**UNIVERSITAT POLITÈCNICA DE CATALUNYA**

# SUSTAINABLE DEVELOPMENT IN CONTRACT LOGISTICS THROUGH GREEN WAREHOUSING AND DISTRIBUTION

## PRACTICAL CASE: MAERSK WAREHOUSE

By

**IVAN NEZHENTSEV**

Supervised by: **GERMÁN DE MELO RODRÍGUEZ**

Project presented in compliance
requirements for obtaining the title of
Master in maritime law, business
and Port Management (Shipping Business)
Fundación Politècnica de Catalunya,
Universitat Politècnica de Catalunya

Barcelona, September 2022

**SUMMARY**

Pages

I PART. CONCEPTUAL FRAMEWORK

Chapter

**I. INTRODUCTION: THE ENVIROMENTAL IMPACT OF WHAREHOUSES .....6**

**II. ROLES AND FUNCTIONS OF WAREHOUSES .....9**

WAREHOUSE LOCATION AND GREEN CONSTRUCTION ..... 12-17

ROLE OF EQUIPMENT .....17

FRAMEWORK OF SUSTAINABILITY IN WHAREHOUSING: MICRO AND MACRO LEVELS..... 31-38

LAYOUT.....38

REDUCTION OF ENVIRONMENTAL IMPACT.....44

WES, WMS AND TYPE OF OPERATIONS .....53

DISTRIBUTION NETWORK PLANNING .....61

GREEN ENERGY USAGE.....67

SOCIAL DIMENSION OF SUSTAINABILITY IN WAREHOUSING .....70

II PART. PRACTICAL CASE

**III. MAERSK WAREHOUSE .....81**

WAREHOUSE LOCATION: SUSTAINABLE FOOTPRINT.....88

GREEN FRAMEWORK: LAYOUT, EQUIPMENT .....91

COMPLIANCE WITH SUSTAINABLE REQUIREMENTS FOR ENVIROMENT .....98

RISKS AND OPPORTUNITIES OF MAERSK WAREHOUSING FOR CONTACTS LOGISTICS .....101

**IV. CONCLUSION .....111**

**REFERENCES**

## ANNEX SUMMARY

Pages

ANNEX 1 – TYPES OF LAYOUTS IN CONTRACT LOGISTICS.....116
ANNEX 2 – MAERSK WAREHOUSE LOCATION IN ZAL EL PRAT.....117
ANNEX 3 – MAERSK WAREHOUSE LOAD / UNLOAD FACES.....118
ANNEX 4 – MAERSK FLOW WAREHOUSE MODULES .....119
ANNEX 5 – MAERSK WAREHOUSE LAYOUT.....120

## LIST OF ACRONYMS

ACER - EU Agency for the Cooperation of Energy Regulators

AGVs - Automated Guided Vehicles

AS/RS - Automated Storage/Retrieval Systems

BREEAM - Building Research Establishment

CASBEE - Comprehensive Assessment System for Built Environment Efficiency

CHP - Combined Heat and Power

DC - Distribution Centre

ECR - Efficient Consumer Response

EDGE - Excellence in Design for Greater Efficiencies

EPCs - Energy performance certificates

EPDM - Ethylene Propylene Diene Monomer Rubber

ERP - Enterprise Resource Planning System

HQE - Haute Qualité Environnementale

HVAC - Heating, Ventilation, and Air conditioning

GHG - Greenhouse Gas Emissions

LEED – Leadership in Energy and Environmental Design

LPG - Liquefied Petroleum Gas

PUE - Power Usage Effectiveness

PPE - Personal Protective Equipment

RFID - Radio-frequency identification

RICS - Royal Institution of Chartered Surveyors

SCORE - Supply chain operations reference

SKU - Stock Keeping Units

TMS - Transport Management System

USGBC - United States Green Building Council

WES - Warehouse Execution System

WCS - Warehouse Control System

WMS - Warehouse Management System

## ABSTRACT

The thesis is dedicated to the staple part of contract logistics – warehousing and distribution. The nature of this study is to show the sustainable development of (green) warehousing, the crucial changes and achievements in the sector and how these improvements impact the environment and society.

The author appeals to the research and analytical methods where he investigates the sources and related documents to analyse the global situation in contract logistics and describe the current situation of green warehousing. The practical method helped to study the Maersk warehouse and to show if it indeed responds to the requirements of sustainable durability as well as highlights the transformations conducting the company towards decarbonisation.

The first part dedicated to the general research of warehousing and distribution. The author investigated the main features of warehouse location and its crucial importance, studied different types of layouts, showed the modernisation and application of WMS facilitating the operation's running, examined the efficiency of equipment usage, light and air conditioning systems and analysed the social impact of warehousing for sustainability.

The second chapter observes the practical case of Maersk warehouse as the first logistic centre for the company in Iberia area. The author not only investigated the main features of warehouse, but also showed how the company is implementing the sustainable tools to reduce the environmental impact as well as gave at the glace the future of warehousing via innovation and technology usage.

# I PART. CONCEPTUAL FRAMEWORK

## INTRODUCTION: THE ENVIROMENTAL IMPACT OF WHAREHOUSES

Despite changes in a business logistic chain as well as the rest of inventory schemes in current contract logistics, such as door-to-door business, warehouses remain the nexus in supply chain. They're not only absorb imbalances in the supply chain, but complete various functional activities and roles alongside the storage of goods. And yet, controversially, it tends to be diminished gradually from a supply chain. In the SCOR model[1]: plan-source-make-deliver-return, warehousing is implicit in sourcing, delivering and return which embraces the reverse logistics process. According to the 3d Party Logistics Study, in 2020, about 74% of companies preferred to outsource at least 1/3 of their warehousing to a third party[2]. It seems a clear indication that they don't consider warehouse management as a part of their core competencies. However, the biggest companies such as Walmart, Amazon, Maersk, Mango etc. use effectively warehousing distribution network. By strategically locating regional distribution centres and warehouses in close proximity to major transport hubs: ports, train stations, airports and motorways. They broke with the long-standing storage tradition of maintaining just one or two warehouses to serve the assigned business area and began to place strategically warehouses to provide timelier and more economical inventory replenishment and delivery of goods. As a result, they make more flexible the short movements of goods (Cross-docking) and keep offering their Fulfillment

[1] Supply chain operations reference
[2] Blanchard D. Supply Chain Management Best Practices

areas to stock the goods as long as it's needed. More warehouses placed, more products arrive and being distributed, more happier customers.

Yet the warehousing and distribution sector was repeatedly criticised by Environmental society due to its non-green policy regarding sustainability. According to the World Economic Forum of 2009, environmental impact of warehouses forms that about 18% of all supply chain emissions stem from logistics buildings, and the emissions coming from warehouses at about 8% of total greenhouse gas emissions[3]. Understandably, environmental issues of warehouses receive considerably less attention than transport operations, which account for the remaining 89% of logistics emissions. Nevertheless, next to environmental improvements there is also a large potential for cost savings by running warehouses more efficiently. Regulatory pressure on the construction industry to reduce its carbon footprint and the cost of land usage in densely populated areas together with a reluctance of residents to have a warehouse close to their neighbourhood make it worthwhile to consider environmental issues in the design and operation of warehouses[4].

The impact of warehouses goes beyond their greenhouse gas emissions. Warehouses add to the traffic of heavy and lighter goods vehicles. They cause noise and cover large areas of land, interfering with wildlife and rainwater trickling into the ground. But they are also a workplace that offers employment and they are essential in making products available to consumers and to keep factories and other businesses running.

[3] World Economic Forum Annual Meeting 2009
[4] The Global Competitiveness Report 2009–2010

This first chapter starts by looking at the portrait of the different functions of warehouses and their design before we investigate opportunities to reduce the impact of warehouses on the environment and to improve their wider sustainability as well as the environmental impact of warehousing and how warehouses can be categorized, risks and opportunities for the companies and we'll investigate the social perception on warehousing green policy.

The second chapter is dedicated to a first Maersk warehouse in Iberia and presents a sum of first chapter, shedding a light on conceptual parts of the warehouse: location, layout, environmental impact, showing how Maersk follows and offers its own solutions for green warehousing. The author shall research the sustainable development of Maersk warehouse and its future projects via functional footprint and conformance in practice of international standards of green warehousing.

## II. ROLES AND FUNCTIONS OF WAREHOUSES

As imposed, warehouses are an important operational part of supporting a company's supply chain strategy. They are the hubs in a supply chain network and they significantly influence service and costs of the network. Failures in holding and effectively delivering the right stock at the right time in the right quantities and quality will result in unsatisfaction of customers. But warehouses and the inventory that is inside them also give rise to costs. These consist of fixed costs for the installation of the building and equipment, and the operational costs, which depend on the initial design of the warehouse. Likewise, the environmental costs are the base from construction phase and from operations. The project of the warehouse and the design of its operational processes are for support the business in general and supply chain strategy.

Warehouses have a range of roles in the supply chain. The most significant differentiator is whether they actually store stock. Cross-docking model is goods being received, processed and dispatched without being stored and is often used for goods that need to be transported fast, for example perishables or medical products. Besides the increased pace, cross-docking is also popular for focusing inventory and saving inventory costs. Cross-docking is gaining further importance in future supply chains. With a reduction of warehouses holding the same inventory the required safe stock can be reduced through the square root law. This is based on the rule of thumb that when concentrating inventory, the ratio of inventory held in a decentralised system to the inventory held in a united system equals the square root of the number of initial locations. As an example, by reducing 15 inventory holding

warehouses to one centralised site, overall safety stock inventory can be reduced by 80%. The number of inventory warehouses is therefore a trade-off between transport costs, in case of long-distance journeys, and the costs for holding inventory. However, the choice is usually more complex with many more considerations[5].

Fulfilment warehouses are another model, where many operational activities occur in the warehouse. Orders are picked either by workers or by automated systems, items are put together in orders, packed and sent out to the customer. Online retailers who use these fulfilment centres, experience very high return rates, which led to improved and specialised facilities for processing returned items in fulfilment centres. Warehouses also cover value-added activities in the final processing and customisation of products. In retail business distribution centres we can also see the preparation of goods for customers, for example putting items on hangers, sort them or adding price tags. But warehouses may also have a stronger inbound focus. Consolidation / deconsolidation warehouses supply smaller deliveries into larger shipments. This can be often found in export-oriented places to ensure shipping containers are filled up with loads from multiple suppliers. Similarly, in warehouses in port-centric logistics, goods are received and consolidated in the warehouse at the port of arrival.

In the just-in-time supply chains, warehouses, at the customer end of the supply chain are avoided. Stock is stored directly at the supplier's manufactory

[5] Blanchard D. (2020). Supply Chain Management. Best Practices, J. Wiley & Sons, Inc. – p. 67-72

or, ideally, only produced as needed and transported to the production line as and when it is needed. This concept is particularly common in car manufacturing and equipment industry. Due to high levels of customisation, just-in-time developed into just-in-sequence, where the delivered products are arranged to suit the production schedule. These concepts are highly complex and vulnerable and require a high level of logistics competence and sophisticated operations in all parts of the supply chain, including the warehouse units. Warehouses in these supply chains are mainly buffering supplier and customer production schedules and prepare goods for delivery direct to the production line.

Despite all these trends and changes in warehouse design, most warehouses still fulfil the classic warehouse function: receiving goods, storing them, and dispatching at a later point. They also combine several roles and operational aspects: have a cross-docking area in addition to holding some stock of other products, often they named as flow warehouses. Many logistics activities are outsourced to external suppliers. In Europe just over a quarter of the warehousing and distribution market is outsourced, and a slightly larger proportion of the contract logistics market, where the entire distribution function to a third party, usually including warehousing, fulfilment and delivery operations is outsourced under contract. The outsourcing of warehouse and fulfilment operations can have many aspects, usually categorised by who owns the assets and manages the operations. Important for sustainability issues is whether the owner of the warehouse has a long-term perspective for a site, which impacts the decision to invest in sustainability measures that have a

longer payback period. Using external service vendors also makes it easier to collaborate with other customers or to use shared facilities, which can result in better usage and economies of scale.

## WAREHOUSE LOCATION AND GREEN CONSTRUCTION

The number and locations of warehouses in a logistics network determine to a large scale, the volume of transportation that is required within the network. Ideally a warehouse is located at the Centre of gravity of the transport journeys in the area that it serves: port, motorway, railway, airport. The number of warehouses in the overall network and the areas they serve are the optimal trade-off between the costs of transport, costs of the warehouses and the inventory costs. A reduction in inventory holding points leads to a reduction of safe stock and consequently a cost reduction in inventory. In this trade-off between inventory holding and transportation, there has been a general trend towards more centralisation of inventory in recent decades. This can mean that a central distribution site may be run more efficiently, but it may also mean more trips and distance achieved. The centralisation of inventory is encouraged by low transportation costs. Additionally, the elimination of border controls, and the resulting reduction of waiting times at border crossings in Europe encouraged companies to concentrate their distribution in fewer sites and often in a single warehouse. Furthermore, logistics approaches like just-in-time in manufacturing and ECR[6] by more frequent deliveries of smaller quantities.

[6] Efficient Consumer Response

The decision on warehouse location is more complicated than a pure optimisation of the transport network at the Gravity centre. Planning permission for a greenfield development may be difficult to obtain and land use can be restricted by legislation. If an existing site is to be used, it may be that available sites are not in the preferred location and a suitable warehouse at a less favourable location is the next best option. Another indication can be access to particular transport modes. The access to rail and water transport may be an essential feature for particular products and sustainability strategies. With increasing cross-border trade, central logistic centres are also becoming more popular. Locations like ports can also be chosen if the warehouse needs to be in a free-trade zone or access to service providers, specialising in sea transport is required.

The proximity to customers or to supply sources is a strategic decision that can be an essential feature in supporting a business's strategy and may even be a requirement in the contract with a large single customer. Access to labour is another aspect: fulfilment centres provide opportunities for employment. In the case of online selles for example, demand during the Christmas period peaks and the fulfilment centre needs large numbers of temporary staff. The availability of sufficiently skilled staff is even more important when more value-added services are performed at the site and when there are more complex logistics processes and handling equipment.

