A MODEL FOR SUSTAINABLE WAREHOUSING: FROM THEORY TO BEST PRACTICES

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ABSTRACT

Sustainable Warehousing has tremendous potential to achieve goals of sustainable development but it is not well-researched for its impact on environmental, social and economic dimensions of sustainability. The authors have examined both academic literature and industry publications to extract high level constructs and operational elements for a sustainable warehouse. Content analysis was used to identify and develop sustainable warehousing themes which were then rigorously tested against industry standards to ensure their validity and reliability. These constructs and elements led to the development of a 'sustainable warehousing model' that is then translated into best practices to achieve environmental quality, social well-being and economic value in a warehouse.

Keywords: Sustainability, Warehousing, Content Analysis, Best Practices

INTRODUCTION

Sustainability has appeared as a "new religion" on the world stage and considered as "panacea for all evils". Firms are hard-pressed by the mandate of sustainability from Governments, general public, social workers, environmentalists, employees and above all customers and consumers. They demand transparency about the conditions under which products are manufactured and distributed. They are aware that it is not only the final product but the entire value creation [77] process that needs to be scrutinized).In addition, immense pressure exerted by mass media and environmental legislation (like EU law) has posed multiple new challenges to organizations such as human rights and workers' safety, reduction in carbon footprint and cost maintenance in wake of financial crisis [81].Thus, in order to remain competitive in an increasing socially responsible world, companies are now aiming to impart the concept of sustainability in their supply chains. Researchers are also of the view that the goal of sustainable development, outlined by the Brundtland Commission [14], can only be realised if appropriate and timely initiatives are taken along the supply chain of a firm [36] [61].

Sustainability, which is defined by Elkington [26] as 'the principle of ensuring that our actions today do not limit the range of economic, social and environmental options open to future generations', needs to be ingrained in each stage of supply chain such as planning, procurement, production, warehousing, transportation and reverse logistics. Seuring and Sarkis [77] defined sustainable supply chain management as 'the management of material *and information flows as well as cooperation among companies along the supply chain while taking goals from all three dimensions of sustainable development, i.e., economic, environmental and social, and stakeholder requirements into account'.* Within Supply Chain literature, researchers have separately investigated various environmental, social and economic issues such as the impact of corporate logistics management on the environment [60]; economic benefits of green supply chain [71, p. 912]; impact of long-distance sourcing [31], just-in-time replenishment [70] and inventory centralization [51] on environment; hiring and promotion issues among logistics personnel [48]; environmental criteria for supplier selection [57]; and use of life cycle analysis (LCA) to assess environmental impacts on supply chains [12] [28]. More recently, work by Carter and Jennings [17] [18] interconnected concepts of environment, safety, human rights, community, diversity and philanthropy into broader constructs of logistics social responsibility (LSR) and purchasing social responsibility (PSR). Also, Carter and Rogers [19] developed a conceptual high level framework for sustainable supply chain management that takes into consideration all the three dimensions of sustainability but other than that sustainable supply chain management is usually considered equivalent to green supply chain management (GSCM). Thus foundation work is required to chalk out sustainability criteria for each stage of the supply chain and to operationalize it at both functional and strategic level.

This paper will focus on 'warehousing' which has received comparatively less attention from researchers but holds tremendous potential to achieve the goals of sustainable development. The Transport and Logistics Industry Skills Council Australia [47] in a recent survey reported that *"...companies are still coming to terms with the question of sustainability. Warehousing facilities have the largest potential in terms of reducing environmental impacts…".*

The above discussion leads to following research questions (RQ):

RQI: How can sustainability be applied to warehousing?

RQII: What are basic constructs and elements of sustainable warehousing?

RQIII: How could sustainability be operationalized for warehouses?

These questions are answered in this paper by developing a theoretical model for sustainable warehousing (SWH). It is based on constructs and elements that are extracted mainly from academic literature and industry publications through rigorous content analysis. These are further used for outlining best practices that could be used for operationalizing sustainability in warehouses. The remainder of this paper will mainly focus on important developments in warehousing, methodology, SWH constructs and elements, SWH model, best practices and finally the conclusion.

SUSTAINABLE WAREHOUSING

When it comes to understanding and alleviating sustainability issues (such as carbon footprints or energy intensity) in logistics, most attention is usually given to transportation. Warehousing (or storage) has comparatively received less consideration from researchers and practitioners. However, it has been a victim of 'green wash' and decorated with titles of green-warehousing or eco-warehousing and the practices that are required to achieve such aspirations are hard to find. This paper will make an effort to fill this gap. It will delineate various best practices (actions or guidelines) for each warehouse construct that could be adopted by logistics firms and managers in order to improve their warehouse sustainability performance.

Latest developments in warehousing

Warehousing is one of the most critical functions in a supply chain as it accounts for 24 percent of logistical costs [27]. Chopra and Meindl [20] defined warehousing as the storage of materials (packaging, finished goods and raw materials) at different stages of the supply chain. A warehouse, also referred to as distribution centre, storage facility and logistics service centre, is used for variety of functions ranging from product distribution, cross-docking and composite storage. Thus it has a wider intensive role based on the provision of many value-adding operations, customization services and rapid fulfilment of customer orders [6].

Warehouses are usually merged with buildings, offices and factories for the purpose of reporting and statistical analysis. The World Resources Institute [88] estimated that on a global scale, commercial buildings emit 5.25 percent of all greenhouse gases (GHG) and 65 percent of this come from energy consumption (such as electricity). Gazeley [33] suggested through life cycle analysis (LCA) that 65-90 percent of energy consumption in a warehouse is due to heating, ventilation and air conditioning (HVAC). Recently, the area occupied by warehouses has tremendously increased and more significantly the duration of operations, size and level of throughput are also rising steeply. This has resulted from changes in corporate strategies to centralize inventories and to serve more geographic area for business expansion [53]. Consequently, the average floor area of warehouses has increased from 19,000 m^2 in 1996 to 34,000 m^2 by 2008 [80]. Also, to reduce response time to customer orders, distribution centres and cross-docking facilities are now usually located near to delivery points, around residential areas and city centres, as compared to supply sites [41].

The increase in capital investment has pushed the management for faster paybacks, which is usually achieved by working more shifts and days per week [7]. As a result, the unit fixed cost is reduced but consumption of energy has increased. It is quite evident that that the strategy to decrease total number of warehouses and concentrate on just a few, by expanding their capacity, size and operational timings, would lead to more vehicles visiting the sites for inbound supplies and outbound deliveries. As many of these sites are near urban centres, more congestion and noise pollution become unavoidable. Also, as more employees are required to perform the job, parking areas and onsite facilities need to be properly planned. In addition, postponement used in agile and adaptive supply chain strategies transfer many value adding activities including labelling, final assembly, and packing of promotional items from manufacturing to warehouses.

This results in greater product differentiation and reduced order lead times thereby further embellishing the role of the warehouse in a supply chain.

