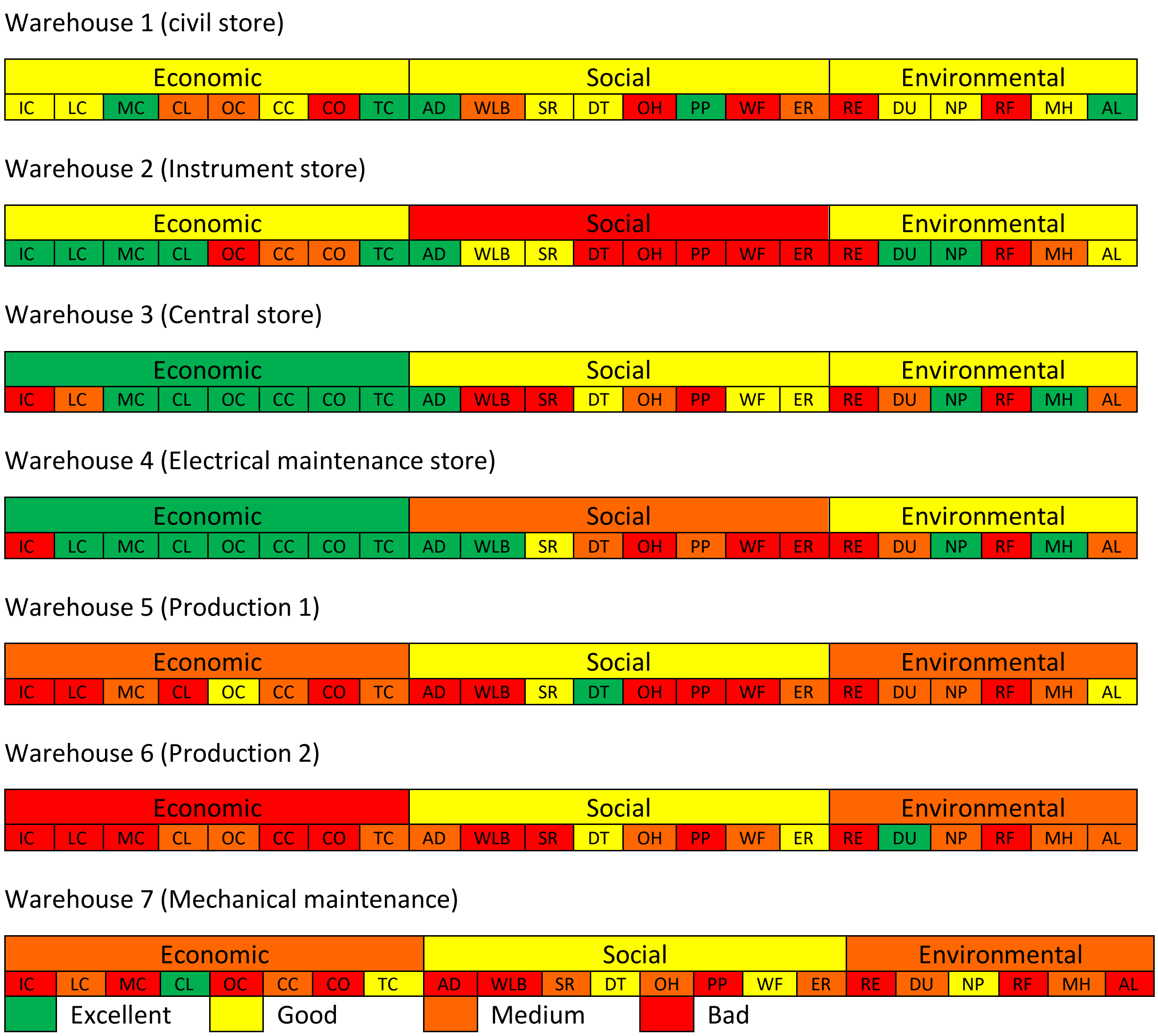


Figure 2: Traffic light classification by criteria of the warehouses

4.5 Post-optimal Analysis

We ran a post-analysis for all warehouses. The goal was to upgrade to the next level. The first step was to ask the general manager of each warehouse (W1-W7) to provide us with the cost of improving the score of each criterion for his warehouse by 1%. As the general manager may not have been aware of all costs, he also met with the finance manager to give a best estimate. As various warehouses store different types of inventory, costs vary accordingly. While the number of employees working in these warehouses may be the same, their cost is different. For example, in Warehouse 1 (civil) and Warehouse 2 (instrumentation), there are significant differences in the cost of handling the material through human intervention, and thus manpower cost is different for these warehouses. This is because the civil store consists of large and heavy items compared to the instrumentation store which, mainly stores small but delicate equipment. Some warehouses, like those of electrical maintenance and production, function around the clock, whereas others, like central and civil warehouses, are open only during the day. Similarly, for different warehouses, their maintenance cost compared to other economic, environmental, and social factors vary according to the nature and use of each warehouse. Therefore, the cost of improving the warehouse also varies according to the nature, size, and functioning of its stock. Table 6 presents an estimate of such costs. It may be noted that four criteria cannot be improved in the current situation.