Companies have shown great efforts to make new-build warehouses more energy efficient not only to gain economic savings but also to pledge social responsibility and to gain a competitive advantage in contract logistics.

This can be analysed by looking at the number of applications of green building certification companies. For instance, nearly 350 distribution centres out of 40.000 commercial projects have been certified across 167 countries by one of the most widely used green building certification systems since 2000[7].

Green building rating and certification systems play an important role to provide an integrated design process and green standards to develop environmentally responsible and resource-efficient buildings throughout their durability. While these systems outline the green standards that need to be followed, they also guide companies to achieve sustainable buildings following the stages through design, construction, operations, maintenance, renovation and demolition during either a new project or an existing one. According to a study conducted by USGBC[8], it is constituted that certified buildings present 35% to 97% savings on energy, carbon emissions, water and waste, respectively[9]. Moreover, it is observed that productivity and occupant health have increased due to better indoor environmental quality, natural daylight and healthier materials. For example, Nike's certified logistics centre in China saved 4.300 tons of $CO_2$ emissions annually through efficient and natural lighting, and on-site solar heating system. During the construction phase, the company also recycled 97% of waste products and 55% of the wood products used[10].

[7] United States Green Building Council, 2017
[8] United States Green Building Council
[9] USGBC warehousing and building requirements report 2017 – p. 234-236
[10] LEED. The first LEED Platinum warehouse in China: Nike's Logistics Center, 2015

The respected green building rating and certification systems in the marketplace are guidance in LEED[11] and Building Research Establishment, CASBEE[12], Green Globes, WELL Building Standard, Building Environmental Assessment Method, EDGE[13], Green STAR SA, BCA Green Mark Scheme, Living Building Challenge, Pearl Rating System for Estidama, HQE[14] and DGNB[15]. Among these, BREEAM[16], which is the world's first sustainability assessment method for buildings, and LEED, which is the most widely used across the world, are the most comprehensive systems for commercial buildings. LEED uses four rating levels: Certified, Silver, Gold, and Platinum for the certified buildings, while BREEAM has five levels: Pass, Good, Very Good, Excellent and Outstanding[17]. Both systems have required and varying criteria with respect to the type of facilities. Main categories in BREEAM are management, transport, land use and ecology, water, energy, materials, waste, health and well-being and pollution. LEED for warehouses has location and transportation, sustainable sites, water efficiency, energy and atmosphere, materials and resources, indoor environmental quality. Both have innovation as an optional but encouraged factor.

A LEED-Silver certified warehouse, for example, is constructed using over 25% recycled content, and over 35% regional materials. It also achieved 9.000 euros annual savings by efficient design and operating systems[18].

[11] Leadership in Energy and Environmental Design
[12] Comprehensive Assessment System for Built Environment Efficiency
[13] Excellence in Design for Greater Efficiencies
[14] Haute Qualite Environnementale
[15] Deutsche Gesellschaft für Nachhaltiges Bauen
[16] Building Research Establishment Environmental Assessment Method
[17] LEED certification. Electronic Source: https://www.usgbc.org/leed
[18] LaSalle Investment Management, 2013

Fieldson and Siantonas suggested that embodied and operational emissions are almost equal during a warehouse's lifecycle. Therefore, the research on green warehousing showed that embodied energy of concrete: in situ, paving and precast and steel used in superstructure and doors, build the largest portions, 48% and 36% respectively, in a typical small distribution centre. For this reason, author imply that the net emission savings of roof insulation, the difference between operational emission saving and the embodied impact emission of insulation, should be carefully evaluated for the lifecycle of a warehouse. For example, the warehouse with 50% roof light and high-level insulation presents 9% ~433 tons savings in net overall operational $CO_2$ emissions for the 25-year design life of the warehouse, it causes increasing embodied emissions with 18.3% ~ 435 tons[19]. Consequently, we conclude that the negative effect of building materials on the embodied energy can be alleviated by reducing material use, waste minimisation, recyclability, and using alternative materials with a lower embodied carbon per weight of the material. For instance, hempcrete is a very decent alternative to reduce $CO_2$ emissions up to 100% compared to steel and timber cladding systems. Moreover, the efficient insulation can reduce an average U-value by 0.2 from around 0.4 in conventional warehouses which usually have low insulated brick, concrete or metal panel walls, and metal or synthetic roofs. U-value shows how effective a material is for insulation, and higher the U-value means the worse thermal performance of the building envelope. For a best practice, Prologis Park Portland distribution center in Illinois reduced heat islands in the

[19] LEED Building Design and Construction: Warehouses and Distribution Centers. Offical website.

facility by using white thermoplastic polyolefin, which absorbs heat from sunlight and does not cause additional cost, instead of traditional black EPDM rubber roofing membranes[20,21].

Roofs also present opportunities to not only reduce heat transfer but also generate clean energy and alleviate the lost green space of cities. Appropriate roofing decreases heating and cooling energy consumption and provides an area for roof-mounted solar panels for clean energy production. The e-commerce giant Amazon declared that it is expected to generate 41 megawatts of energy by installing solar panels on the rooftops of its 21 warehouses by the end of 2022, and put the others by 2024[22]. In this way, Amazon plans to meet 90% of its energy in these warehouses annually. State-of-the-art roof designs can also contribute to water conservation through collecting rainwater for later use in washroom, landscaping, or even in cooling, which are the major water consumption areas in warehouses.

## ROLE OF EQUIPMENT

The operational processes in a warehouse are supported by the use of handling equipment which is also a major consumer of operational energy. The selection of equipment is usually determined by the purpose and design of the warehouse and the goods that are processed during the operations. The level of automation varies considerably between warehouses. Unmanned automated warehouse equipment, often referred to Automated

[20] Ethylene Propylene Diene Monomer Rubber
[21] ProLogis, n.d.
[22] Etherington, 2022

Storage/Retrieval System (AS/RS), usually leads to higher bandwidths, but also decreases flexibility. Using more staff also makes it easier to cover peaks more easily. Fulfilment centres in particular rely on human labour, as the packing of boxes is difficult with automated equipment and returned goods rely on human judgement of whether they are in a re-sellable condition. Automation might be a preferable option in harsh environments, for example in refrigerated warehouses or in low-oxygen environments. Conveyor belts, cranes and dredgers are used to handle bulk cargo. Other typical equipment is forklift trucks, commonly found in palletised goods environments. Forklift trucks come in many varieties and engines, using batteries, diesel or even hydrogen.

All these types of operational equipment have different characteristics. After strategic considerations of longevity and amortization of investment and flexibility and operational aspects of throughput capacity, item characteristics and warehouse site need to be exanimated. If a warehouse is expected to have a high throughput, goods need to be stored more densely, otherwise the trips between receiving, storage, order, picking, and dispatching become too long. Also, the location and cost aspects may restrict the land use of the warehouse. Automated warehouse equipment can cope with a higher throughput, and it also achieves a higher storage density as it can reach higher levels in the warehouse and needs less aisle space for manoeuvring than forklifts[23].

[23] Grant D.B., Trautrims A., Yew Wong C. (2015) Sustainable Logistics and Supply Chain Management, Revised Edition., Kog. P. Limited. – p. 88-95

Especially where land scarcity or land costs are high, warehouse managers prefer to keep as many products as possible in a storage area. This is also good in terms of reducing embodied energy of the building and reducing environmental damage due to land consumption. Storage density in a warehouse can be increased in several ways:

- increasing depth of lanes or racks
- making aisles narrow
- increasing stack/rack heights

Increasing lane depth allows multiple pallets of a SKU[24] to be stored back to back and on top of each other in a lane to compensate aisle space devoted to it. While deeper lanes compensate the devoted aisle space, they cause unused pallet locations in lanes because they are usually dedicated to a single SKU to avoid double handling. So, even though a storage location is unoccupied, it is not available for storing other SKUs. This inefficiency in storage usage is called honeycombing problem. The vertical honeycombing in block-stacking might be resolved by using storage racks that allow individual access to pallets. The horizontal honeycombing can be reduced by determining optimal lane depth that minimises total space lost for storage. Besides, workers should be very careful when getting into deeper lanes in order to avoid any accidents. Thus, deeper lanes also increase put-away and picking times.

[24] Stock Keeping Units

Aisle's width is a tactical decision that affects the flow of materials, movement of workers, and the type of material handling equipment needed. Hence, the width of aisles affects the economic and social dimension of sustainability. Aisles can be categorised as wide, narrow and very narrow aisles in terms of their width. Wide aisles can easily accommodate standard forklifts that can reach up to 6 meters, with a width of greater than 3.5 meter for handling 100x120 pallets, American type. Narrow aisles have a width of 2.5 to 3 meters and require reach trucks that can lift up to 9 meters. Very narrow aisles can be narrower than 2 meters. While wide and narrow aisles are located in labor-intensive warehouses, very narrow aisles are mainly located in automated warehouses. Therefore, assuming a 100x120 pallet load and wide aisles as the base line, narrow and very-narrow aisles are expected to accommodate 30% and 55% more products than wide aisles, respectively.

Even though, narrow aisles provide significant space saving, wide aisles with counterbalance lift trucks have been the most commonly implemented system in warehouses because of their flexibility, high speed, low cost, a short learning curve, higher weight capacities and a great variety of options. On the other side, although reach trucks in narrow aisles help workers to access high locations, they have disadvantages of slower travel speeds, higher cost, slower put-away and extracting rates and longer learning curves than standard forklifts. Repetitive usage of reach trucks also causes neck strain, eyestrain and driver fatigue because of looking straight upwards to load and unload pallets. Another disadvantage of narrow aisles is not to allow workers pass each other within an aisle. Because a picker may block another worker to go

towards an aisle or to access a location for picking, narrow aisles may induce congestion in a warehouse. So, congestion reduces picker productivity and increases labor cost, as well as causing accidents and affecting employee morale. Gue et al. The narrow aisle causes between 4-13% congestion based on the number of workers and picks in an order picking system. They also could be preferred when space cost and the required storage capacity is high, while wide aisle is preferred when labor cost and required throughput are high[25].

In order to use the floor area due to Cross-docking operations and economising a space, the warehouse designers are making aisles narrow, they also increase the height of the storage area. Therefore, high-density storage systems are designed with very-narrow aisles and very high storage spaces. These storage areas require specialised material handling and storage equipment. Manned turret trucks are the most commonly used manually controlled equipment in these storage areas because of their flexibility to travel between aisles. Turret trucks can easily work in an aisle with a width of between 1.5-2 meters and go up high to 13 meters. Although initial investment cost is high compared to forklift and reach truck, the savings associated with space and productivity can offset its investment in a short time, especially in large warehouses. Because man goes up and down along the rail with the equipment, safety is a very important concern such that safety belts and harness use should be strictly enforced.

[25] Akkucuk U. (2018) Handbook of Research on Supply Chain Management for Sustainable Development, IGI Global. ISBN: 9781522557579. – p. 139-148

As aisles get even narrower, warehouses will certainly start to need an automated system. Computer-controlled AS/RS[26] can be used for handling both pallets and small units. Based on the characteristics of a load, the system can be designed within an aisle width of 0.15 meter and a height of 30 meters. The advantages of AS/RS are high throughput, high order accuracy, low labour and operating costs, and of course space savings. Moreover, while turret trucks have slow vertical speed because of safety, AS/RS have very high speed along both horizontal and vertical axes. However, their initial investment cost and energy consumption are high. Additionally, AS/RS system is not flexible as others because it works only on a single aisle in which it goes forward and backward along a rail.

Counterbalance, reach and turret trucks are the most widely used mechanical, and AS/RS is the electro-mechanical equipment. While mechanical trucks use either the combustion engine or electricity, electro-mechanical equipment is powered by electricity. The fuel for the combustion engines could be diesel, natural gas or LPG[27]. The electricity in mechanical trucks can be supplied by different type of batteries such as rechargeable lead-acid electric batteries. There have been contradictory explanations on the emissions of electric and LPG forklifts. The electric forklifts produce significantly lower emissions than any internal combustion engine forklifts to transport a ton of load over a distance of one kilometer after carrying out a lifecycle analysis on ten different forklifts.

[26] Automated Storage/Retrieval Systems
[27] Liquefied Petroleum Gas

The following simulation model shows the evaluation of energy consumption in a warehouse, which has a capacity of 1500 pallets, during operations picking and storing of loads with varying weights. It concluded that electric forklifts are environmentally preferable when the load is less than 3000 kg, whereas LPG forklifts slightly induce less emission for carrying more than 3000 kg. Based on the studies, the environmental impact of forklift changes based on the size of loads, capacities of equipment, their technologies and even driving habits. Briefly, electric forklifts have several advantages such as less noise, longer durability, no fuel-storage equipment, no tailpipe emission and lower cost per hour to operate. Their disadvantages over internal combustion forklifts are slower in acceleration, higher initial cost, heavy batteries, battery operating life (need to be recharged every 8 hours) and limited load capacity. As battery technology advances and the majority of electricity is generated by clean energy sources such as solar or wind power, electric forklifts or forklifts with different power sources will be more environmentally friendly and widely used in the industry. For example, plug Power, a hydrogen and fuel cell producer, shared that Amazon started to use a hydrogen fuel-cell forklifts, instead a battery-operated forklifts since 2017. It is declared that the advantages of hydrogen-fuel cells are no waste, no emission, long operating time until recharge, and quick recharge[28].

With an increasing consciousness on sustainability and increasing implementation of automation in warehouses, researchers have increased

[28] Baker P. (2010) The Principles of Warehouse Design, 3rd edition., The Chartered Institute of Logistics and Transport in the UK. – p. 99-105

their attention on the energy consumption of automated equipment and their effects on the environment. Let's give another simulation model of detailed energy efficiency for mini-load AS/RS to evaluate $CO_2$ emissions based on throughput and mechanical model of S/R machine with the hoisted carriage. An interesting result showed up that increasing velocity of the S/R machine doesn't always increase throughput, but it always increases $CO_2$ emissions. So, an installation of two independent AS/RS instead of S/R machine with extremely fast drives provide low energy consumption and $CO_2$ emissions while both provide the same throughput.