The above discussion shows the diversity of areas affected by warehouse operations. On one hand, there are firm-level inputs related to energy, land, water, fuel and building, and on the other hand, the outputs of operations not only impact the firm but also the local environment and society in the form of atmospheric emissions, waste, congestion, noise pollution, accidents, water contamination, burden on public transport etc. This discussion clearly highlights that warehousing holds tremendous potential for achieving goals of sustainable development.

Methodology

Many researchers have pointed out the need for the development of more concrete theoretical basis for supply chain concepts [44] [56] [55]. This need is more desperately felt in the domain of sustainable supply chain management. This research paper makes an effort in this direction and develops a model for sustainable warehousing which is translated into a set of best practices.

SUSTAINABILITY THEMES

Development of sustainability themes

Initially, high-level sustainability frameworks such as Natural Capitalism, Cradle-to-Cradle, biomimicry, Life Cycle Analysis, Total Beauty, Sustainability Helix and The Natural Step were thoroughly studied to identify the key sustainability themes that could provide a reasoned direction to the review and exploration of warehousing literature. All the frameworks were found to be quite diverse in terms of their application, strengths and weaknesses. However, they mostly focused on the same three sustainability dimensions – environment, social and economic. The jargon used might have been different but numerous common areas of focus were easily evident through development of codes in *NVivo* software. Nodes (material containers) were developed through broad brush coding, word frequency query, tree maps, tag clouds[1] and close analysis of material. Data was extracted from the frameworks one after another until 'saturation' was achieved and no new nodes could be created. Both linguistic and interpretive approaches were considered in data collection and synthesis [4] [11]. The 'high-level sustainability themes' that were derived include ecosystem services, reduction of toxic materials, less energy for heating, efficient use of capital, waste reduction, recycling, renewable energy, eco-effective materials, worker/employee well-being, social fairness, corporate ethics, material reutilization, hazardous emissions, etc.

Development of sustainable warehousing themes

The inductive approach used for this thematic content analysis [73] emerged from Grounded Theory [34]. Themes were developed to determine areas that need to be focused for establishing and running a best-in-class warehouse. The purpose was to use them as a pre-requisite or baseline for a sustainable warehouse. These were further expanded by combining them with the 'high-level sustainability themes' identified earlier. This helped to narrow down the keyword

[1] Please refer to Addendum for brief description of NVivo, nodes, broad brush coding, tag clouds etc.

search in warehousing literature for syntactic and semantic analysis. Free nodes[2] were developed initially that grew into tree nodes[2] which were later refined and categorized into eight sustainable warehousing (SWH) constructs. Mainly supply chain literature, industry publications, white papers, online magazines, books and benchmarking reports were used for analysis. This was an iterative process and resulted in the following constructs for a sustainable warehouse. Each construct has various elements that are briefly discussed later in this paper.

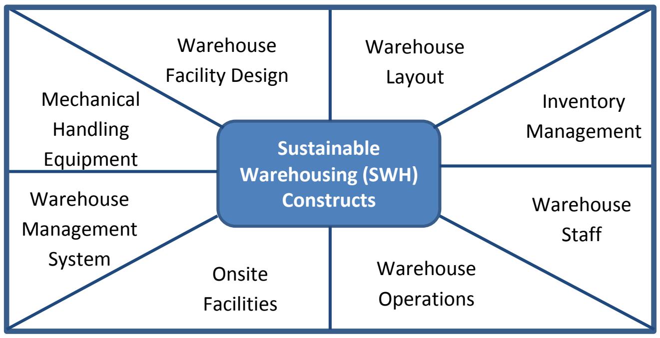

Figure1: Sustainable Warehousing (SWH) Constructs

The conceptualization of data was based on 'constant review and comparison' from one stage of analysis to another. The relationships between meta-constructs, constructs and elements were constantly compared with one another and with academic and professional literature until theoretical saturation was achieved. This was a non-linear and highly iterative process and can be generally outlined as follows:

- Creation of free nodes (open coding)
- Selection of emergent themes based on thematic analysis of sustainability frameworks
- Coding (using emergent theme) or arranging data into categories
- Enhancement of coding structure/hierarchy
- Clustering of codes/nodes to form analytical taxonomies
- Identification of key sustainable warehousing constructs and elements
- Evidence hunting to determine impact of elements on dimensions of sustainability
- Testing against GRI indicators and corporate sustainability reports

RESEARCH DESIGN

Reliability and validity of research

Concepts of reliability and validity are now increasingly used in qualitative analysis. Anderson [2] mentions that, in qualitative research, "validity relates to the honesty and genuineness of the research data, while reliability relates to the reproducibility and stability of the data". In order to ensure validity of constructs and elements, triangulation is used. Altrichter et al. [1] states that triangulation "gives a more detailed and balanced picture of the situation." According to O'Donoghue [66], triangulation is a "method of cross-checking data from multiple sources to search for regularities in the research data."The results (sustainable warehousing constructs/elements) were compared with Global Reporting Initiative [35] that is the most

[2] Please refer to Addendum for brief description of Free nodes and Tree nodes

prevalent industry standard for sustainability. It is inherently operational in nature and outlines key indicators to measure each dimension of sustainability. It is currently used by about 5,000 companies worldwide. Thus 'data triangulation' was applied which revealed contradictions and spurred further analysis, coding, and re-coding of data. Some constructs and elements were added, modified or even deleted after thorough analysis. Literature was thoroughly examined to find evidence in order to support these decisions.

In addition, results were tested against the 'annual sustainability reports' of top 10 firms in the food sector to ensure reliability. These firms were selected by Sustainable Asset Management (SAM) – a company that focuses sustainability investments and collaborated with Dow Jones in 1999 to launch Dow Jones Sustainability Indexes. SAM uses its extremely reliable set of criteria and ensures a thorough review of environmental, social and economic performance of firms. Again 'constant review and comparison' was done in order to develop reliable constructs and elements for sustainable warehousing model.

Scope of the research

The content analysis clearly showed that all major constructs of 'sustainable warehousing', shown in figure 1, are vast areas of research within themselves. For example, the construct 'facility design' is an extensively researched domain and several key experts have contributed to it in the last four decades such as [30] [59] [67] [39] [75]. They have elucidated the design process, outlined steps, identified inter-relationships among various design activities and debated on optimal solutions and trade-offs. The domain has matured and evolved into several sub-domains. Thus various technical details pertinent to building design, lighting, thermal materials and building architecture are left to the experts of those sub-domains [84]. However, the advantages and disadvantages of different operational strategies and the application of life cycle assessment (LCA) tool have not been discussed [85]. Moreover, this paper will neither try to establish techniques for social or environmental assessment nor develop a list of key performance indicators (KPIs) or metrics for a sustainable warehouse. It will not tackle problems related to various warehouse concepts such as zone picking, cross-docking, storage location assignment, unit-load replenishments, level of automation, optimal storage and handling equipment, operational policies etc. Its scope is restricted to the development of major themes (or constructs) and identification of important elements for each theme. Moreover, the evidence related to the 'primary impact' of elements on each dimension of sustainability is extracted through content analysis. The model for sustainable warehousing is grounded in concrete empirical research rather than constructed in an abstract manner. Finally the constructs, elements and the model are used to outline best practices that could be used for operationalizing sustainability in warehouses.