Table 6: Cost of improving 1% of sustainable performance

No	Criteria	Cost of improvement						
		W1	W2	W3	W4	W5	W6	W7
1	Inventory Cost	$180	$50	$450	$120	$250	$325	$180
2	Labour Cost	$2	$1	$5	$1	$3	$4	$2
3	Maintenance Cost	$24	$12	$32	$30	$50	$55	$28
4	Cost of Land	No cost as it will be same land						
5	Overhead Cost	$32	$12	$14	$20	$40	$46	$20
6	Construction Cost	$12	$11	$14	$14	$18	$21	$10
7	Cost per Order	$8	$6	$15	$10	$17	$18	$11
8	Transportation Cost	$4	$2	$4	$2	$6	$7	$4
9	Renewable Energy Sources	$220	$60	$650	$400	$500	$502	$280
10	Daylight Usage	$15	$23	$45	$25	$35	$36	$25
11	Noise Pollution	$1,50	$1	$7	$2	$3,50	$3,55	$2
12	Recycling Facility	$135	$80	$450	$130	$300	$305	$200
13	Material Handling Equipment Power Sources	$65	$30	$150	$70	$100	$99	$45
14	Artificial Lighting Scheme	$2	$2	$25	$2	$5	$6	$4
15	Aisles Design	Not able to change the aisle design						
16	Work-Life Balance	Not able to improve						
17	Shift Roster	$240	$230	$220	$200	$450	$445	$200
18	Driver/Operator Training	$2	$2	$7	$4	$9	$8	$5
19	Occupational Health and Safety	Not able to improve						
20	Picking Processes	$2	$2	$6	$3	$4	$5	$2
21	Welfare Facilities	$45	$70	$46	$55	$90	$93	$52
22	Emergency Room	$12	$15	$30	$20	$25	$22	$13

The post-analysis improvement is calculated with the mathematical program of Equation (9). Where it is not possible to improve criteria, we use very large costs.

Table gives the optimal improvements. It may be noted that some criteria do not contribute to optimal improvement of the warehouse: renewable energy sources, recycling facility, material equipment handling, power sources, and the shift roster. This is not surprising, as they are the most expensive criteria to improve (Table 6). The highest improvement effort lies in the costs of labour, noise pollution, and picking processes, which are cheap to improve (Table 6).

Table 7: Optimal percentage improvements (cost reduction)

No.	Criteria	W1	W2	W3	W4	W5	W6	W7
1	Inventory Costs	0 %	0 %	0 %	0 %	166 %	0 %	0 %
2	Labour Costs	215 %	36 %	749 %	55 %	190 %	626 %	999 %
3	Maintenance Costs	0 %	21 %	0 %	0 %	26 %	0 %	2800 %
4	Cost of Land	-	-	-	-	-	-	-
5	Overhead Costs	0 %	121 %	0 %	0 %	3 %	0 %	220 %
6	Construction Costs	0 %	32 %	0 %	0 %	202 %	89 %	73 %
7	Costs per Order	0 %	38 %	0 %	0 %	33 %	156 %	764 %
8	Transportation Costs	0 %	57 %	7 %	9 %	0 %	168 %	170 %
9	Renewable Energy Sources	0 %	0 %	0 %	0 %	0 %	0 %	0
10	Daylight Usage	0 %	11 %	222 %	0 %	0 %	0 %	169 %
11	Noise Pollution	178 %	87 %	50 %	51 %	89 %	391 %	165 %
12	Recycling Facility	0 %	0 %	0 %	0 %	0 %	0 %	0 %
13	Material Handling Equipment Power Sources	0 %	0 %	0 %	0 %	0 %	0 %	0 %
14	Artificial Lighting Scheme	0 %	33 %	314 %	399 %	7 %	194 %	1454 %
15	Aisle Design	-	-	-	-	-	-	-
16	Work-Life Balance	-	-	-	-	-	-	-
17	Shift Roster	0 %	0 %	0 %	0 %	0 %	0 %	0 %
18	Driver/Operator Training	167 %	1150 %	225 %	0 %	54 %	0 %	180 %
19	Occupational Health and Safety	-	-	-	-	-	-	-
20	Picking Processes	78 %	435 %	235 %	109 %	173 %	362 %	259 %
21	Welfare Facilities	0 %	88 %	0 %	0 %	3 %	0 %	0 %
22	Emergency Room	0 %	18 %	19 %	0 %	0 %	0 %	0 %