Another integrated simulation model shows the total evaluation of $CO_2$ emissions, which is induced by equipment, lighting, heating, ventilation and air-conditioning while considering the interaction between inventory, warehouse size and dimensions, aisle-width, and material handling equipment. The AS/RS warehouses have the lowest $CO_2$ emissions whereas warehouses with wide aisles and counterbalance forklifts have the largest emissions.

Many companies have implemented the 5S[29] methodology as a starting point for a continuous improvement and becoming a lean facility. These companies have reported increasing productivity, decreasing space requirement, decreasing indirect labor costs, increasing throughput, decreasing inventory and safety incident rates and many more improvements. Hence, 5S has been one of the most popular lean management tools that

[29] 5S stands for five Japanese words as Seiri, Seiton, Seiso, Seiketsu and Shitsuke and these are translated into English as Sort, Set to order, Shine, Standardise and Sustain, respectively.

enhances a great opportunity for warehouse managers to keep their facilities organized, safe, productive, waste-free, and eventually lean. In Toyota production system, lean simply means reducing seven wastes: defects, excess inventory, setups, breakdown, excess handling, lead-time and surging[30]. Hence, each S in 5S methodology aims to contribute to reducing some of these wastes.

Sort is the first step that requires workers to determine what is and is not needed in the storage area to perform the warehouse operations. The second step is set to order and aims to organise essential equipment and materials in order to minimize worker and material movement. So, specific locations should be set and clearly reserved for each set of equipment and materials such that anyone can find anything at any time. For example, a worker should not look for where the trans-pallets or empty pallets are located when they are needed. Additionally, when a worker is done with using an equipment, he should know that where it should be left. Then, it is time to keep the workplace clean in the third step – shining. For example, aisles, racks and forklifts should be cleaned and their condition should be checked periodically to avoid unexpected situations. Many products are wasted just because of contamination when a leakage occurs and the racks are not cleaned immediately. Many accidents occur just because of leaving pallets on aisles when workers could not find an empty location or an appropriate equipment to put-away. The last step, sustain, aims to spread the philosophy behind of 5S over the workers and make these steps in normal way of doing business. In practice, Menlo

[30] Hopp and Spearman, 2011

Worldwide Logistics in the USA implemented the 5S methodology in its warehouses to detect any misplaced materials or waste lying around to organise and clean workplace and to increase visual control. Venkateswaran et al. also implemented traditional 5S and the Hybrid 5S, which also integrates process improvement and inventory management, in three different hospital's warehouses. Authors presented that 5S methodology helps to increase turnover rates and even reduces required warehouse space. As a result, initializing a 5S project in a warehouse might be one of the primary steps in making an existing warehouse lean.

Using the data from ACER[31] reported that primary sources of electricity usage in warehouses in Europe are lighting – 39%, cooling – 17% and ventilation – 15%. Similarly, space heating – 89% is the major consumption component of natural gas. In total energy consumption in the Spain warehouses, heating – 23% and lighting – 42% are the major two components according to data from Ministry of Industry, Energy and Tourism[32]. Additionally, it is estimated that material handling equipment accounts 30%, and old-fashioned sodium luminaries make up 75% of the electric energy cost in warehouses in Spain. So, these figures show that heating, ventilation, air conditioning and lighting constitutes the main part of the energy consumption. The Spanish Government's Energy Efficiency Best Practice program suggests that housekeeping or simple business-as-usual strategies can provide a 60%

[31] EU Agency for the Cooperation of Energy Regulators
[32] Regulation EU No 1227/2011 of the European Parliament and of the Council of 25 October 2011 on wholesale energy market integrity and transparency

reduction on direct energy used for lighting, HVAC[33] and powering equipment[34]. Everyone knows that ongoing advancement in technology changes the types of materials and equipment used not only in warehouses but also in our life. Today's technology becomes primitive for tomorrow's industry. However, the following lists of simple housekeeping practices might present a conceptual framework for warehouse managers to follow and look up potential energy, cost and emission reduction areas for sustainable warehousing. Moreover, some of the following practices aim to increase worker's safety, health and job satisfaction. Below listed the best practices, expected to reduce emission and energy bills in warehouses:

- To control temperature at satisfactory level for the stored products, it requires controlling minimum and maximum temperature level, as well as controlling the humidity.
- To use zoned or time-controlled thermostats.
- To control temperature and ventilation for workers to perform their work in comfort.
- To use close fitting barriers or door locks, or fast-acting doors where forklifts go in and out frequently in order to avoid heat loss.
- To segregate unloading and loading areas from other areas where main warehouse operations are performed to prevent from heat loss.
- To turn off lights when an area is not in use or is sufficiently naturally lit. Alternatively, to use motion sensors in low traffic zones to dim lights. To

[33] Heating, Ventilation, and Air conditioning
[34] Secretaría de Estado de Energía (2021). Estrategia de Almacenamiento Energético. ISBN: 978-84-18508-43-1, Madrid.

catalyze this practice, label the appropriate switches so that workers know which ones for lighting.

- To use LED lamps for parking lot, loading dock, security, and exit signs.
- To install photo sensors to control outdoor lighting.
- To clean skylight glass roof panels to keep obtaining natural light.
- To clean and replace lamps periodically to ensure full light output. To reuse wooden o plastic pallets or recycle those to minimize waste. Warehouse managers even may prefer to use slip-sheets and corrugated trays as an alternative to the use of pallets if products are lightweight.
- To ensure regular maintenance of HVAC systems, including replacement of filters.
- To ensure that exhaust fans are shut off when building is unoccupied.
- To ensure that wall and roof insulations are appropriate for local climate.
- To conserve water to use in toilets or watering plants.
- To generate more environmental friendly energy; for instance using solar or wind power nowadays.
- To use mobile terminals for order lists instead of paper lists.
- To use a print-on-demand solution to reduce obsolescent inventory and paper consumption.
- To design efficient packaging thereby reducing material requirement and handling costs.
- To charge forklift batteries during in off-peak hours.

- To ensure technical and soft-skill training for all workers to change their work habits and accommodate new procedures.
- To performance periodic maintenance and service of material handling equipment.
- To use identification systems such as barcode or RFID[35] for tracing pallets and storage locations to reduce travel time and increase productivity and order accuracy.
- To use voice-to-pick or pick-to-light systems to increase picking efficiency and reduce error in picking. These also alleviate worker's eyestrain caused by reading paper lists.
- To design shift roster such that disruption to natural body clocks is counterbalanced.

Hence, 20% cost savings and significant emission reduction can be obtained by replacing 400w of high-pressure sodium-light bulb with Triphosphor tubular fluorescent in lighting. Additionally, reducing storage temperature by 1 degree may provide 10% savings in energy. Using fluorescents or LEDs in a medium-size warehouse may reduce required lighting energy by 85% to 95% and decrease $CO_2$ emissions between 24-38%. By improving building insulation, HVAC energy consumption might be reduced by 8% to 18%, and $CO_2$ emissions may be decreased by 6% to 14% because of decreasing heat loss[36].

[35] Radio-frequency identification
[36] Baker P. (2012) The Environmental Impact of Warehouses., Proceedings of the Logistics Research Network Conference. – p. 23-27

Greenhouse Gas Protocol 2014 presented a guidance for companies to calculate their emissions. In this guidance, storage-facility related emissions are calculated using two methods based on the availability of data. The first one is called site-specific method that requires detailed fuel and electricity use and air-conditioning or refrigerant leakages. Therefore, the following formula is proposed in the guide for calculating total emissions of a storage facility based on site-specific method:

Emissions of a storage facility (kg $CO_{2e}$) = fuel consumed (kWh) x fuel emission factor (kg $CO_{2e}$ / kWh) + electricity consumed (kWh) x electricity emission factor (kg $CO_{2e}$ / kWh) + refrigerant leakage (kg) x refrigerant emission factor (kg $CO_{2e}$ / kg).

The second method, called average-data method, helps managers to estimate emissions based on average data such as average emissions per pallet or cubic meter stored per day. Hence, the guide simply presents the following formula: Emissions of a storage facility (kg $CO_{2e}$) = volume of stored goods ($m^3$ or pallet) x average number of days stored (days) x emission factor for storage facility (kg $CO_{2e}$ / $m^3$ (or pallet) / day)[37].

## FRAMEWORK OF SUSTAINABILITY IN WAREHOUSING

The environmental balance of the warehouse consists of two stages: the emissions from the construction and the operational emissions. To understand

[37] Blanchard D. (2008) How to Build a Lean-Green Warehouse Network, IndustryWeek, p.64–65.

better how the impacts from emissions can be reduced, the author should examinate the current standards to assess the environmental performance of warehouses.

The most widely used standards for evaluating the sustainability of warehouse design are the Leadership in Energy and Environmental Design framework – US method and the Building Research Establishment Environmental Assessment Method – UK method. Both schemes measure the sustainability of warehouses by awarding point scores in several weighted categories. Depending on the overall point the warehouse is accredited a certain sustainability class: BREEAM statuses range from Pass to Outstanding; LEED categorises warehouse sustainability from Certified to Platinum. Both schemes add a weighting factor of 10% for innovation. The first warehouse to achieve an Outstanding status under the BREEAM scheme was the G Park Blue Planet distribution centre in Chatterley Valley, England[38].

Despite the proposed operational savings resulting from high environmental ratings this doesn't necessarily lead to equivalently higher yields in terms of rent or value. A recent study found that energy savings expressed in better Energy performance certificates ratings didn't result in an equivalent increased rent and there is only limited evidence that better EPC ratings had an impact on profitability. Although tenant surveys express willingness to pay a premium for operational savings, tenants also identify a

[38] LEED Building Design and Construction: Warehouses and Distribution Centers. Offical website.

tendency to shorter-term leaseholds, which reduces the attractiveness of longer-term investments in sustainability measures.

The gap between environmental performance and rents may be explained by the different interests of the many interested parties involved in a building over its lifetime. Real estate developers are mainly interested in the return on investments, short-term risks and only indirectly in the functional quality of the warehouse. Financial investors have their main interest in the return on investment, the expected development of the property value and the anticipated risks. If the warehouse is going to be owned by the company, future rents are not part of the consideration, but more focus is on functionality, risks and lifecycle costs. Tenants in contrast are mainly focused on the rent and functional quality, while the public authorities are mainly interested in the external costs and total costs of the warehouse and the risks anticipated with the construction.

The accreditation schemes initially focused very much on the design stage of warehouses. However, they have developed guidelines for assessing sustainability improvements at existing sites. Implemented energy in existing buildings is often overlooked and an evaluation of the whole lifecycle of a building, considering the integrated energy, carbon, and other emissions, is therefore a more complete approach. This also applies to considerations of end-of-life issues, such as the disposal of materials and the energy consumed in the deconstruction. In total, the lifecycle analysis should consider inputs and outputs from raw material extraction, manufacturing, construction, use and waste disposal. One must also note that the accreditation schemes use a set

framework without considering variations between countries in the importance of various sustainability aspects. In water- deficient countries water usage may have a much higher priority than land use.

The total environmental balance depends on the sum of emissions from all stages of the warehouse lifecycle. It may therefore be less environmentally damaging to use an existing site despite poor operational performance, since the included energy and emissions have already occurred. The relative proportions of operational impact and embodied impact differ significantly between warehouses and strongly depend on their durability. In a comparison of various roof light ratios and insulation options, Rai et al identified that the combined impact of included and operational $CO_2$ emissions of a warehouse over a 25-year durability didn't show huge differences in the total $CO_2$ impact. The study compared scenarios of decisions on roof lights and insulation at the design stage of a conventional distribution warehouse of 8.000 $m^2$ and the impact they have on heating during the operational phase of the warehouse. Due to the higher carbon integrated in the insulation material and the roof lights, an increased level of insulation had only a very marginal positive effect on the environmental balance of the warehouse over its whole life. However, the proportion of operational impact and embedded impact is crucial in the lifecycle analysis. Gregori and Wimmer assume that 80% of costs are caused during the operational phase of a logistics building, which gives sustainability considerations in the design stage more attention. They also point out that over the 25-year durability of a warehouse, one needs to assume rising costs for energy. An assessment is even harder to make when looking at the often high

turnover of tenants. A warehouse may often not be fully utilised, leading to inefficiencies. It can also mean that additional emissions from construction activities occur at a later point when altering the warehouse to a new tenant's needs.

## MICRO AND MACRO LEVELS

There has been comparatively little research into the impact of warehousing upon the environment and local communities. This is surprising given that vast warehouse facilities, sometimes upwards of a thousand hundred square feet, are being constructed at strategic locations throughout developed and developing markets. This trend has been driven not only by the desire to consolidate inventory holdings on a regional basis, but also by omni-channel, e-selling strategies of retailers and manufacturers.

In the context of the modern contract logistics industry, warehousing and distribution activities include not only the full range of distribution facility operations but, increasingly, VAS services such as postponed manufacturing. This means that warehouses become units of major economic activity, sometimes employing more than a thousand people. The consequence of this is that the environmental and public impact of warehousing goes far beyond the walls of the building. For example, there are obvious issues related to the movement of lorries to and from the facility, but for many residents the real problems are caused by visual intrusion of the building; the movement of staff at the start and end of shifts; the consequential accumulation and noise; water

run-off from large staff car parks; and noxious odours emanating from the building.

The activities that take place within the warehouse also have consequences in terms of GHG[39]. These are known as Operational carbon, and this is separate from the Embodied carbon or carbon footprint of the physical warehouse itself. There is, of course, a large amount of interaction between the building fabric and the operations that take place in and round it, lighting for example. Latest best practice requires there to be more natural light allowed into the warehouse and this impacts on the design of the building. This is also the case with minimizing or maximizing air flow. Therefore, the way the building is designed has an impact on energy usage and hence operational costs[40].