SUSTAINABLE WAREHOUSING CONSTRUCTS AND ELEMENTS

The content analysis revealed eight major warehouse constructs, namely warehouse facility design, warehouse layout, inventory management, mechanical handling equipment (MHE), warehouse staff, warehouse operations, onsite facilities and warehouse management system (WMS). The elements of each construct are briefly discussed and their **"primary impact"** on various dimensions of sustainability is represented in corresponding tables.

Warehouse Facility Design

Warehouse facility design is an extensive domain of research in itself. Discussion in this paper is limited to critical sustainability elements related to the design and structure of 'warehouse building and site'. These can be considered during development of a new facility or while renovating an existing structure. Consultants can also be hired in order to obtain expert opinion. Saunders [76] reported a number of organizations that provide consultancy and assessment services such as BREEAM (Building Research Establishment Environmental Assessment Method) in UK, GREENSTAR in Australia, and LEED (Leadership in Energy and Environment Design) in US. ***Sustainability elements*** for facility design are discussed below:

- ***Renewable energy sources:*** This element dictates that efficient energy consumption must be ingrained in the entire warehouse facility. Energy costs are usually 5-10 percent (ambient warehouses) and 15-20 percent (temperature-controlled warehouses) of operational expenses. It is one of the major inputs, other than materials and water, and has a direct impact on both environment and operating costs. Currently, major energy inputs are oil, gas, coal and electricity and they all produce greenhouse gas emissions (GHG) such as CO_2, CH_4, N_2O etc. Every effort should be made to use renewable energy sources such as solar thermal, solar photovoltaic, wind, biofuels, biomass (wood chips or other waste), geothermal resources and energy recovered from process waste (such as heat from air compressors etc.). Also biodiesel and natural gas, which are low carbon alternatives, can also be used. The choice and mix of renewable energy source should be made prudently keeping into consideration market factors, operational cost and regulatory compliance [52].

- ***Daylight usage:*** The warehouse facility must allow maximum use of daylight. It depends on numerous elements such as building height and orientation, aisle width, daylight hours etc. Entry points for daylight are usually windows, entrances and spaces in roofs. Their number and placement need to be determined carefully keeping in view the weather conditions and landscape of the locality. In addition, walls and ceilings with light colour also help to distribute sunlight. The combination of natural and artificial sunlight is also very critical. The artificial light should be dimmed appropriately according to the intensity of sunlight which may be different for different sections of the warehouse [16]. Thus proper mechanisms and daylight management techniques need to be adopted. An optimal use of daylight would not only reduce utility bills but would also decrease considerable GHG emissions.

- ***Artificial lighting scheme:*** It is one of the most important determinants of sustainability, although not much discussed for its impacts but comes out very strongly from content analysis. Recent research has shown that it not only helps to reduce emissions and bills but also has a strong impact on the productivity of the staff. Poor lighting scheme results in impaired visibility that leads to low productivity, as about 80 percent of the sensory input comes through eyes. Good quality of light is also proved to positively impact the mood and alertness of staff and this can considerably reduce accidents in a warehouse. It helps to maintain an ideal level of hormones (cortisol, melatonin and serotonin) which trigger alertness, reduce sleep and increase happiness [16]. The impact of lighting scheme on environment can be imagined from recent figures by Powerboss Eluma [52] that a 400 watt sodium bulb operated continuously for a year produces 1.69 tonnes of CO_2. Therefore, choice of luminaries, lamp type and control gear for office space, main halls and car-parks should be made wisely. In addition, proper control mechanisms can also help to reduce utility bills. Manual switches can be combined with automatic controls such as motion and light sensors. In short, thorough analysis should be done to determine lighting requirements of different areas in a warehouse facility (internally and externally) by considering peak and off-peak hours, amount of daylight available, nature of job done and even the age of the staff working in a particular area.

- ***Temperature control:*** Warehouse temperature needs to be controlled mainly to keep the products in a satisfactory condition. It is a priority in every warehouse guideline and appears frequently in the text. Statistical figures related to its impact on environment are quite hard to find but surely reduction in temperature would help to conserve both energy and environment. According to [15] 1^0C decrease in internal warehouse temperature results in 10 percent energy consumption savings which would automatically lead to decrease in emissions. Marchant [52] pointed out that the internal warehouse temperature depends on the type of the product stocked, humidity, weather conditions, orientation of the warehouse facility, type of insulation used in walls, volume and thermal mass of the facility and heat produced by operating mechanical handling equipment such as forklift trucks etc. Thus if any of these factors could be controlled then huge economic and environmental saving could be attained.

- ***Water consumption:*** The global figures of water consumption by warehousing facilities are not available. However, digging into text and data available through Elsevier and Emerald revealed few studies done by Greater Vancouver Regional District (GVRD) on water consumption in that area by wholesaling and warehousing facilities. According to the report the sector used almost 10 percent of the commercial water in that region [78]. The breakdown of this usage is washroom (26 percent), landscaping (38 percent), kitchen (3 percent), cooling (23 percent) and others (10 percent). Water can be conserved through state-of-the-art roof design which can help to collect rainwater for later use in the warehouse and other areas of the facility. Brown and green roofs, roof drainage techniques, water irrigation technology and modern sanitation fixtures can also be used to conserve water. Moreover, water use for cooling compressors, chillers and steam boilers can be avoided by considering air-cooled equipment and chemical treatments at the design time [78]. Gazeley [32] reported that some of the key ecological benefits of water conservation include lesser burden on municipal water supplies, reduction in distribution piping and decrease in release of chlorine into the environment. In addition, Gazeley’s eco-template mentions that collection of rainwater fulfils about 89 percent of the water requirements in toilets, saves water required for nearly 89,000 flushes and if purified about 25,000,000 tea cups per year.

- ***Noise pollution:*** It is usually related with transportation and fleet management by most of the conventional supply chain and sustainability literature. However, semantic and contextual analysis of warehouse facility construct revealed that there are many steps that could be taken while designing and planning a warehouse facility to minimise the impacts of noise pollution on nearby communities afterwards. Some of the important points are the selection of site and situation of building [78], use of green roofs that absorb noise transmission and use of photovoltaics (PVs) that silently convert sunlight into electricity [32].

- ***Biodiversity:*** It is also known as 'biological diversity' and refers to various life forms that exist in a particular locality consisting of natural vegetation, forests, animals, micro-organisms, waterways and eco-systems. Biodiversity is necessary for sustaining life on the planet Earth. Biodiversity is important for individuals, communities and businesses. Research shows that the property value of buildings near green spaces and parks is on average 8 percent more than those far away [21]. Also, businesses with greener setting have more motivated employees which lead to increased productivity and reduced sick leaves [63]. However, the warehousing and supply chain literature seems to be alien to the concept of biodiversity but content analysis exposed lot of emphasis from latest sustainability standards [35] and annual sustainability reports by companies. Thus biodiversity is added as an element in the sustainable warehouse facility construct and it must be considered at the time of designing and renovating the facility.