5. Discussion and Practical Implications

The study's proposed methodology (AHPSort-traffic light visualization with post-optimal analysis) is general in nature and can be implemented in any company by changing the identified criteria. In the case of XYZ Company Ltd. in this study, experts and decision-makers validated the criteria categorized from the literature review from a triple-bottom-line perspective to propose a sustainable criteria framework. This framework, together with the AHPSort-traffic light visualization method, was utilized in XYZ Company Ltd. to evaluate and classify their seven warehouses. The traffic light approach, as mentioned in Figure 2, shows the classification of the warehouses tudied in terms of economic, environmental, and social impact. The most economical warehouses are Warehouses 3 and 4, since almost all their sub-criteria are well within the range as defined by the decision-makers. Similarly, Warehouse 6 is bad, or not economical, since all its sub-criteria are in the bad and medium ranges as defined by the experts. Environmentally, warehouses 1, 2, 3, and 4 are good. Warehouses 5, 6, and 7, however, qualify environmentally as medium. Lastly, in terms of social practices, Warehouses 1, 5, 6, and 7 perform well socially, while Warehouse 2 performs worst. In terms of overall sustainability (Table 5), Warehouses 1, 2, 3, 4, and 7 qualify as "good" warehouses, whereas warehouses 5 and 6 qualify as medium warehouses. This classification of warehouses using the proposed framework will help managers and decision-makers strategize to achieve more sustainable warehouse operations. This will also help them categorize the warehouses in terms of all dimensions of sustainability. Post-optimal analysis indicates where significant cost savings already exist, and guides the case company as to what can be improved.

The proposed framework was used in collaboration with the AHPSort-traffic light visualization technique and post-optimal analysis to aid the managerial decision-making process for categorizing warehouses and providing areas for improvement. Overall, the managers and decision-makers now have a clear vision of the sustainability of their warehouses. This will enable them to adopt best practices in the operations of their low-sustainability warehouses to then improve and achieve greater sustainability performance. Moreover, a long-term improvement plan such as transitioning from the consumption of non-renewable to renewable resources (Zailani et al., 2012) will help them achieve excellence in all warehouses. The proposed framework will also help them classify their warehouses in terms of sustainable investment levels. The traffic light approach to warehouse classification will provide the decision-makers with an overview, and indicate performance in terms of excellent, good, medium, and bad. Finally, the post-optimal analysis results will provide them with indications about where to improve.

6. Conclusion and Future Research

In order to achieve sustainability in their businesses and operations, companies need to transition from traditional ways of doing business to more sustainable ones. Warehouse operations have enjoyed only limited attention in terms of sustainability transitioning. However, warehousing is a major contributor to increasing greenhouse emissions in supply chains (Bartolini, Bottani, and Grosse, 2019). This means that warehousing is one of the major functions of supply chains that needs greater attention when focusing on sustainability in supply chain operations. This study attempted to address this research gap by proposing and evaluating a sustainable criteria framework for warehousing operations in a case company, referred to as XYZ Company Ltd., and based in India. The evaluation was aided by AHPSort traffic light visualization and post-optimal analysis method. The result in Table 5 shows Warehouses 1, 2, 3, 4, and 7 are classified as "good" warehouses whereas Warehouses 6 and 7 are classified as "medium" warehouses in terms of overall sustainability. The post-optimal analysis results indicated certain cost-efficient areas. It also indicated where warehouses require further sustainability strategies to aid in transitioning towards excellence in warehouse performance.

The results of the study are not without limitation, which serve as fertile ground for further research. Future studies can benefit from our proposed framework in the following ways:

- The warehouse sustainability dimensions criteria were identified in the literature review and validated by the case company managers. However, a survey from different companies within a similar sector could be perform to validate the criteria.

- The case company managers set the (limiting) criteria for the profiles. However, a survey of different companies in a similar sector could be performed to validate this limiting profile.
- We implemented our framework in a power plant components company. However, in order to achieve external validity, we would recommend implementing it in other manufacturing or service sectors after slight modifications.

As can be seen, even though this study provides some significant contributions to the academic literature and practice, it sets the stage for additional work on this important sustainable development topic.

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