Although it is usually cheaper and quicker to build on greenfield locations, there are many environmental reasons why it is better to develop brownfield locations i.e., the land previously used for industrial purposes. Not least of these reasons is that it offers an opportunity to clean up areas that are often contaminated. In addition, they provide a source of regeneration and employment in already populated areas. Vise versa, building on greenfield locations, especially in rural sites, can leave an occupier with the problem of recruiting staff. This can lead to the influx of low-skilled, low-paid foreign labour to communities that lack the infrastructure like house construction, social and

[39] Greenhouse Gas Emissions
[40] Directive 2009/31/EC of the European Parliament and of the Council of 23 April 2009 on the geological storage of carbon dioxide and amending Council Directive 85/337/EEC, European Parliament and Council Directives 2000/60/EC, 2001/80/EC, 2004/35/EC, 2006/12/EC, 2008/1/EC and Regulation (EC) No 1013/2006

transport to cope. Locating warehouses on greenfield locations can also increase the carbon emissions of staff travelling to work, as in many cases there will be little provision of public transport.

Local authorities are more likely to support the development of brownfield locations especially when the developer commits to improving local infrastructure such as roads and drains. The use of brownfields can also provide opportunities to reuse or recycle building materials. This not only reduces the embodied carbon footprint of the building infrastructure but also reduces GHG emission generated by the movement of building materials to the site.

As green logistics now is a top public policy issue around the world, governments have started to require or encourage the adoption of environmental standards for logistics property development. Best requirements now include[41]:

- using solar panels and wind turbines;
- reducing waste in construction;
- using environmentally friendly, recyclable materials;
- reducing $CO_2$ emissions;
- reducing water usage and use of rainwater (grey water);
- reducing pollutants;
- increasing biodiversity and enhancing local habitats;

[41] Blanchard D. (2021) Supply Chain Management Best Practices, Third Edition, John Wiley & Sons Inc. – p. 56-67

- increasing energy and resource efficiency;
- stormwater collection and use of permeable paving;
- energy efficient lighting – solar panels;
- green roofs.

To encourage developers to work towards best environmental practice, companies and governments have established initiatives that can measure and accredit the sustainability of warehousing projects. In terms of European legislation, the 2020 Energy Performance of Buildings Directive is the main regulation which, transcribed into national law, governs many aspects of property sustainability, including that of the distribution sector[42]. It requires that:

1. EPCs[43] are included in all advertisements for the sale or rental of buildings.
2. EU countries must establish inspection schemes for heating and air conditioning systems or put in place measures with equivalent effect.
3. All new buildings must be nearly zero energy buildings by 31 December 2025 and the public buildings by 31 December 2028.

EU countries must set minimum energy performance requirements for new buildings, for the major renovation of buildings and for the replacement or retrofit of building elements: heating and cooling systems, roofs, walls, etc. According to property developer Prologis, this Directive has meant that green

[42] Fabbri M., Glocker J., Schmatzberger S., Rossini A.V. (2020) A guidebook to European Building Policy. Key legislation and initiatives. - Chapter Building renovation and decarbonisation of building stocks by 2050 - p. 25-32
[43] Energy performance certificates

warehousing has now become best practice in the industry. In other words, a gold standard against which all warehousing is measured[44].

The award of the EPCs is, of these points, the most important. It allows companies to choose the most efficient buildings in terms of energy as well as helping them to reduce to minimum their carbon footprint. This is not straightforward as the different climates experienced across the region mean that different building styles are required. For example, UK warehouses are designed to optimise air tightness and insulation whereas those in Southern Europe: Spain, Italy, Portugal require air circulation to prevent over-heating in summer months. For this reason, EPC certification is devolved to EU level.

## LAYOUT

Warehouses are typically designed to do what it is supposed to do: keep the products safe as required and flush them out as soon as possible when demanded. Therefore, cross-docking warehouses, where products are sent for shipping after receiving operation without putting them away to storage locations, are very efficient and becoming popular in warehouses, if applicable. Hence, during warehouse operations, the primary objective is to arrange warehouse such that it maximies throughput, minimizes travel, maximizes storage usage or storage capacity. Even though the number of automated vehicles and robots have been increasingly used to increase efficiency in warehouses, the majority of the warehouses are still operated by human

[44] Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC

workers. Considering that workers spend at least one third of their life at work, doesn't it really matter how the warehouse is organised from worker's perspective? This is a sharpening question for the warehousing industry that has been focusing on mainly financially oriented performance measures in designing workplaces. Hence, four major areas were proposed that needed to be taken into consideration to create human-centric warehouses: industrial phycology, architecture and interior design, safety and ergonomics, and operations. Walgreen's Anderson distribution centre located in South Carolina might be given a good example to a human-centric warehouse. One of the most sharpening things in this warehouse is that almost 40% of the workers are physically disabled or mentally handicapped. The warehouse is specially designed with flexible workstations, wheelchair ramps, elevators and full of touch screens for vision-impaired workers to make workers work easily and comfortably. Another bright example is Maersk warehouse in Spain. It equipped with "Comfy room", the essential part required by Well-being comity, it is a place to relax mentally and physically from stressful situations as well as take a first aid in case of accident. By company's policy, all warehouses should obtain the Comfy rooms. Therefore, with a good level of collaboration between workers and managers and appropriate training, they achieved more productivity than some other distribution centers[45].

Because the design of a warehouse is established before workers start to work and is not easily changed after it is built, its effect on the flow of materials and human lasts a long time. The author will examinate how to deal

[45] Maersk Warehousing & Distribution strategy 2022. European warehouses. Spain. – p. 34

with sustainable warehouse layout problem and review several recent developments in warehouse design in this part.

Warehouse layout decisions mainly comprises of the placement of departments and designing inside of the departments. The main departments in a typical warehouse are receiving, storage and picking, and shipping. Among these, storage and picking areas actually refer the same place because we pick from where we put-away. However, these areas may be divided into different areas within the warehouse with respect to the type of handling: unit-load, case, piece-picking or type of product characteristics such as flammable, perishable or frozen. So, how to locate these departments affect not only material handling cost, construction and maintenance cost, space and equipment utilization but also products and worker's safety and health. While good layouts provide higher productivity in warehouses through reducing travel distances, reducing congestion on aisles, and increasing communication and supervising between departments, it also enhances safe and pleasant working environment by preventing unwanted interaction of departments. Thus, very well-defined warehouse layouts contribute to the sustainability in warehouses.

To deal with warehouse layout problem there exist both quantitative and qualitative techniques. While quantitative models focus on reducing total travel distance between departments, qualitative models consider the required level of relationship between them. The simplest form of the quantitative model is called Quadratic assignment model that aims to assign number departments to number locations such that total weighted distance among them is minimised. Because the main assumption in this model is that departments

have equal shape and space, the pairwise-exchange method can be used to solve this model to obtain good solutions. More advanced model was developed to locate departments with an unequal area in a continuous two-dimensional space and proposed an efficient solution methodology. Among qualitative models, Muther's systematic planning approach is the most commonly known and applied method. This method relies on adjacency relationship between the pair of departments. The relationships between a pair of departments is defined by using five metrics: absolutely necessary, especially important, important, ordinary, unimportant and undesirable, according to the underlying reason of the relationship. These can be accounted as a convenience, flow of material, ease of supervision, usage of same equipment, cleanliness, dust and fumes, contamination and safety regulation. To solve these quantitative and qualitative models that arrange the departments easily with satisfactory results, there also exist computerised tools called LOGIC, CRAFT, BLOCKPLAN, ALDEP, CORELAP and MULTIPLE[46]. One recent study also proposed a hierarchical approach using MCDM techniques to select the best design among several alternatives with respect to space, distance and energy related metrics. Eventually, these methods result in rough layouts that need to be processed in detail.

Detailed warehouse design is interrelated with many medium level tactical decisions such as number and orientation of aisles, width of aisles, height of storage area, numbers and the places of receiving and shipping

[46] Layout design tools which facilitate the efficient visibility for construction

docks, type of material handling and storage equipment as well as occupational safety regulations and fire codes.

Generally speaking, there are two types of aisles in a warehouse: cross and picking aisles. While cross aisles are spaces that facilitates travel from one location to another, picking aisles are used to access a storage location for put-away or picking. Although aisles are accounted wasted space because they are not appropriate for storage, they are required for operational efficiency such that they reduce travel distance and prevent from congestion, which may cause accidents. In conventional rectangular shape warehouses, as picking aisles are oriented straight and parallel to each other, cross aisles are arranged perpendicular to them (see Annex 1). Because traveling accounts almost half of order-picking cost, which is the costliest operation in a warehouse and travel time is accounted as an unproductive and a non-value-added time. Many studies focus on investigating the effects of numbers and locations of cross aisles in conventional warehouses under different operational assumptions. For instance, the optimal number and length of cross aisles with the location of a depot such that order picking tour length is minimised in a conventional warehouse. Because there are numerous studies available for conventional warehouse, only recently developed non-traditional warehouses are reviewed in this part. Therefore, it's suggested for a comprehensive review on conventional warehouse design.

In conventional warehouses, workers move in rectilinear (90 degrees) travel that goes along horizontal and vertical travel path through aisles. This design present savings in single-command travel distance, which is the

distance between an input-output (IO) point and a storage location, up to 15% and 25%, respectively. An IO point in these warehouses usually refers place where workers start and end their travel. For example, this can be a dock, stretch-wrap machine, or an inspection office. The main insight behind these designs is that workers get to many locations more quickly through angled aisles. These remarkable savings attract both researchers and industrial practitioners to consider angled aisles in warehouse design. While practitioners take a conservative position because of the design constraints in these designs, academician started to investigate their potentials under different design assumptions. A fishbone designs offer improvement in travel distance for dual-command operation, where two locations are visited on a tour, and turnover-based storage policies, respectively. The fishbone designs present up to 12% reduction on tour length for order-picking operation based on several warehouse sizes and order settings. The aforementioned non-traditional aisle designs assume that material flow through a single, centrally located IO point on the front of the warehouse. The flying-V still offers improvement in distance when multiple IO points are added on the front of the warehouse, but not much as the original design. A constructive aisle model in a discrete environment to search for the optimal aisle angles under different IO point configurations and different storage policies. Using this model, non-traditional aisles present up to 12% savings in distance based on the locations of multiple IO points.

Although non-traditional designs fasten retrieval rates and reduce costs for operating warehouses significantly, and these designs require extra

storage space to accommodate the same number of storage locations with the equivalent conventional design, in which there is no cross aisle because of no benefit in a single-command distance. The reason of this extra space is caused by additional cross aisles and angled aisles. For instance, while Chevron presents up to 19% improvement in distance for the majority of the warehouse sizes in industry, it requires up to 9% extra storage area[47]. Similar results are also valid for other non-traditional aisle designs. Even though non-traditional aisle designs reduce operational emission by leaning put-away and picking operations, it is obvious that they cause additional embodied emission during the life cycle of the building due to extra storage space compared to the equivalent conventional warehouse. Moreover, this causes extra $CO_2$ emissions because of extra lighting, ventilation, heating and air-conditioning. A detailed lifecycle analysis should be conducted to investigate the net emission savings of non-traditional aisle designs to reflect their contribution to the sustainable warehousing.

## REDUCTION OF THE ENVIRONMENTAL IMPACT

Following the lifecycle concept, for buildings we can generally differentiate between operational or equivalent carbon emissions and the implemented emissions. Investments in the operational improvement of the sustainability of a warehouse may often occur at the construction stage and it is therefore important to understand the purpose and the anticipated lifecycle of the building. RICS[48] considers the share of embodied carbon equivalent

[47] Minghini J. (2016) How to Control Warehouse Storage Costs, Material Handling & Logistics, p. 24–26.
[48] Royal Institution of Chartered Surveyors

emissions to be 65% of a warehouse's overall $CO_2$ equivalency emissions. However, if assuming a lifecycle of only 10 years, the share of embodied $CO_{2e}$ rockets to 95%, shifting the focus of emission savings from the operational phase to the construction itself. In comparison, a supermarket over its lifetime would usually have a ratio of 13% captured energy to 92% operational energy, as a supermarket typically uses a lot more energy than a warehouse[49].

The derivation becomes crucial when discussing what emission reduction levels are supposed to be achieved. For the erection of a short-term warehouse, operational emissions can almost be ignored, and more attention needs to be placed on avoiding $CO_{2e}$ in the construction operations and material. While for long-term use of a warehouse, operational savings become more worthwhile even if they cause more emissions in the construction phase, for example for additional insulation. While constructing, emissions are caused by the construction materials and the construction processes. The emissions embodied differ in the construction materials. An aluminium curtain wall contains around 1.000 MJ/$m^2$ of embodied energy but has a durability of less than 40 years[50].

For warehouses, it may be unlikely that they will really be usable for the full 40 years life cycle. Storage and logistics requirements change over time and particularly the layout of multi-customer sites needs to be changeable to

[49] Sinden G. (2010) The contribution of PAS 2050 to the evolution of international greenhouse gas emission standards. International Journal of Life Cycle Assessment, 14, p. 196
[50] Fieldson R., Rai D., Sodagar B., X Hu. (2011) Assessment of $CO_2$ emissions reduction in a distribution warehouse. Energy, 36, p. 2273-2274

adjust the number of doors, allow more height, floor strength for heavy goods or special storage arrangements like clean rooms or refrigerators.

Many logistics sites cluster in areas that are close to the transportation centres of gravity for the markets they are serving, or they group around ports and airports as was mentioned above. Availability of the right warehouse space in the right areas therefore becomes an issue. The most popular locations are most often found in relatively densely populated areas, where space is limited and expensive. Additionally, traffic congestion and local restrictions on traffic and operating hours restrict warehouse operations. The high cost and limited availability of space may lead to the construction of higher buildings and the installation of handling equipment that uses up less space, and real estate developers will naturally look into brown-field developments. Although this incurs demolition costs, it may benefit sustainability as upgrading existing structures avoids the addition of embodied carbon from construction material used in building a new warehouse.

The use of land itself is an emission and newly built warehouses interfere with the environment. This can be rainwater no longer trickling into the ground, interference with local wildlife and destruction of green areas, and visual impact on the landscape. The area also becomes unable to absorb any carbon, which in the case of the site that was once agricultural or vacant, has a permanent effect. The amount of territory used for warehousing in Europe has been increasing significantly over the last decade and is now greater than the land covered by offices or commercials.