SWH Constructs	SWH Elements	Environment	Social	Economic
Warehouse Design	Renewable Energy Sources (RES)	✓		✓
	Daylight Usage (DU)	✓		✓
	Artificial Lighting Scheme (ALS)	✓	✓	✓
	Temperature Control (TC)	✓		✓
	Water Consumption (WC)	✓	✓	✓
	Noise Pollution (NP)	✓	✓	
	Biodiversity (BD)	✓	✓	

Table1: Warehouse Design Elements

Warehouse Layout Construct

The layout construct has strong impact on warehousing costs. Layout decisions are mainly divided into two broad categories – first is related to the placement of departments (receiving, storage, picking, shipping etc.) and second concerns the design of layout, paths, storage etc. [24]. Thus the layout configuration, type of storage system, design of aisles, and division of space into departments, partitions and zones determine the efficiency and flexibility of warehouse operations. The main objective is to reduce travelling distances and increase space utilization. An optimal layout improves product flow, reduces cost, enhances responsiveness to customer orders, ensures safety of staff and ameliorates working conditions. ***Layout elements*** are discussed below:

- ***Layout configuration:*** Warehouse layout configuration is a tactical decision made at design time [74]. Most of the warehouses have conventional layouts that are rectangular with parallel straight aisles both for storage and order-picking areas. Sometimes modifications are done with additional cross-aisles creating multiple-block layouts. It must be noted that the layout decision is not made in isolation but it is inter-related with several other decisions such as equipment selection, operational strategy, aisles width etc. The goal is to arrive at a design that results in minimal travelling distance for warehouse operations. Researchers have concluded that only order-picking process accounts for 55 percent of warehouse operating costs [83]. Moreover, syntactic analysis of literature for the keyword 'travelling distance' highlighted some innovative layouts such as flying-V, fish-bone and chevron-aisles which are expected to decrease the travelling distance to retrieve a single pallet by 10–20 percent as compared with traditional layouts [54] and thus result in more economical warehouse operations.

- ***Storage system:*** Storage system is a critical part of internal warehouse layout and is used to hold (or store) goods or materials of different types, forms and sizes. It has structural attributes that concern with the physical design of the system and performance attributes that are related to the storage capacity, ease of access, space utilization and storage policies. Storage can be broadly classified as unit-load or small-load storage and selection of a storage system is a strategic decision made at design time [74] where one has to decide from long list of choices such as block stacking, selective racks (single-deep), drive in/through racks, double-deep racks, mobile racks, flow through racks, push back racks etc. Also, automated storage that mainly comprises of carousels, A-frames and AS/RS should only be considered when labour cost is very high or there are special considerations pertinent to staff protection and uniformity of handling [8]. Different storage strategies can be employed such as class-based (ABC classification), random and dedicated storage [39]. The storage location assignment problem (SLAP) is discussed in detail by [38]. Another important characteristic of storage systems that could improve the economic dimension of sustainability is the command cycle. Both single and dual command could be used for achieving maximum efficiency levels in a given warehouse [40].

- ***Aisle design:*** Design of aisles is an important part of material handling strategy. It directly impacts the economic and social dimension of sustainability. Poor design will result in wasted travelling and congestion that might lead to accidents. Decisions are related to the orientation of aisles, their length, width, location and number [39] and must achieve the optimal blend of flexibility, space utilization, equipment cost, safety and productivity. Aisles are usually categorized as wide aisles (WA) that use counterbalanced trucks, narrow aisles (NA) that use stand-up or double-deep reach trucks and very narrow aisles (VNA) in which turret trucks are used.

- ***Departmentalization:*** The placement of different functional areas (receiving, storage, picking and shipping) in a warehouse layout is called departmentalization. In addition to traditional functions, many warehouses provide value added services, rework damaged stock and keep customer returns. Also, sometimes blocked-stock is kept awaiting approval from the quality department. All these functions are performed in separate departments which can be further divided into partitions and zones. The storage department is divided into forward (or picking) and reserve areas to reduce material handling and movement. The reserve area may be further partitioned into sub-areas based on unit load size and customer demand and forward area may be partitioned into sub-areas corresponding to slow, medium and fast moving products [39]. Moreover, zones can be identified in a picking area with an order-picker assigned to each zone [24]. Once departments, partitions and zones are decided, their arrangement should be done in such a manner that could ensure the most efficient workflow pattern (circular, U shape, serpentine or straight-line). It must be noted that regardless of the most appropriate layout, efficient storage system and optimal aisle width, flawed departmentalization would have disastrous impact on the economic dimension of sustainability.

SWH Construct	SWH Elements	Environment	Social	Economic
Warehouse Layout	Layout Configuration (LC)			✓
	Aisles Design (AD)		✓	✓
	Storage System (SS)			✓
	Departmentalization(DPT)			✓

Table2: Warehouse Layout Elements

Inventory Management Construct

Inventory management helps to keep an optimum level of inventory (or stock) that could meet the fluctuating customer demand. This results in improved revenues; reduced degradation and obsolescence; improved warehouse utilization; and lower utility, labour and capital costs. Thus it is both directly and indirectly tied to huge financial gains.

- ***Inventory optimization:*** Inventory optimization is very crucial to the achievement of sustainability objectives. Excess inventory results in obsolescence and wastage while lower inventory levels might lead to lost sales and stock-outs. Inventory optimization is an arduous task as it is linked to replenishment lead times, forecasting, visibility, future inventory prices, available warehouse space, customer returns, obsolete inventory, carrying costs, quality of supply etc. All these competing factors need to be balanced to achieve optimal inventory levels. However, a start can be made by implementing warehouse management system, improving communication in supply chain, eliminating obsolete inventory, improving supplier lead times and quality, forecasting accurately, standardizing parts/components/ingredients, implementing vendor managed inventory (VMI) or just-in-time (JIT) inventory programs etc.

- ***Inventory accuracy:*** Inventory is an asset of the company and thus inventory records must be accurate. It is money in the form of goods or materials and needs to be counted on regular intervals for tracking and valuation; managing stock levels; and controlling theft, shrinkage and loss. Inventory counts are also required for providing stock details to insurance companies in case of a natural disaster; ensuring supply of seasonal products; and placement of most valuable or frequently accessed items in the warehouse. Inventory counting is one of the most fundamental operations and its importance increases tremendously if viewed with sustainability glasses. Natural disasters such as floods, earthquakes and tsunami have become a regular event in a calendar year. Thus companies need to know their stock value to safeguard their assets against such catastrophes. Also, inaccurate inventory records will lead to high safety stocks and increase the inventory carrying costs. They will also result in lower productivity of pickers, increase in searching time and travelling distances and will fail the effort of optimizing the warehouse layout. Moreover, incorrect records might also result in unavailability of promised stock to customers, resulting in lost sales and customer dissatisfaction [72]. Technology should be employed such radio frequency (RF) readers and barcode scanning to improve speed and results of this operations [68].