Construction processes rely on heavy machinery and engines to move construction material, stones and wastes. Usually, warehouses are lighter structures than office buildings, it shows that the construction processes add significantly to the carbon footprint of any building, including warehouses. However, supply chains in the construction industry are influenced by many stakeholders who have different interests. Involving all stakeholders of a building's life cycle is complex and must look beyond the client-contractor-supplier relationship. The shift towards sustainability in construction must come through the purchasing power of influential buyers and their demand for specified performance criteria. During the construction phase much of the building material is delivered directly from manufacturers to the site and very little communication exists across the network of manufacturers, contractors and hauliers. Transport efficiency is also negatively affected by the geographical location, accessibility and a lack of infrastructure at greenfield locations.

Besides the embedded emissions in the building resulted from the construction materials and processes, the operational emissions need to be considered. Although the discussion is mainly focused on reducing the energy consumption of a site, the warehouse's operational sustainability also consists of other aspects like using all resources more efficiently and reducing the waste generated by a site.

Comparative analysis and comparison of the energy performance of warehouses is difficult as they are built in different environments and contexts and for different longevities, products and purposes. Also, environmental

auditing schemes vary and may work in favour of particular solutions. For example, the PAS 2050 carbon auditing guidelines exclude employees commuting journeys from the audit, giving an advantage to a warehouse that's operated with more human labour and less technology and ignoring the additional emissions from commuting trips if a warehouse is poorly connected to public transport and far away from the employees' residences[51].

Temperature control in warehouses is estimated to contribute up to 25% to a frozen goods of warehouse's operating cost. Refrigeration units use obviously electricity; the way, that electricity is produced therefore determines much of the carbon footprint. Heating systems are usually based on burning fossil, fuels or materials from renewable sources. The loss of heat depends on the temperature difference between the inside and outside of the warehouse, insulation and building material, and controlled and uncontrolled air ventilation. Warehouses may require a wide control of humidity or even the oxygen content. For example, fresh fruits are usually stored in a $CO_2$-filled environment to decelerate the ripening process. However, temperature control also needs to consider the comfort of warehouse employees. Although the storage area may be refrigerated, the staff room right next to it will be heated at the same time. Health and safety regulations limiting employees time in the low temperature environment and safety clothing limit the operations in such warehouses. The heat from handling equipment, lighting and machines adds to the required refrigeration effort. Temperature-controlled warehouses (Cold

[51] Office of Public Sector Information. (2020) Guide to PAS 2050. How to assess the carbon footprint of goods and services. - p. 118-120

store) therefore not only depend on the ability to achieve the required temperatures, but also to hold those temperatures.

Regardless of whether, the warehouse requires heating or cooling, thermal insulation and heat-cold loss barriers reduce the consumed operational energy, although they may increase the embedded emissions. Some ventilation is required to exchange air and maintain an environment that is safe for people to operate in; however, controlled and uncontrolled air ventilation has to be considered separately. The exchange of air means constant temperature adjustment. A warehouse with high rates of uncontrolled ventilation – infiltration, wastes energy for heating or cooling. Air leakage causes about 27% of heat loss in a typical industrial building. Unnecessary losses of temperature-controlled air from ventilation can be prevented through separating temperature zones effectively: installing fast-acting gates, closely fitting doors, using thermostats and opening doors and gates only when necessary. Warehouses are usually built with very high ceilings. Hot air rises, which can lead to temperature differences between ground level and close to the ceiling of up to 10 degrees Celsius. Ceiling circulation fans redistribute the heat back to the ground floor where the operators are working. Usually, the savings from the value of heat exceeds the energy consumed by the fans.

The thickness of insulation reduces the temperature loss and therefore also reduces the required energy for constant temperature adjustment. However, the thicker the insulation the larger the realised energy in the insulation material; there is consequently a maximum at which insulation makes sense. Warehouses can also be separated in zones, with barriers

between them to limit the ventilation to smaller units and to adjust temperatures more precisely. The lower the temperatures required the greater the refrigeration effort and the electricity consumed. Therefore, separating products into groups of the same temperature storage requirement levels avoids the storage of products at temperatures lower than necessary.

An ambient warehouse of an average size (~50.000 $m^2$) uses about 2/3 of its electricity consumption for lighting. Installing more efficient lighting technology, roof lights, and switching off unneeded lights can reduce the electricity used for lighting. New energy efficient lights, like LEDs or fluorescent lights, convert a higher proportion of the input energy into light and less into heat than conventional lights. They are also lower in maintenance and have a short payback period of only a few years. The total number of installed lights can also be reduced by about 33% through the installation of reflectors above the light source. Generally, however, the lighting requirements are determined by the tasks performed in a particular part of the warehouse, for example lighting at the storage area depends on aisle width and height. Solutions therefore need to be adapted to individual warehouse designs and purposes[52].

Allowing sunlight to shine into the building, for example through the installation of roof lights, can be a way of reducing the need for artificial light. Natural sunlight is besides perceived as more comfortable than electric light. However, roof lights need to be considered in their overall effect, as they may have a negative impact on thermal insulation. Both roof and electric lights

[52] Baker P. (2012) The Environmental Impact of Warehouses., Proceedings of the Logistics Research Network Conference. – p. 67-72

require cleaning periodically, as the dust of two years of operations can reduce the light levels by up to 55%, increasing energy consumption by 18%.

Light arrangement only in the areas where it is needed, turning off lights manually, the installation of movement sensors or time controlled light switches saves significant amounts of electricity. Changes in warehouse lighting usually show rather short payback periods, making it an attractive sustainability improvement for rented warehouse sites and shorter lease times.

Another field of energy consumption in the warehouse is the use of operational equipment. This includes automated storage systems, which consume electricity for moving goods around and computer systems controlling the movements and storage. Forklifts can come in many varieties to suit the characteristics of the goods and the site. They run on various types of fuels or electricity. Similar to lighting installations, material loading equipment emits heat in addition to energy consumption, increasing the energy used in temperature-controlled warehouses. Fumes from fuel-based operational equipment also increase the need for ventilation, reducing the thermal efficiency of the building. A shift to lower emission fuels and electric forklifts reduces the $CO_2$ emissions from warehouse operations. No clear general statement of what energy type for forklifts causes the least emissions can be made from prior studies. Evaluations differ between well-to-pump, well-to-wheel, outlet-to-battery, battery-to-wheel and wheel-to-exhaust, making the alternatives hard to compare. A full lifecycle analysis including maintenance, durability, disposal and energy consumption would have to be considered to really compare the options. The complexity of such an assessment and the

difficulty of comparing the alternatives tend to lead to a cost-of-ownership approach rather than a total emissions assessment[53].

Improvements in battery technology and energy efficiency may increase the sustainability and attractiveness of electric forklifts. As they are charged from the electrical network, the source for the electricity can be determined by the warehouse user. Modern electric forklifts can also regain energy when the forks are lowered with a load or when the machine brakes. The regaining of energy together with improved battery endurance, faster charging modes and better energy efficiency results in longer operating times, reducing the total number of batteries or forklifts required. Through advances in technology, electric forklifts became the main mode for the indoor use of forklifts.

Likewise, the optimisation of any other transport network, movements within the warehouse made by forklifts or other mechanical handling systems can be optimised by using IT and warehouse management systems (WMS). Forklifts enabled to communicate with the WMS who can reduce the number of movements, for example by avoiding detours to input data into a computer station. Other electricity-consuming technology applications in the warehouse are picking systems, such as pick-to-voice – voice-directed warehousing system with speech recognition for more efficient VAS services or pick-to-light[54].

[53] Directive EU 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources
[54] Browne M., McKinnon A., Whitening A. (2012) Green Logistics: Improving the environmental sustainability of logistics, 2nd edition, Kogan Page. – p. 78-81

A total warehouse's emissions can also be reduced by consideration of the wider operational issues. Operating hours and delivery can be scheduled to avoid peak traffic times. Avoiding congested areas for the warehouse site also means fewer lorries are sitting in traffic.

Warehouses also consume water. Water is spent for worker’s needs, but also in the cleaning of the warehouse lorries and in the processing of goods, especially if value-added activities are happening at the warehouse site. Also, refrigeration units may consume water. Due to the usually large roof surface many warehouses are ideal for harvesting rainwater and reusing it in grey water areas in the warehouse.

Depending on the level of value-adding activities and packaging processes, warehouses create waste like any other industrial site. Incoming deliveries may need to be split up, unpacked or re-packed before they are stored. Outgoing products need wrapping, may be put on disposable pallets or packaged in other ways. Reducing and avoiding packaging, recycling packaging materials and packaging in a way that makes it easier to recycle, all reduce the environmental impact of the warehouse's waste.

## WES, WMS AND TYPE OF OPERATIONS

The focus of any distribution operation is basically inventory, but that's about the only thing that all companies will agree on. When it comes to inventory, how much a company should carry changes according to the time of year, the industry a company is in, the corporate philosophy of senior management, the flexibility of its suppliers, and most especially, the demands

of its customers. No company wants to be caught short, but sometimes having too much inventory can be just as bad as not having enough. The short answer, to the question of how much inventory a company should carry is: it depends.

Knowing how much inventory the company needs is important, but equally important is knowing where that inventory is at any given time. A WES[55] coordinates all of the processes that take place inside a warehouse or distribution center, including material, handling equipment, devices, inventory management, and employees. A WES typically integrates with a WMS[56], ERP[57] or other inventory management software. Warehouse execution systems have been around in various forms since the early 2000s. They provide DCs with flexible and efficient material handling processes – both automated and manual. While WMS systems typically include system-directed picking, replenishment and other functions, AS systems add sophisticated process optimization capabilities. WES vastly improve the productivity, efficiency and throughput of core DC activities. WES systems take two main forms: automated and manual.

The role of tracking product location within a warehouse is typically assigned to a WMS, a software application that interfaces with supply chain planning, order management, ERP, and transportation management systems, and can track the locations of a company's products by purchase order, bar code, lot number, pallet location, or other identification system. Thanks to the

[55] Warehouse Execution System
[56] Warehouse Management System
[57] Enterprise Resource Planning System

usage of RFID tags, urged on manufacturers by major companies and the US Department of Defense, the companies can already track at least some products in real time, and the end goal is being able to know exactly when and where those products were manufactured, packaged, and shipped.

Companies that used to rely on manual and paper-based inventory systems have found significant labor savings by adopting a WMS solution integrated with handheld bar code scanners and other supply chain technologies. For instance, an order can be entered directly into an ERP system, which will send the order to the warehouse or DC for picking and shipping. The system will then automatically send an invoice to the customer. Order pickers in the warehouse use the scanners to check rack and shelf locations, and to verify every order that they pick. The scanner informs the picker exactly where on the dock to take the order.

Companies that have adopted a WMS typically experience labor savings between 25% and 45%. Space usage is typically 15% to 25% more efficient when using a WMS, inventory levels could drop by as much as 55% after three years, and the costs of conducting a physical inventory check can be reduced by 78%. In addition to adopting WMS solutions, warehouses are increasingly going the wireless route, which includes voice recognition systems: pick-by-voice, RFID, handheld devices, global positioning systems (GPS), geofencing, wireless networking and other solutions that facilitate real-time access to

inventory data. Actually, 82% of the companies identified as best-in-class use real-time mobile devices to process transactions[58].

For example, Ace Beverage, a major beer distributor for Anheuser-Busch, has a wireless data system that communicates real-time delivery data throughout the day. This system has greatly improved delivery efficiency, helping the distributor to eliminate 16 to 21 hours per week that it used to spend on driver and loading dock worker overtime. Thanks to the wireless system, when retail orders are in-house by 2 p.m., Ace Beverage starts loading the trucks according to scheduled stops, gaining a big jump on the loading process. Warehouse can start preparing loads early by picking the products from the warehouse inventory and staging them without having to load them onto trucks[59].

A Cross-docking logistic process is the distribution process of rehandling freight from inbound trucks and loading it onto outbound trucks, without first storing the freight. According to a study conducted by logistics services provider Saddle Creek, 50% of respondents are cross-docking durable goods, followed by high-value products – 25%, nondurable goods – 22%, and perishable goods – 19%[60]. Tom Patterson, senior vice president at Saddle Creek, says that cross-docking is worth considering if:

[58] Carter C.R., Rogers D. S. (2008) A framework of sustainable supply chain management theory., International Journal of Physical Distribution & Logistics Management, 38 (5) – p. 364
[59] Richards G. (2022) Warehouse Management – The Definitive Guide to Improving Efficiency and Minimizing Costs in the Modern Warehouse, Fourth Edition., Kogan Page Limited. – p. 45-47
[60] Saddle Creek Warehouse and Distribution solutions study 2020

- Your traditional distribution methods and current order cycles are not sufficient to handle customer needs.
- Your distribution network is outdated and inefficient, leading to extended cycle times and compromised shelf-life guarantees.
- Your transportation networks are overextended, negatively affecting your on-time delivery performance and requiring excessive reliance on expedited service.
- Your distribution costs are increasing faster than your sales growth.

Another one of the warehousing best practices that sellers like Walmart, Amazon, Target, Auchamps, IKEA have adopted cross-docking planning, where inbound products are unloaded at a distribution center, sorted by destination, and then reloaded into lorries. The goods are never actually warehoused at all, but they are just moved across the dock. This strategy allows a seller to unload, for example, a truckload of high-definition TVs at a regional DC, and then load a single TV into different lorries headed for different destinations. Ideally, the trucks should be timed to arrive and leave at roughly the same time. Cross-docking has lately developed into a best practice for manufacturers too, thanks to the needs of companies to consolidate and reduce their inventory as much as possible. Over the years, 68% of the cash-to-cash improvements throughout all industry sectors have come from reductions in days of inventory, notes Ted Farris, a professor with the University of North Texas, and he credits cross-docking for some of those reductions. Therefore, if companies are using cross-docking to see how much inventory they're holding, that's good. However, if they're only shifting

inventories within the company and holding them elsewhere, that's not so good because there's no change in the cash-to-cash cycle, Farris points out. Since the inventory hasn't been sold, it's still considered accounts payable[61].

Most companies define cross-docking as the process of rehandling freight from inbound trucks and loading it into outbound vehicles, but there can be more to it than that. For instance, some of the merchandise for the outbound loads may already be stored in the DC[62]. In other cases, goods from a truck that arrived a few days ago is held in a staging area until the complete mix is available to fill an outbound order. Some cross-docking warehouses are designed with a large storage area and a cross-dock staging area because their requirements involve withdrawing product from storage as well as rehandling inbound freight. So, the key is to use cross-docking strategically. Some companies, for instance, position their inventory in several regional warehouses so they can cross-dock and provide next-day service to customers. Geographic postponement coupled with cross-docking can eliminate the need to have product inventory at all locations. Cross-docking can also be applied to less traditional situations, such as transferring a load from an inbound ocean container directly into a lorry. This tactic has become a popular way to circumvent congestion at the ports, especially in the USA, UK and Australia.

Below author gives and example how the cross-docking works:

[61] Brodin H. Kohn C. (2005) Centralized distribution systems and the environment: how increased transport work can decrease the environmental impact of logistics. International Journal of Logistics Research and Applications, 11 (3) – p. 234-236
[62] Distribution Centres

1. The supplier is notified of the shipping time, date, carrier, stock-keeping units (SKUs), and quantity for each order.
2. The supplier is notified by the carrier of the arrival date and time for each shipment.
3. The supplier receives the order details from the customer.
4. The outbound carrier is notified of the pick-up time, load description, destination, and delivery date and time.
5. The customer is notified of shipment detail, carrier, and arrival date and time.
6. A dock location is selected for trucks involved in receiving and shipping.
7. Labor and handling equipment are scheduled.
8. Receipts are recorded and reconciled, and any receiving variances are noted.
9. Labels are created, and cases and pallets are routed and tracked from receiving to dispatch.

It’s very important that a company follows all these steps and collects performance measures on carriers and warehouse operations.

Warehouse management isn't exactly a recent phenomenon. Commercial warehousing can be traced back at least to fourteenth century Venice, and cross-docking has its roots in nineteenth-century transit sheds. So, while the idea of warehousing may not be quite as old as Methuselah, it's pretty close. Nevertheless, in today's world, thanks to the insistence by customers on perfect orders, just-in-time delivery, quick response, and fully

integrated supply chain processes, the role and mission of warehouse operations are changing and will continue to change dramatically. Companies are being pushed to minimise their inventories, which severely reduces the margin for error in their supply chains. As a result, the accuracy and cycle time performance pressures in warehousing are immense. Companies are being pushed in opposite directions simultaneously, as market pressures demand they increase warehouse productivity while employing fewer workers. More often than not, the solution to that operational tug-of-war involves the use of material handling technology, increasingly, a combination of hardware and software, within a company's warehouse operations. Material handling, as defined by the MHI, a trade association serving material handling and logistics companies, encompasses the movement, storage, control, and protection of materials, goods, and products throughout the process of manufacturing, distribution, consumption, and disposal. The focus is on the methods, mechanical equipment, systems, and related controls used to achieve these functions.

Material handling equipment includes powered vehicles, such as lift trucks and AGVs[63]; conveyors and sortation systems; automatic identification, including RFID and data collection systems; lifting, positioning, and overhead handling equipment, including robots; automated storage and retrieval systems (AS/RS); order picking equipment; packaging and shipping materials.

[63] Automated Guided Vehicles

## DISTRIBUTION NETWORK PLANNING

One of the main principles that drives distribution best practices is: take care of the situation and know the capabilities of the site. It isn't necessarily need a new warehouse to handle increased business, and while many companies take a technological route to increasing productivity, it's quite possible that better processes are the answer, not necessarily automation.

Following are several best practices that companies have taken to maximise the productivity of their distribution facilities that go well beyond a throw money at it and pray strategy[64]:

1. Reduce the amount of inventory and run as lean an operation as possible. Especially, eliminate all the obsolete products in the warehouse, the so-called dead inventory that the finance department has resisted writing off because they assume storage is free. Work more closely with the suppliers to time the receipt of goods as closely as possible to the time of use.
2. Be selective in what the stock and where to stock it. Inspect the order pattern to determine which are the fastest moving products, and then keep them at the front of the warehouse. If use both regional and central DCs, keep the most expensive items upstream to avoid having to move that expensive inventory.
3. Add hours or shifts. Sometimes even the best technology and processes aren't enough to satisfy customer demand, especially

[64] Grant D.B., Trautrims A., Yew Wong C. (2015) Sustainable Logistics and Supply Chain Management, Revised Edition., Kogan Page Limited. – p. 68-72

during peak season. In these situations, many companies opt to increase throughput by increasing hours of operations. While the labour costs will increase, company gain in the short term by not having to invest in capital equipment. As a long-term strategy, however, warehouse manager has to determine if running an extra shift year-round is more cost-effective than investing in technology.

4. Take the dock area clean. Sometimes the best solution is also the easiest: Insist that every incoming lorry have an appointment, so that every dock door is run off a firm schedule. The more predictable the operation, the more efficient will be the flow-through. Consider drop-and-hook for truckload deliveries, where an inbound trailer is unhooked and dropped off in the yard, brought via a jockey truck to the dock for unloading, and then returned to the yard.
5. Bypass the DC entirely. This strategy, known as pre-distribution management or more colloquially as the DC bypass, aims at delivering products directly to the shops or the point of consumption, rather than a warehouse. The greatest benefit here is promptness.
6. Outsource your warehousing to a third-party logistics provider. Before you consider hiring a 3PL to take over the bulk of your distribution processes, it's vital that you first analyse the specific needs and determine if your company will be better served by letting a specialist run the warehouse. Further, in the second part of thesis, we'll have a look on the outsourcing process of Maersk warehouse when 3PL is carrying the operations.

On-time delivery is a fundamental premise behind supply chain management, and it's a key indicator on the road to achieve the desired order. Although same-day delivery is now available from many DC and logistics providers, any company relying on the fastest and most expensive transportation options to fulfill its delivery obligations is either going to figure out a way to pass those costs on or it isn't going to be in business very long. According to a study undertaken by ProLogis, a consulting firm specialising in logistics real estate, the number-one challenge for supply chain professionals is to create a distribution network that can deliver on customer demands while keeping costs in line.

High-tech manufacturer HP operates one of the largest supply chains in the world, and one of the most sophisticated distribution networks. The company has learned that it is absolutely necessary to consider logistics activity when deciding where to source products and where to build factories. HP relies on collaboration across its entire supply chain to design the optimum distribution network to bring a given product to a specific marketplace. The company used to rely on design for manufacturability strategies to build products as efficiently and inexpensively as possible, but they shifted to a best practice known as design for supply chain[65]. This concept looks at all of the costs throughout a product's lifecycle, even past the point of its functional use. By its very nature, design for supply chain requires the involvement of multiple departments when a product is being designed.

[65] HP. (2016) Supply chain responsibility: Our approach. HP Development Company, L.P.

Design for supply chain includes not only research and development type people but also those who involved with logistics and packaging, and people who are focused on the environment. The applications of design for supply chain are seemingly limited only by a company's imagination, as well as its ability to effectively pull together disparate functions. Design for postponement, which is popular with the apparel industry as well as high-tech companies, allows a company to wait until the last minute to finish making a product, pushing off configuration or a value-added feature until the product is as close as possible to the end customer. HP also engages in design for commonality and reuse, which involves using similar or identical components in different products. HP's designs for take-back and recycling efforts are supplemented by its own recycling operation plant.

A well-run supply chain depends on having a streamlined distribution network to receive raw materials and deliver product to the customers, and that network needs to use the least number of intermediate steps possible. Developing such a network where total system-wide costs are minimized while system-wide service levels are maintained involves studying and weighing numerous factors. The ultimate goal of this network planning is a supply chain that is properly balanced between the competing considerations of inventory, transportation, and manufacturing. The objective of strategic distribution network planning is to come up with the most economical way to ship and receive products while maintaining or increasing customer satisfaction requirements; simply put, a plan to maximize profits and optimize service.

Distribution network planning determines how many warehouses or distribution centers a company requires to satisfy its customer base, as well as where those warehouses should be located. A distribution network plan, should answer the following questions[66]:

- How many distribution centers (DCs) do the company need?
- Where should the DCs be located?
- How much inventory should be stocked at each DC?
- Which customers should be serviced by each DC?
- How should customers order from the DC?
- How should the DCs order from suppliers?
- How often should shipments be made to each customer?
- What should the service levels be?
- Which transportation methods should be used?

Depending on the market needs of a company and its overall supply chain mission, the answer to question 1 may necessitate adding one or more DCs to the network, or conversely, it may require consolidating several DCs into a single regional warehousing hub. When the company get right down to it, all logistics is local. Amazon, for instance, operates more than 175 fulfillment centres throughout the world. McDonald's has more than 200 DCs worldwide to supply its more than 38.000 restaurants. In just the United States alone, Walmart has more than 150 DCs, each of which supports 90 to 100 stores in

[66] Handfield R.B., Melnyk S.A., Walton S.V. (2012) The green supply chain: integrating suppliers into environmental management processes. International Journal of Purchasing and Materials Management, 2012, 34 (2), p. 5-6

a 170+ km radius. Biggest world shipowner company – Maersk, possesses over 400 DC and warehouses over the globe.

And yet, there's a feeling that the site selection process is more art than science, more luck than strategy. Determining exactly where a company should locate its logistics and distribution centers requires a study of many factors beyond just transportation costs, although transportation is a major factor in the decision. To determine a metropolitan area's overall logistics ease of operation, following are 10 key areas companies should consider in their site selection evaluation[67]:

1. Transportation and warehousing industry. How many businesses and employees within a city provide transportation, distribution, warehousing, and related services?
2. Workforce and labor. How many white and blue colour workers live in the area or could be attracted to the area? And what is their average salary?
3. Road infrastructure. How many lane kilometers are available per capita, interstate motorway access, kilometers of paved roads, and average daily traffic per motorway lane?
4. Road congestions. What's typical traffic volume like in a city? How many delays, accidents, and other factors affect the smooth flow of traffic?

[67] Akkucuk U. (2018) Handbook of Research on Supply Chain Management for Sustainable Development, IGI Global. ISBN: 9781522557579 – p. 114-117

5. Road and bridge conditions. What percentage of bridges are functionally obsolete or structurally deficient?
6. Interstate motorways. What is a city's access to interstate motorways, and how many auxiliary interstate routes are in the area?
7. Taxes and fees. This includes things like lorry user fees and motor fuel excise taxes.
8. Railroad services. How many rail carriers serve a metro area?
9. Waterborne cargo service. What's the ocean port capacity as well as capacity of any inland waterways?
10. Air cargo service. How many air courier companies are in the metro area, and what's the total air cargo tonnage for the area?

## GREEN ENERGY USAGE

Since much of the operational emissions is related to energy consumption, the harnessing of green energy at warehouse sites can be used to improve the overall operational sustainability of the warehouse. Warehouses are often situated away from residential areas in industrial estates, close to ports, motorways and other transport infrastructure. Opposition from local resident's groups to green energy harnessing installations in their neighbourhoods can therefore often be avoided, making warehouse sites most suitable for the generation of green energy. Solutions to the sustainability of new non-domestic buildings are categorized into on-site rich: 64% of regulated reductions to comply with targets coming from on-site improvements, off-site rich: 45% of reductions from on-site, and balanced –

55% of reductions from on-site. On-site reductions mainly come from higher building energy efficiency and the use of low and zero carbon energy generation. The ability to generate low-carbon energy on-site and therefore the reduction of emissions on-site will depend hugely on a site's context and environment; the installation of wind turbines for example may be politically much easier at a rural site close to a motorway than in an urban location.

Green energy produced on-site can either be consumed directly, fed into the electric grid or a combination of both, whereby on-site produced green energy is consumed by the site but a connection to the electric grid is used for balancing out the site's power supply and demand. At the same time, electricity bought in from energy suppliers can also be sourced from a green form of electricity generation.

Energy at a warehouse site can be generated from biomass or low-carbon fuels, which are not totally carbon-neutral, but may have a lower emissions impact than a previously used fuel, wind turbines, solar panels, recovered waste energy, kinetic energy and thermal-exchange units. The way energy is generated and sourced for a warehouse site is individual to the site's requirements, settings and context. The decision on the types of electricity and energy to be used depends on operational, regulatory, environmental and market factors. The general issues are operational patterns of energy consumption against the generation of energy at the site; the costs of the energy generation technology and the scale at which the energy can be produced at a reasonable cost and whether there is enough demand to build

a power-generating facility of the necessary scale; the availability and maturity of technology; and regulations and market conditions.

The generation of energy on-site increases the complexity of energy management. Balancing energy demand with supply, the fluctuation of energy market prices, the fluctuation of production depending on local geographical circumstances and weather, the proximity of other energy consumers nearby and infrastructural access to the national grid all make energy management and the investment decision more complex. Despite energy generation on-site warehouses need to be connected to the electricity grid to transfer electricity into the wider network and to source from it. Around 46% of the on-site generated electricity will be fed into the national grid. Governments worldwide are currently implementing different ways of encouraging or even enforcing an increase in low and zero carbon energy generation. Feed-in tariffs – a regulated price for renewable energy that is fed into the national grid, financially encourage the installation of renewable energy-generating infrastructure. Other regulations impose minimum energy efficiency levels for sites, the purchase and trade of renewable obligation certificates or emission allowances, the sourcing of a certain percentage of the consumed energy from renewable energy sources, or the inclusion of on-site energy generation in planning permissions for new buildings.

The costs for sourcing and generating green energy vary across the available options. Comparing the costs for on-site and off-site generated energy from renewables, the on-site solutions appear more costly in many cases. The annual cost per kilogramme $CO_2$ avoided for small-scale wind is

more than tenfold the cost of large-scale wind. The cost for solar photovoltaic installations is even higher, whereas the usually off-site installation of a biomass CHP[68] plant is not much more expensive than the large-scale wind option. Large-scale wind and biomass CHP are more likely to be off-site, as they often require more than one user. Off-site solutions in most cases use an external supplier avoiding the warehouse operator being tied to a long-term commitment. Solar panels for example only make sense if the warehouse user owns the facility or if the owner considers the solar panels a worthwhile investment; the payback period in the EU, for example, is around 15 years. Sourcing green energy from an external supplier might therefore in most cases be cheaper and carry less investment risk than small-scale on-site generation[69].