SWH Constructs	SWH Elements	Environment	Social	Economic
Inventory Management	Inventory Optimization (IO)			✓
	Inventory Accuracy (IA)			✓

Table3: Inventory Management Elements

Warehouse Staff Construct

The warehouse staff construct focuses work/life balance, shift management, staff training and occupational health and safety. The optimal storage equipment, operational strategy, MHEs, picking etc., is only effective if employees are satisfied and happy. The following elements highlight the importance of social dimension of sustainability.

- ***Work life balance:*** Work life balance is simply a balance between an individual's personal life and work. Traditional supply chain books do not extensively focus on one of the most important actors in the supply chain – people. The keyword search of "work life balance" in many different forms resulted in zero occurrence of the word in about 10 supply academic books. The word "balance" when searched separately showed up in the context of 'balance sheet', 'balanced scorecard', 'balance between supply and demand', 'balance between competing objectives' and so forth. Academically, work/life balance (WLB) is defined as "a 'fit' or satisfactory level of involvement between multiples roles in an individual's life" [42]. Content analysis and keywords search on mainstream research databases and Google Scholar showed that there is almost no research on the impact of 'happy' warehouse (or supply chain) staff on throughput, inventory accuracy, worker productivity, error minimization etc. However, the 'high-level sustainability themes' identified earlier in this research study clearly showed that human capital is an ingredient of all the sustainability frameworks. In addition, later comparison with market prevalent standards and corporate sustainability reports also confirmed that policies for ensuring WLB of warehouse staff needs to be a priority for management and not a superfluous agenda item.

- ***Management of shifts:*** Latest research has shown that shift work, especially night work, is a major contributor to fatigue which leads to mental and physical impairment. Also human vigilance varies with the time of the day as individuals are programmed to sleep at night and to be awake during the daytime. Shift work is defined as 'any work pattern that causes a change in normal sleep patterns' [64]. Shift work during early hours of the day and at night time results in limited sleep and creates a 'sleep debt'. This impacts the immune system, mental health, cardiovascular health, safety and productivity of an individual [23]. Supply chain literature again seems to be silent about management of shift work and its impacts on productivity and safety. However, analysis of corporate sustainability reports clearly highlighted that some companies have achieved higher worker productivity and reduced accidents by adopting employee friendly shifts management practices. These include implementation of systems to identify fatigue impairment, planning tasks to avoid fatigue accumulation, providing ample opportunities for fatigue recovery, planning shifts so that interruption to natural rhythms of alertness is minimised, designing a roster that allows employees to periodically reset their body clocks to natural rhythms etc. Since warehouses usually operate for 2–3 shifts/day, thus proper management of shifts, especially roster rotation is extremely crucial for achieving productivity and safety objectives [79].

- ***Staff training:*** Training is important for all warehouse staff in order to ensure their safety and efficient warehousing operations. Nearly all warehouse and supply chain literature emphasizes on various kinds of staff training. Thus this element has been separately mentioned under the 'warehouse staff' construct. Contextual analysis revealed different training that cover areas such as safe and efficient use of MHEs, manual handling, neutralizing of hazardous substances, personal hygiene, stress and fatigue management, emergency escape, warehouse operations, storage equipment audits, MHE maintenance, stock counts, dealing with spillages and breakages, use of fire-fighting equipment etc.

- ***Occupational health and safety:*** This is a well-researched area and companies seem to be very concerned about it due to legal requirements. Generally occupational health and safety (OHS) is concerned with workplace illness and injuries and covers all forms of unpaid or paid work in all environments. Literature does provide evidence that good OHS management improves productivity [50]. Content analysis shows that there are significant economic and social costs attached to OHS. In 2006, the cost of workplace illness and injuries in New Zealand was about 4 percent of GDP ($ 4.2 billion) [62]. Main safety hazards in a warehouse are related to vehicular movement, storage and racking, loading and unloading, hazardous substances, noise, fire risks, manual handling, electricity, uneven slippery floors etc. Accidents or injuries can be avoided by having good housekeeping standards, regular staff training, avoiding any need for climbing, providing personal protection equipment (PPE) to all workers, servicing MHEs on regular basis, restricting access to only authorized people, implementing specific rules for warehouse traffic (such as forklift trucks), clearly marking the emergency escape route, regularly inspecting electricity and refrigeration system etc. [45] [46].

SWH Constructs	SWH Elements	Environment	Social	Economic
Warehouse Staff	Work Life Balance (WLB)		✓	✓
	Shifts Roster (SR)		✓	✓
	General Training (GT)		✓	✓
	Occupational Health and Safety (OHS)		✓	✓

Table4: Warehouse Staff Elements

Mechanical Handling Equipment Construct

Warehouses use different types of mechanical (or materials) handling equipment (MHE) for rapid movement of goods in order to achieve required efficiency levels and throughput. It is typically used for unloading, loading, moving and lifting of products. A manual warehouse will use counterbalanced trucks to unload products and hand-pallet truck to move them to block stacks. Reach trucks are used in warehouses having selective racks (single or double-deep) while order-picker trucks are used for efficient picking. In addition, highly specialized electro-mechanical equipment can also be used such as conveyors, A-frames, robotics [5] as discussed in 'storage systems' construct. However the focus of this section will be limited to human-driven MHEs (i.e. forklift trucks).

- ***MHE power sources:*** The choice of power unit in forklift trucks is between those that use an internal combustion engine and those that use lead-acid electric or nickel-metal hydride batteries. For combustion engines the fuel could be diesel, liquefied petroleum gas (LPG) or compressed natural gas (CNG). The selection of most environment friendly power source might seem simple but an interesting research by Johnson [43, p. 1572] showed that 'fuel carbon footprints of electric and LPG forklifts are, in principle, about equal, while in actual practice, LPG's footprint is smaller than that of electricity'. Actually, the problem lies with the definition of 'system boundaries', meaning that comparison of emissions for two energy sources (such as LPG and batteries) should be based on operational boundary or one should also consider the emissions produced during production, generation, operation and disposal of these energy sources. There is no industry standard in this regard and thus as per Johnson [43], overall LPG is more environment friendly as compared to electric batteries. New generation of forklift trucks have also made a debut in the market with alternative power sources such as bio-diesel and hydrogen fuel cells [49]. In addition, trucks with hybrid fuel combinations are also launched that operate on lithium-ion battery and diesel. Their fuel consumption is evaluated through JIS D6202 test that showed 39 percent reduction in fuel intake and 14.6 tons decrease in CO_2 emissions per year as compared to regular models [58, p. 49]. The thematic analysis showed that all sustainability standards emphasize on reducing consumption of fossil fuels. Thus the decision regarding the choice of MHE, which is traditionally based on its usage rather than energy source, needs to also take into consideration its impact on environment in order this achieve sustainability objectives.