It may often be governmental regulation and incentives that make on-site energy generation a considerable option. Looking at the large investments and long payback periods for green energy generation on-site, it is probably unsurprising that managers prefer to invest in energy saving and waste avoidance solutions like improved lighting, recycling and air circulation fans than solar panels or wind technology.

## SOCIAL DIMENSION OF SUSTAINABILITY IN WAREHOUSING

The social dimension of sustainability also needs consideration in warehousing. With value-added activities and processes being increasingly

[68] Combined Heat and Power
[69] Browne M., McKinnon A., Whitening A. (2012) Green Logistics: Improving the environmental sustainability of logistics, 2nd edition, Kogan Page. – p. 57-61

shifted to logistics service providers, warehouses and distribution centres employ more people with a wider set of skills. Technology and the increasing complexity of supply chains mean warehouse operators require new skills sets and knowledge.

Issues of health and safety need to be considered in the warehouse and workplace design. With the demographic change to older populations in many developed countries, ergonomic workplace design and wellbeing gain more importance. The use of handling equipment and supportive technological applications needs to be considered differently in the light of an ageing workforce. Additionally, the overall number of workers is shrinking, making it more important to keep staff and to provide an attractive workplace.

The discussion of sustainability in warehousing is often limited to the environmental sustainability of structures and operations, usually in combination with an economic evaluation of environmental measures. But as places of employment, warehouses and logistics sites also impact on the social dimension in their sustainability under the triple bottom line concept. For example, the Austrian do-it-yourself (DIY) seller chain bauMax runs a company-wide programme to integrate employees with disabilities into the organization, mainly in logistics and maintenance processes but also in customer service and in headquarter functions. Moreover, integrating employees with disabilities and collaborating with disability charities form an essential part of the company’s global corporate strategy.

When looking at their overall response to improving their sustainability, logistics and supply chain companies typically focus on the following topics[70]:

1. Lighting. Warehouse lighting is a very important part of total energy consumption, accounting for up to 2/3 of electricity costs. To reduce expenditure on this item, companies are increasingly installing more energy efficient lighting. Movement sensors allow lights to switch on only when areas are being accessed. Increased automation will lead to lower lighting requirements. In some cases, warehouse lighting costs have been reduced by 65%, with new lighting infrastructure projects paying for themselves in just two years.

   LED lighting is now seen as the most energy efficient system. Not only is it more efficient, but the bulbs last between five and seven times longer than traditional bulbs. LED's other benefits include: integration with enhanced sensing controls; maintenance savings; reduced electrical infrastructure; lower radiated heat; better light quality for employees; lead and mercury-free fixtures.
2. Heating. Monitoring heating usage and ensuring that load-bay doors are closed when not required. Positioning heating units away from open bay doors is one such example of an easy fix.
3. Energy Use Reduction. Strategic energy waste maps can be developed to assess the energy usage of machinery within the

[70] Richards G. (2022) Warehouse Management – The Definitive Guide to Improving Efficiency and Minimizing Costs in the Modern Warehouse, 4th Edition., Kogan Page Lmtd. – p. 34-38

warehouse environment. Those that are working inefficiently can be identified and addressed.

4. Energy Generation. Solar panel installation has become popular, especially utilizing the large roof space that is characteristic of warehousing. The electricity generated from large projects can be fed back into the grid and thus some companies have encouraged investment from third parties, while benefiting from savings themselves.
5. Water Usage Reduction. Reuse of grey water is an important part of any new warehouse constructed and managed to the latest environmental standards. Identifying leaks and vehicle wash management are also important.
6. Loading Systems. Systems exist that allow for the optimal loading of trailers and containers through 3D-visualisation. Stacking pallets, where possible, increases the utilization of each vehicle.
7. Zero Waste to Landfill. Best practice in waste management now proscribes the use of landfill sites. Warehouses generate large amounts of packaging waste that can be collected for recycling. Domestic waste, such as plastics, bottles and cans can be sorted and, when recycling is not an option, sent for incineration in energy recovery schemes. Food waste can also be diverted from landfill to anaerobic digesters that produce electricity and fertilisers for agricultural use.

8. Packaging technologies reduce waste. Packaging materials are a major generator of waste, within the warehouse and in the home or office of the end-recipient. With the massive growth in e-commerce and related parcels deliveries, the problem has become worse. Inefficient dispatch systems can mean that multiple orders can result in multiple consignments without consolidation into the same box. In addition to this, the use of sub-optimal packaging size can mean that more air is shipped than product within a box.

   To address this latter problem, new technology has been developed that customizes packaging for each individual order. Fully automated, each picked product is scanned and a flat carton is cut to precisely the right size. The product is then mechanically packed with order information automatically inserted alongside any other required marketing or customized instructions. One of the major benefits of such a system, outside of the cost reductions resulting from using less labour, is the reduction of weight and size of the cartons. As well as the lower shipping costs, the reduced volume and weight means that fewer shipping containers are required, reducing carbon emissions.

9. Warehouse Layout. An inefficient layout of a warehouse, for example the location of fast- and slow-moving items not only wastes time but also increases the fuel use of forklift trucks.

10. Paper Reduction. Reducing the number of copies of proof of deliveries (PODs) required; double-sided printing or moving to a paperless environment completely.
11. Green Roofs. Depending on the prevailing climate, roofs may need to be insulated to prevent heat loss or coated with reflective material to keep the warehouse cool. This also has an effect on the local environment as less sunlight is absorbed by roads and buildings, meaning that urban areas do not heat up as much.

Designing and constructing a warehouse with sustainable features is more expensive than one built to lower standards. Although operating costs are likely to be lower, the occupier will be keen to establish what sort of return on investment will be delivered by the more sustainable facility. The shorter the lease the less likely it is that higher rental costs will be off-set by cheaper operating costs.

When environmental initiatives result in cost savings they are sometimes referred to as green and gold. Below are three examples of where a focus on environmental impact can bring about benefits within a warehouse. They show the return on 'green' warehouse lighting initiatives[71]:

Example 1. 20.000 $m^2$ clothing warehouse – three stories of mezzanine racking, built in 2002 operating 12 hours per day, five days per week. Audit identified that implementation of lighting controls, lighting replacement and

[71] Trunick P.A. (2005) How to Design a Cost-Effective DC., Logistics Today, p. 42–45.

reduction of lighting levels could result in 35.000 euros saving with a payback period of three years.

Example 2. Ambient warehouse 1.500 $m^2$ operated 11 hours per day, Monday to Friday. Lighting cost savings identified of 40% with a payback period of 2.5 years.

Example 3. Audit of 26.000 $m^2$ warehouse, operating 24/7, found that 10 energy saving opportunities could save 55% of costs with a one-year payback period.

Another way of looking at these initiatives is that for many businesses a 25% cut in energy costs represents the same bottom-line benefit as a 6% increase in sales. There are opportunities not only to reduce the amount of energy usage within the warehouse, but also to use the building itself to generate energy to meet its own requirements and to feed back into the energy grid as a revenue-generating activity. This can be achieved, for instance, by using the large expanse of roof space to generate solar power or constructing a wind turbine within the footprint of the facility. In addition, the large footprint that usually accompanies warehouses can be used for ground thermal exchange units – air and water can also be employed where appropriate. Another example of green energy that results from utilizing the waste products generated by the warehousing activities includes the use of waste packaging for incineration.

## RISKS AND VULNERABILITY IN WAREHOUSING

In the economic dimension of sustainability, risks and supply chain disruptions have gained importance. Globalisation, extremely lean supply chains with low inventory levels and a trend for centralisation of inventory have increased the vulnerability of supply chains and the impact if a warehouse fails to operate properly. Warehouses are often essential nodes in supply chains and the damage or loss of a warehouse can cause significant disruption to a business and threaten its economic wellbeing. Preparing for supply chain disruptions does not always come with higher inventory levels, but depends more on risk profiling, visibility and the right supply chain design.

Natural and man-made disasters can disrupt companie's supply chains. Warehouses form a sort of buffer for such cases and can be set up to mitigate supply chain risks; however, they are also vulnerable themselves even if they are located in otherwise safe locations. The outbreak of a fire in a distribution centre or warehouse will most likely have an immediate and significant impact on business operations. The Buncefield oil depot fire in the United Kingdom is a good example: the depot burst into flames shortly before Christmas 2005 and had a serious impact on oil distribution in England. Furthermore, distribution centres on a commercial estate nearby could not be accessed for several days due to heavy smoke and the damage to the building's structure caused by the explosion of the oil depot. Most of the stock was damaged not only by the explosion but also by the water from sprinklers. It took fire brigades several days to put out the fire. During that time ASOS, one of the fastest growing online fashion retailers, could not use its central warehouse and

distribution site and couldn't send goods out. The company had only moved into its single global distribution site months before. The potential effect on the business in the run-up to Christmas was so significant that its shares were initially suspended from trading. Although ASOS recovered from the disruption, it shows the significance of warehousing on the economic dimension of a business's sustainability.

With the rapid development of computer and internet technology a new form of warehousing emerged: the storage of electronic data. Physical documents and files used to be stored in archive buildings which are essentially warehouses but the introduction of electronic documents did not eliminate the need for storage. Storage facilities for electronic data are usually called data centres. Within a data centre a large number of servers perform computing operations to store and process data. Although only little physical traffic goes in and out of the site after the construction phase is finished, a lot of data traffic emerges and is transported in and out by communication technology.

The amounts of data that need processing and storing are continuously increasing. The ACER[72] forecast that despite the industry improving energy efficiency, the energy use for EU servers and data centres was just under 160 billion kWh in 2023. The electricity used by Google alone is equivalent to the power consumed by 250.000 homes[73].

[72] The European Union Agency for the Cooperation of Energy Regulators
[73] The European Union Agency for the Cooperation of Energy Regulators. Ten-Year Network Development Plan of Energy Consumption 2019

Data centres are a worthwhile target for energy savings. The typical annual energy costs per square metre are 15 times that of a typical office building. In extreme cases datacentres consume up to 100 times more energy than a standard office building. Data centres also operate continuously with peaks following office working hours and therefore have to source much of their electricity when it is the most expensive in time-dependent tariffs. Opportunities for energy efficiency improvements in data centres exist at four major points: cooling, server load and computing equipment, power conversion and distribution, and alternative power generation. The electricity consumption in a data centre can be differentiated into supply – support systems like cooling, lighting, etc., and demand – computing equipment such as server power supply, processors and communication equipment. More energy-efficient server components therefore have a leverage effect on the overall data centre's energy consumption as not only the energy in the production is saved but also the energy required by the support systems is reduced.

Energy required for cooling can be reduced through improved air management. Optimised distribution of cool air and the collection of waste heat for energy production can be addressed in design and operations at the data centre. On average cooling accounts for around 40% of a data centre's energy consumption. Cooling is one reason why Facebook built its own 35.000$m^2$ data centre in northern Sweden, where temperatures are low most of the year and even in summer don't rise above 20 degrees Celsius. During 10 months of the year outside air can be used for cooling. Furthermore, Facebook can source

its energy for the site primarily from a nearby hydropower plant, reducing its carbon emissions even further[74].

A major performance figure for benchmarking data centres is the power PUE[75], which is the total power used by the data centre divided by the energy used for IT systems: the lower the consumption of auxiliary systems the lower the PUE score. A state-of-the-art data centre like Facebook's in northern Sweden achieves a PUE score of 1.07 and Google claims to reach a PUE of 1.13 across all its data centres. Apple on the other hand builds up its own green energy supply by building a large solar array park in North Carolina, producing 65% of the total energy consumption of its nearby data centre.

[74] The Guardian (2011) Facebook builds "green" data centre in Sweden. Electronic source: https://www.theguardian.com/environment/2011/oct/27/facebook-green-datacentre-sweden-renewables

[75] Power Usage Effectiveness

# II PART. PRACTICAL CASE

## III. MAERSK WAREHOUSE

Warehouses are crucial components of most modern supply chains. They are likely to be involved in various stages of the sourcing, production and distribution of goods, from the handling of raw materials and work-in-progress through to finished products. As the dispatch point, serving the next customer in the chain, they are critical to the provision of high customer service levels. Warehouses are an integral part of the supply chain in which they operate, and therefore recent trends, such as increasing market volatility, product range proliferation and shortening customer lead times, all have an impact on the roles that warehouses are required to perform.

Warehouses need to be designed and operated in line with the specific requirements of the supply chain. They are therefore justified where they are part of the least-cost supply chain that can be designed to meet the service levels that need to be provided to the customers. Owing to the nature of the facilities, staff and equipment required, warehouses are often one of the most costly elements of the supply chain and therefore their successful management is critical in terms of both cost and service. The nature of warehouses within supply chains may vary tremendously, and there are many different types of classification that can be adopted, for example[76]:

[76] Manners-Bell J. (2017) Supply Chain Ethics—Using CSR and Sustainability to Create Competitive Advantage. Kogan Page Limited – Chapter 07: Sustainable Warehousing and Distribution. – p. 78-84

- by the stage in the supply chain: the materials, work-in-progress or finished goods;
- by geographic area: a parts warehouse may serve the whole world, a regional warehouse may serve a number of countries, a national warehouse may serve just one country, or a local warehouse may serve a specific region of a country;
- by product type: a small parts, large assemblies, frozen food, perishables, security items and hazardous goods;
- by function: inventory holding or sortation (as a hub of a parcel carrier);
- by ownership: owned by the user (the manufacturer or seller) or by a third-party logistics company;
- by company usage: a dedicated warehouse for one company, or a shared-user warehouse handling the supply chains for a number of companies;
- by area: ranging from 100 $m^2$ or less to well over 100.000 $m^2$;
- by height: ranging from warehouses about 3 metres high through to high-bay warehouses that may be over 45 metres in height;
- by equipment: from a largely manual operation to a highly automated warehouse.