- ***MHE maintenance and servicing:*** The benefits of new designs and hybrid energy sources are eroded by poor maintenance and servicing of forklift trucks. Technical issues and problems, that go unnoticed for weeks or months, prevent forklift trucks from working at optimum efficiency. Daily checks, weekly maintenance and monthly servicing schedule should be followed in order to avoid any fuel or battery leaks, under-inflated tyres, misalignments, loose screws, unnecessary friction etc. According to a British government report, an under-inflation of 20 percent in tyres reduces fuel efficiency by 2 percent and increase rolling resistance by 10 percent [25]. In addition, research studies have estimated that only 2^o axle misalignment increases fuel consumption by 8 percent [13]. In addition, a typical defect in forklift trucks is poor combustion that results in increased emissions and wasted energy. Content analysis could not find any specific statistics for warehouse MHEs in this regard; however, this brief discussion clearly shows that regular MHE maintenance and servicing positively impacts the economic and environmental dimensions of sustainability.

- ***Driver/Operator training:*** Even though training is considered before in 'warehouse staff' construct but content analysis showed that nearly all the literature pertinent to MHEs explicitly emphasizes the periodical training of operators. The focal areas should be fuel-efficient driving, daily checks of forklift trucks and driver behaviour for safe movement of goods in a warehouse. Computer simulations could be used for this purpose [87].

SWH Constructs	SWH Elements	Environment	Social	Economic
Mechanical Handling Equipment (MHE)	MHE Power Sources (MPS)	✓		
	MHE Maintenance and Servicing (MMS)	✓		✓
	Driver/Operator Training (DT)	✓	✓	✓

Table5: Mechanical Handling Equipment Elements

Warehouse Processes Construct

Warehouse processes correspond to an extensive range of physical activities carried out in the warehouse on daily basis. These include unloading, receiving, put-away, storage, pallet relocation, pallet handling, rework, picking area replenishment, case picking, retrieval, loading, handling returns, inventory counting etc. All these operations need to be carefully coordinated in order to achieve optimal space, time, labour and equipment utilization. For clarity purposes, we have broadly divided these operations into four main categories – inbound, storage, picking and outbound in order to analyse their impact on sustainability.

- ***Inbound processes:*** The inbound processes mainly comprise of operations such as unload, receive, rework and put-away. When goods are brought to a warehouse at the inbound (or receiving) dock, they are unloaded using counterbalanced forklift trucks to a staging area (a partition in the receiving department). The purpose is to inspect them for conformance with quality standards and to update the warehouse management system (WMS) so that they become available for put-away. Once material is unloaded, inspected and received in the system, it is put away to assigned locations determined by WMS as per the storage strategy (dedicated, random or class based).The incoming goods that are rejected after quality inspection are moved to the rework department. Usually materials with minor issues such as missing labels, torn packaging, damaged cases and non-standard pallet build are moved to rework department, until quality requirements are satisfied, and then these are received in the system for put-away. Clearly the cost of quality associated with rework, flawed storage strategy and inefficient staff would severely impact the economic dimension of sustainability during inbound processes.

- ***Storage processes:*** Sometimes storage is confused with put-away operation; however, thorough study of academic literature and industry reports showed that there is a very fine line between placing incoming goods into assigned locations and management of physical storage. After rigorous discussions we concluded that inbound operation cannot be completed until put-away is done, thus it makes good sense to treat put-away as part of inbound processes separate from physical storage. Thus storage processes comprise of activities that start when a pallet is placed in a storage location and end when it is retrieved for picking. These will include housekeeping activities, efficient utilization of storage slots, pallet relocation and inventory counting. Once pallets (or products) are placed by put-away process in storage locations, the housekeeping activities related to pallet orientation, physical condition of cases and pallet stacking must be done. In addition, pallet relocation and inventory counting is required in order to improve utilization of storage slots and efficiency of consequent handling activity related to retrieval and put-away processes. Inefficient storage processes negatively impact the economic dimension of sustainability.

- ***Picking processes:*** Picking is considered to be the most costly process in a warehouse as it accounts for 55 percent of the operating costs [83]. It mostly includes activities related to replenishment of picking area (or forward area) and case picking when a full-pallet-load is not ordered by the customer. Picking is classified into two main categories namely, picker-to-stock (in-the-aisle) system and stock-to-picker (end-of-aisle) system. In former system the picker needs to travel or ride to the storage location. According to [68], an order picker may travel six miles a day through various aisles in a warehouse and 75 percent of his time is spent in non-value added activities (searching: 10 percent, writing: 5 percent and walking/riding: 50 percent) while the actual picking is only 25 percent of the entire process. Thus effort should be made to reduce travelling time so that dead-heading (travelling with empty forks) can be minimised. In later system (stock-to-picker) the pallet or container is mechanically brought to the picker. Examples include AS/RS, carousels, A-frames and miniload systems, however, in this method the container's travel time simply replaces the picker's travel time. Content analysis clearly shows that picking processes have a huge impact on economic dimension of sustainability. In addition, if non-value added activities of an order picker could be reduced somehow then it will surely help in reducing emissions of various GHG into the environment.

- ***Outbound processes:*** Outbound processes are related to stock movements aimed at fulfilling customer orders. These activities include transfer of stock from pick (or forward) area to outbound staging area, loading and finally despatching the vehicles to customers. Outbound operations may also include pallet customization or repacking of products into new format (or standard)in order to address specific customer/business/market requirements.

SWH Constructs	SWH Elements	Environment	Social	Economic
Warehouse Processes	Inbound Processes (IP)			✓
	Storage Processes (SP)			✓
	Picking Processes (PP)		✓	✓
	Outbound Processes (OP)			✓

Table6: Warehouse Processes Elements

On-site Facilities Construct

A number of facilities emerge from content analysis that must be present on the warehouse site to support employee welfare and handle any medical emergencies. In addition, cross-docking is also added under this construct. It is not a compulsory part of a warehouse but can help to save costs under special arrangements. Finally, content analysis showed that onsite recycling is considered as a mandatory constituent of a warehouse facility by sustainability literature.

- ***Welfare facilities:*** These include free access to drinking water, washing facilities, change rooms, showers, toilets for males and females, canteen, dining room and personal storage. These are the minimum requirements as per the national and state laws in most of the developed countries [3]. In addition, in case of a warehouse, special facilities for drivers staying overnight and staff working on night shifts should be provided. These might include a workout area or a gym, a rest room, common area with television, sports area catering to indoor games such as table tennis, foosball, chess, arcade video games etc. Good personal hygiene standards must be reinforced at all times such as disinfection of toilets, cleanliness of shower and change rooms, proper seating in dining room, pest disinfestation etc. Parking space should also be provided to all the employees.

- ***Emergency room:*** First-aid facilities should be available in a warehouse at all times. It is preferred to have an emergency/medical room staffed with a trained doctor and a nurse during the day. Proper signage and instructions must be provided to all staff members and some wardens should be trained in various first-aid and cardiopulmonary resuscitation (CPR) techniques. The emergency room should be large enough to accommodate at least two beds; few cupboards for storing dressings; linen and medicaments; proper disposal system; a stretcher; workbench or dressing trolley; wash basin with hot and cold water etc. [86].

- ***Cross-docking facility:*** A cross-docking facility in real sense is a warehouse process in which products are directly transferred from inbound to outbound area and reconfigured according to customers' orders. It might include bulk breaking, sorting, merging and then consolidation but by-passes costly put-away, storage and picking processes [69]. Even though it sounds easy and efficient but very few retailers have been able to implement true cross-docking due to extremely intricate coordination, transport management and order planning. However, Wal-Mart is famous for pulling a large percentage of their products to their stores through their cross-docking sites. Also, Maytag maintains 41 cross-docking facilities in the U.S. with zero inventory and covers 70 percent of the U.S. population [9].

- ***Recycling facility:*** Reverse logistics is a vast domain in itself and it is not possible to even touch upon its various aspects in this paper. However, syntactic analysis showed very high frequency of words similar to recycling, take-back programs, reprocessing, reuse etc. Then contextual analysis showed these words in regard to store sites, building, retail outlets and also warehouses. Thus it is considered important to accentuate the importance of a recycling facility within a warehouse premises for reprocessing cardboards, shrink wraps, packaging etc. In addition, stock that is damaged, expired, rejected by quality and returned by customers also need to be properly discarded or recycled [65].

SWH Constructs	SWH Elements	Environment	Social	Economic
On-site Facilities	Welfare Facilities (WF)		✓	
	Emergency Room (ER)		✓	
	Cross-Docking Facility (CDF)	✓		✓
	Recycling Facility (RF)	✓		✓

Table7: Sustainable Onsite Facilities Elements

Warehouse Management System Construct

A warehouse management system (WMS) is extremely crucial for managing a best-in-class sustainable warehouse. It controls the movement and storage of goods in a warehouse and performs all associated transactions for receiving, shipping, stocking and picking. The extent of work done in a warehouse can be easily imagined from former discussions in this paper. Thousands of transactions are executed in real time in parallel. WMS not only controls the internal processes but also manages the entire warehouse facility [68]. Thus it could play an important to measure the social and environmental performance of the facility.

- ***Performance measurement:*** One of the core functions of WMS is to keep track of all the key performance indicators (KPIs) for performance measurement. These may be clubbed into various reports for convenience such as order fulfilment, inventory management, staff productivity, shelf-life monitoring, work planning etc. In addition, KPIs related to work/life balance, employee absentees, training, emissions generated, housekeeping targets, MHEs fuel consumption etc., should also be programmed into WMS. This will help to measure the sustainability performance and to identify avenues for further improvement.

- ***Warehouse strategy and roadmap:*** Continuous improvement can only be achieved by effectively using a WMS. It helps to bottlenecks, monitor current performance, perform comparative analysis, set future targets, benchmark against industry standards, perform simulations etc. Thus the warehouse future roadmap and strategic planning for achieving highest levels of economic, social and environmental performance is not possible without WMS.

SWH Constructs	SWH Elements	Environment	Social	Economic
Warehouse Management System	Performance Measurement (PM)	✓	✓	✓
	Warehousing Strategy and Roadmap (WSR)	✓	✓	✓

Table8: Performance Measurement Elements

SUSTAINABLE WAREHOUSING MODEL

The sustainable warehousing model (SWM) shows all the constructs and elements discussed above. It groups the elements with regard to their impact on various dimensions of sustainability. It can be easily seen that there are very few elements that only affect a single aspect of sustainability. Many of them have triple impact and those with dual impact are the maximum.

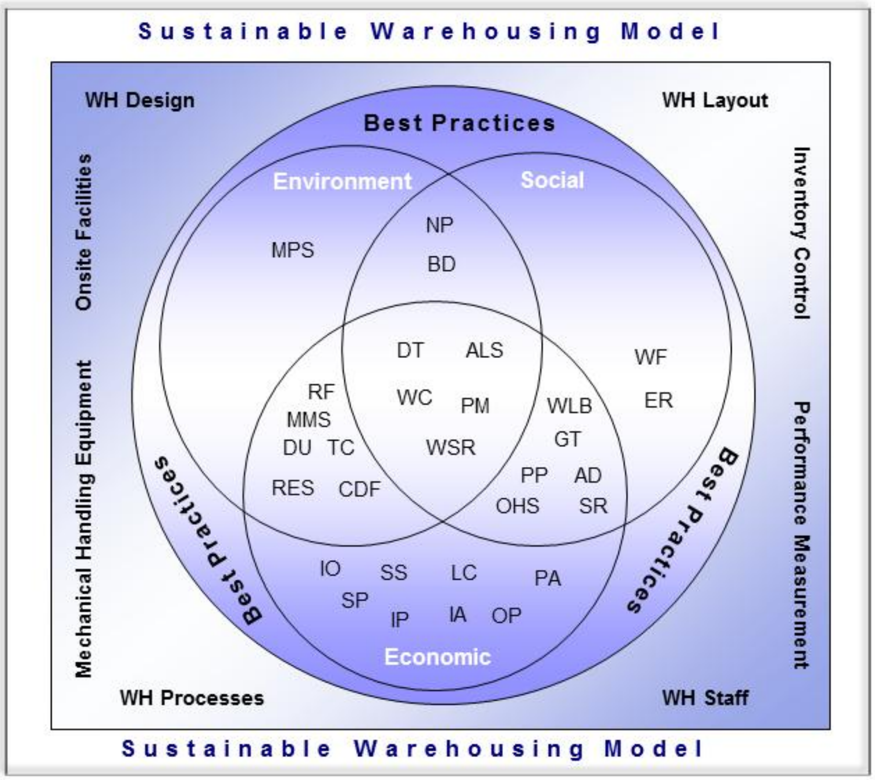

Figure2: Sustainable Warehousing Model

Analysis

Impact-wise analysis in Figure 2 shows that there are 5 elements that 'primarily impact' all the three dimensions of sustainability, 14 elements have dual and 12 have single impact magnitude. Close analysis reveals that in this model with 30 elements, 25 elements (87 percent) result in economic value, 15 elements (48 percent) result in social well-being and 14 elements (45 percent) lead to preservation of environment. Also 19 elements (63 percent) impact more than one dimension of sustainability. The dimension-wise also shows the same picture from another angle. Both graphs accentuate the fact the investments in sustainable warehousing are bound to produce good economic value and would help to fulfil social and environmental responsibilities.

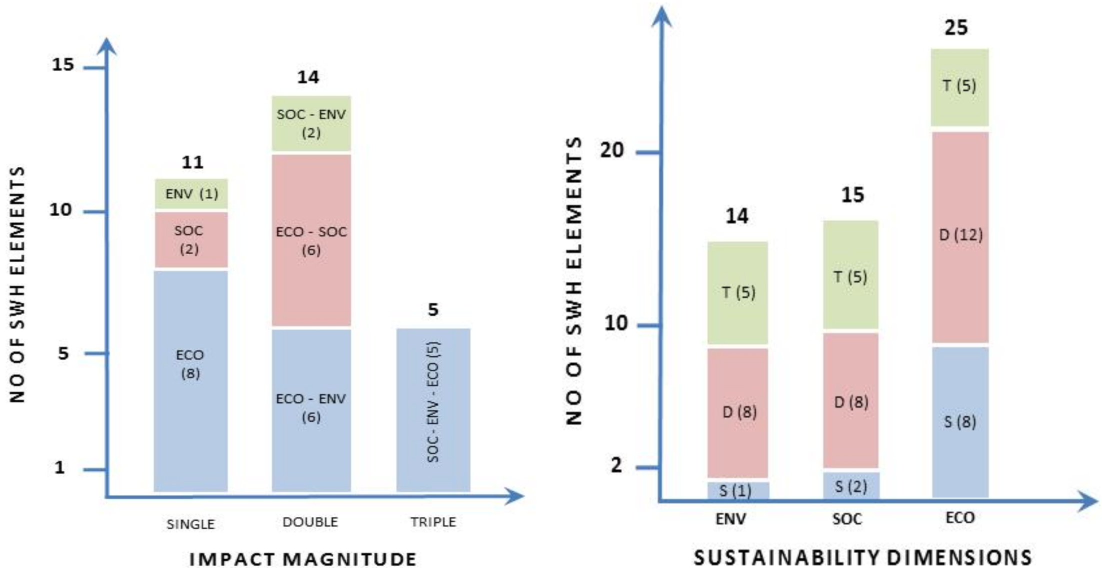

Figure3: Impact & Dimension Wise Analysis

Sustainable warehousing best practices

Finally, the sustainable warehouse constructs, elements and model are translated into best practices as shown in Table 9 below.

CONCLUSION

This research is an important step towards operationalizing sustainability for warehouses. It has practical value and academic worth as benefits can be realised in both supply chain/warehouse managers and researchers. It clearly shows that initiatives to achieve objectives of sustainable development are not in conflict with economic benefits. As such, societal and ecological improvements can be seen to result in both short-term and long-term profitability.

Also, it is not advisable to adopt all best practice activities in one step as this process has to evolve over time. Thus the list of best practices, coming out from this research, can be used as a roadmap for setting future targets and goals. The main focus of this research was to evaluate each element for its 'primary impact' and not the indirect and secondary impacts.

It is therefore possible that many of these elements might have effects on other dimensions of sustainability as already identified. It is proposed that this model could be further examined and enhanced through more qualitative analysis, extending it toward a quantitative approach in future.

Sr. #	**Sustainable Warehousing: Best Practices**
1.	Use renewable energy sources for running warehouse operations.
2.	Maximise the use of natural sunlight.
3.	Efficiently manage the artificial lighting in the warehouse.
4.	Maintain warehouse temperature at a level that requires least amount of energy.
5.	Conserve water through latest water-management techniques.
6.	Minimise noise pollution by using noise reduction technologies.
7.	Enhance bio-diversity of the facility and its surroundings.
8.	Use warehouse layout that minimises the travelling distance for daily operations.
9.	Use storage system and strategy that optimizes the warehouse operations.
10.	Design aisles such that wasted travelling and congestion is minimised.
11.	Arrange warehouse departments for the most efficient workflow pattern.
12.	Optimize inventory levels to avoid both obsolescence and lost sales.
13.	Ensure accurate inventory records through regular counting.
14.	Adopt policies that ensure work/life balance of warehouse staff.
15.	Design shift roster such that disruption to natural body clocks is counterbalanced.
16.	Ensure both technical and soft-skill training for all warehouse staff.
17.	Maintain high standards of occupational health and safety.
18.	Use MHEs that have environment friendly energy source.
19.	Plan daily, weekly and monthly maintenance and servicing of MHEs.
20.	Train MHE operators for fuel-efficient and safe driving.
21.	Optimize inbound processes for efficient unloading, receiving, rework and put-away.
22.	Optimize storage processes to improve utilization of storage space.
23.	Optimize picking process such that picker's travelling time is minimized.
24.	Optimize outbound processes for efficient loading and despatch.
25.	Provide welfare facilities (e.g. toilets, canteen, parking etc.) to all employees
26.	Maintain an emergency/medical room with proper facilities and trained staff.
27.	Use cross-docking to enhance operational efficiency and customer response time.
28.	Establish a recycling facility onsite to minimise waste production.
29.	Implement a robust, scalable and reliable WMS for performance measurement.
30.	Develop future warehouse strategy using WMS to improve sustainability performance.

Table 9: Sustainable Warehousing Best Practices

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Addendum

NVivo Software

Manual analysis of qualitative data was not possible for this research as material related to sustainability, supply chain management, warehousing, research methodologies, green buildings, inventory management, layout configurations, MHEs, facility design, staff management etc., is so extensive that it is not possible to analyse with manual note taking/recording techniques. All these knowledge areas were studied from books, academic articles, industry publications, market reports, supply chain periodicals, warehousing magazines, company reports etc. Thus computer assisted qualitative data analysis software (CAQDAS) – NVivo was used for this research. It is a qualitative analysis software developed Qualitative Solutions and Research (QSR) company. It helps researchers in theory development by organizing and analysing qualitative data. Documents are imported into NVivo software quite easily in most of the prevalent formats (pdf, doc, rtf, digital videos, multimedia files etc.). Various data analysis tools help to perform deep analysis which leads to the development of theme and models.

Coding using *Free and Tree Nodes*

Coding is a well-researched area and there are many techniques, methods and tools available for it in the market. It is simply transforming data into understandable form or organizing data into categories/classes/codes that could facilitate analysis. In NVivo software 'Nodes' are similar to codes and a researcher initially develops 'free nodes' which represent emerging themes and these could be grouped into 'tree nodes'. Simply putting it, a tree node is like a parent node with various child nodes. It is similar to creating a hierarchy, classification or taxonomy of related concept/themes grouped under relevant categories.

Data Analysis Tools

NVivo software provides many options for data analysis such as broad brush coding, word frequency query, tree maps, tag clouds etc. These tools help to explore, arrange, sort, classify and examine data through searching, linking, shaping and modelling. Word frequency query has multiple options to determine words that occur most frequently. For example, if the word 'balance' appears often then it can be easily saved along with its context in a node. Results of such context analysis can be seen visually through a 'word tree' in which 'balance' will be shown with all its contexts in the form of branches coming out of the word. In this research the word 'balance' appeared with numerous contexts such as balanced score card, balance sheets, work/life balance, balance between competing warehouse objectives etc. Tree maps and tag clouds are also used to visually see the frequency of various words on relative basis and help to compare nodes by number of coding references.