With over 30 years of experience and deep expertise across many different sectors and industries, Maersk processes excellence, compliance to industry standards, lean, quick and efficient operations, with the warehousing and distribution expertise to offer solutions and improvements. The global footprint and extensive network means, the company facilities ready to handle

the supply chain, whether at origin or destination. By combining shipping with warehousing and distribution, customers benefit from a seamless end-to-end solution with fewer logistic service providers. Complexity in the supply chain is reduced, and cooperation gains by speed, control and visibility.

Presently, Maersk owns more than 250 warehousing facilities in 50+ countries with an overall 1.5 million $m^2$. As per Maersk contract logistics policy, warehouses classified: Consolidation and Deconsolidation centres, Fulfillment centres and Flow warehouses[77]:

Consolidation Centre – consist of loading materials from incoming trucks, railroad cars or containers and loading these materials directly into outbound trucks, railroad cars or containers, with little or no storage in between. It may be done to change the type of conveyance, to sort material intended for different destinations, or to combine material from different origins into transport vehicles with the same or similar destinations bonded and non-bonded warehouses.

Deconsolidation Centre – consists of unloading materials from incoming trucks, railroad cars or containers and loading these materials directly into outbound trucks, railroad cars or containers, with little or no storage in between. It may be done to change the type of conveyance, to sort material intended for different destinations, or to combine material from different origins into transport vehicles with the same or similar destinations.

[77] Maersk Warehousing & Distribution strategy 2022

When the cargo arrives at its destination market, keep the goods flowing through the supply chain without missing a beat. Many of the facilities are ideally situated close to key ocean ports for major shipping routes, allowing faster throughput of your cargo.

The deconsolidation solutions in Maersk have multiple service offerings depending on where the cargo needs to go – straight cross-docking transload, or building consignments direct to distribution centres or final destinations:

- Cross-docking transload – the cargo is transferred from containers directly into outbound trailers, allowing you to reduce inventory, reduce handling and increase throughput by building consignments direct to Distribution centres.
- Cross dock and delayed cross dock – for container cargo bound for different destinations, goods are expertly sorted into consignments and transferred to trailers for onward distribution.
- DC Bypass – the cargo is transferred from containers to trailers bound for final destination, without passing through a Distribution centre. This allows to reduce storage and inventory costs, freeing up working capital, and increase the speed to market.

Fulfillment centre rovides the customer with B2B and B2C capabilities, with services like receipt and storage of goods, inventory management and pricing & packing of pallets, cases and/or each is based on outbound orders to end customers etc.

Basically, it is a centre where the seller or a company the seller hires to outsource their fulfillment, a third-party logistics (3PL) provider, fulfills customer orders placed through an ecommerce shops and/or business-to-retail fulfillment where the seller fulfills wholesale orders to big box retailers. It is larger in size and scale than a standard warehouse that a company own or rent. The main function of Maersk fulfillment centres is to manage the seller's inventory, store the inventory, ship orders directly to customers and/or retailers, and assist sellers in managing the entire vital, yet often difficult fulfillment operation.

Actually, Maersk warehousing & distribution solutions are underpinned by investment in technology, automation and robotics. The company steadily expanding the fleet of Automated Guided Vehicles (AGVs), automated sorters and hybrid systems, all of which deliver superior picking efficiencies. All this is supported by the IT landscape consisting of best-in-class Warehouse Management Systems, providing completed integration capabilities, visibility and improved accuracy, allowing to respond quickly to any events in the supply chain.

Multifunctionality of warehouses conducts the company to offer the integrity of services in contract logistics to satisfy the customer's needs. Distribution services, for a seamless fulfilment solution, combine order processing with distribution services to handle the last leg of the supply chain. Handling product deliveries via Full Truck Loads (FTL), Less than Truck Loads (LTL) or parcels to suit the customer's requirements; whether that's to DCs, Wholesalers, Shop or end-consumer:

Full Truck Loads – benefit from economies of scale and productivity when shipments are large enough to require the use of the entire truck. Reduce transit time by direct deliveries to final destination and avoid cargo to be handled en route.

Less than Truck Loads – it takes an advantage from the transportation of relatively small freight at a fraction of the cost of hiring an entire truck for an exclusive shipment. Reduce handling costs and the risk of damage during transit by configuring shipments with the least amount of handling units possible.

Parcel Delivery – suits the requirements when delivery becomes the most optimal transportation mode using the speed, individualisation and specialisation of delivery services.

Value added services refers to the additional distribution and warehousing services offered by third-party logistics providers to business looking to outsource their supply chain operations. Whenever logistics providers add value the right way, it affects the level of customer satisfaction, while indirectly increasing their bottom line. Service providers know the ins and outs of the business and they can assist companies in responding to customer's needs. Value-adding is not a one-time task – it requires continuous maintenance and 3PLs are working toward providing value-added services in conjunction with their more traditional offerings.

Adding value to the packaging and transportation process can give the company an edge in the market and enable you to stand out from the

competition. Service providers offer a range of contributions that add value to the Maersk brands. The company offers the following VAS in its warehouses and distribution centres:

- Cargo sorting. The sorting center handles and sorts the cargo based on your requirements (for example sorting of cartons on customer PO level);
- Scanning. For fast, easy and accurate inventory management, the facilities make use of barcode scanner technology to scan cargo as per customer's requirements (carton barcode scanning).
- Labelling. Label printing and placing according to the requirements, for example, any type of pallet or carton labelling, inner carton label, etc).
- Garments on hangers. For clothing packaging that requires the utmost care, Maersk dedicated Garment on Hanger facilities to ensure garments can travel from origin to destination without being folded.
- Re-packaging. We assist you with packing or repackaging of cargo based on specified requirements – repacking cargo from damaged box into a new box.
- Quality control procedures can be worked into the goods flow as per customer's requirements, e.g. checking if product is still functioning.
- Pallet Logistics. Both origin and destination facilities can store and transport cargo stacked on pallets as a unit load.
- Shaving/topping off pallets. If the supply chain has specific height requirements, adjust the height of a pallet by removing the upper layer of cartons.

- Return solutions. Where reverse logistics are required, the company provides support to the operations by managing the customer's goods return flows into the warehouse.
- Goods disposal. Should it be required, our facilities are equipped to handle goods disposal for products or parts.

Flow Maersk warehouses combine the functions of fulfillment and consolidation/deconsolidation centres. They represent, actually, 35% of business capacities in Maersk contract logistics with increasing features for customer's needs.

## WAREHOUSE LOCATION: SUSTAINABLE FOOTPRINT

With logistics operations becoming increasingly globalised a key factor in contract logistics is the total cost of operating in any market. Traditionally, it tended to be rent, local taxes and service charge costs that were taken into account; however, these factors can often hide other key factors such as the cost of labour employed in the warehouse, the cost of electricity and the cost of fuel for vehicles. Warehousing property costs are highest in the largest cities where big populations and constrained land supply meet high demand from consumers and businesses.

Locating a warehouse strategically and in the most cost-effective geographic location is one of the most important decisions a company will make. For example, in terms of fulfilment centres, because of the nature of deliveries, an important criteria is the need to be located near to the motorway network and to the parcel hubs to delay the latest collection time from the

parcel companies and therefore enable companies to introduce a later order cut-off time for next-day delivery.

The selection of a Maersk warehouse location required multiple criteria that was assessed, including both quantitative and qualitative data. The company looked at the location and size of customers, proximity to economic centres, transport and land costs, and the presence of modern and efficient infrastructure. Positioning to serve global trade routes is also important as is access to highly skilled staff. Other factors impacted the choice of location include transportation costs, land cost, skilled labour availability, travel minimization and overall cost of operation. The environment also played a significant a part in the decision-making process. The following are specific factors that were considered when the company decide on a warehouse location[78]:

- cost of land, rent and rates of ZAL;
- access to transport networks;
- proximity to multimodal hubs;
- availability of affordable, skilled labour;
- languages spoken;
- transport links for staff;
- availability of funding, grants;
- availability of existing buildings;
- availability and cost of utilities including telecoms;

[78] Maersk Logistics & Services Spain: Contract logistic coverage in EU. Warehousing and Distribution enhancement in SWE area. – p. 68-69

- availability of finance and resources;
- goods traffic flows;
- proximity to ports and airports;
- location of suppliers and manufacturing points;

These criteria have ensured that, in general, the prime locations for warehouse deployment haven't changed in a total scale of sector's practice.

Maersk warehouse located in Barcelona is the first logistic facility in of the company in Southern West Area and especially, in Iberia region, opened in January 2022. Warehouse is assigned as a Flow type and operates exclusively a dry cargo.

Barcelona warehouse is located in a plot belonging to "Zona de Actividades Logísticas" (ZAL) in Barcelona. As was studied in a previous chapter, it's a crucial for the companies to choose a strategic location for their warehouses or distribution centres. ZAL is located right next to the city's port, the airport and railway terminals what corresponds to customer's requests that warehouses are built in immediate vicinity to the port/airport/railway terminals with easy access to the Intermodal terminals (Annex 2). In Barcelona and its immediate surrounding there is no other option than ZAL available which fulfils the customer's demand and company's strategy.

What does mean the choice of location for sustainability? First of all, a close access to intermodal transport ways allow to reduce the expenditures on transportation of goods from inbound and outbound trucks in warehouse, as

well as decrease embodied $CO_2$ emissions for 23% (forecasted for 2023)[79]. Secondly, being located in an industrial zone, the chosen slot didn't affect significantly the natural habitat, however, certainly, the soil and bio ambience were afflicted due to construction process. This intervention into bio ambience, estimation of losses and assumption of affection on nature called Sustainable risks. Actually, as Maersk decided to construct the warehouse itself on the ZAL land, the company resort to the best practices based on experience in other areas to minimise these risks and build it according to international requirements. Thirdly, the warehouse has an easy access to reach it, using a public transport connection with ZAL which enables to reduce the environment impact by reducing embodied emissions of $CO_2$, avoid the traffic congestion, consumption of electricity in the entrance gates to get the access to the ZAL area, any kind of leakage of chemical components, used in cars: oils, cleaning products etc. Additionally, Maersk has implemented outdoor space usage efficiency method – Coordinated circulation layout of inbound and outbound lorries: container's discharge – West side, charge – East side, as well as for services vehicles – South side to reduce the workload from conglomeration (Annex 3).

## GREEN FRAMEWORK: LAYOUT, EQUIPMENT

The design of a warehouse requires attention to details and can be very complex and relies on the collection and compilation of large quantities of relevant data. Whether a company is building a new warehouse, moving into

[79] Maersk Sustainability report 2021

an existing building or looking to re-design their own facility, there are a number of fundamental areas that need to be addressed. There are many companies who assist that the layout of the warehouse is based on the available space, the requirements and a budget. There are also simulation software packages that enable to build the warehouse on a computer and simulate the operation to see which layout is the most effective.

When re-designing a warehouse there are a number of factors that need to be taken into account. These include the company's likely growth over the next 5 to 10 years, the possible change in product and customer profiles, total sales during this period and the likely sales channels such as online B2B, B2C and e-commerce.

Maersk is following its strategy of innovation and durability, using the best features to provide the sustainable solutions in contract logistics. Current warehouse is about 8.000 $m^2$ and includes two main modules: Module 1 – Cross-docking and Module 2 – Fulfillment area (Annex 4). Fulfillment module is up to 4200 $m^2$ and disposes the racks which allow to store the good till further requirement of the customers. Cross-docking module compose 3.800 $m^2$ and provides deconsolidation solutions for the clients.

Main features of a Maersk warehouse[80]:

1. It's a bonded warehouse – shippers store the imported goods before customs have processed them. Goods stored in bonded warehouses

[80] Maersk Logistics & Services Spain: Contract logistic coverage in EU. Warehousing and Distribution enhancement in SWE area. – p. 68-71

aren’t liable for customs duties. When the goods have been delivered to their next destination, all applicable duties become payable. This warehouse is a bonded flow warehouse carrying only a dry cargo. Using a bonded warehouse means the company deliver the goods closer to their final destination.

2. 39 loading / unloading docks with discharging capacity till 100 daily containers (FTL).
3. 5.500 pallets storage capacity in fulfillment area which allows to store 148.500 palletised boxes.

   LEED Gold certified warehouse. LEED is a globally recognised standard for green and sustainable buildings. The 4 main levels of LEED Certification are Green, Silver, Gold and Platinum. Each of these levels is achieved after earning a certain number of points in a LEED Certification analysis. Sustainable construction practices, materials used, energy efficiency, new technology, water and waste management systems are used to determine the quantity of points a project is awarded. The goal wasn’t to meet every single point, but to aim to find solutions that work for the warehouse and the environment. Of course, the more company have, the more points it gets and the higher the certification the company achieve. Maersk warehouse is collected in total 78 points.
4. Energy auto consumption due to solar panel roof project. Warehouse equipped 184 photovoltaic panels which gives an 81% of auto energy consumption and reduces environment impact for 29%.

5. Flexibility to work 24/7 schedule. To attend and satisfy the client's requirements, the warehouse is planned to activate the shifts 24/7 to facilitate discharge inbound and charge outbound lorries. For now, the operational team entered to attempt three main shifts: from 7 a.m. to 21 p.m. as per business running.

Layout of warehouse has a conventional type (Annex 1, 5), approved by company's best practice in contract logistics. And one of the most important actions that was taken in this warehouse regarding the layout, or any other logistics centre of the company in which vehicles of any type are operating, is to ensure that staff and vehicles are segregated into separate areas as far as is reasonably practicable. Usually, this will involve providing separate pedestrian and vehicle traffic routes. To help enforce segregation, barriers, signage and designated crossing points are likely to be needed.

Designated Pedestrian Routes. The first stage of the risk assessment was to identify the areas to which pedestrians require access; where they are coming from to access those areas; and what type of people require access. As an example, drivers of vehicles making deliveries need to report to the warehouse administration office (CTC) to hand in their delivery notes. In a poorly organised warehouse, of which the author has had a chance to see far some of them, a driver making their first delivery to the premises have no idea where to report, and need to wander around the building trying to find the right place.

A much safer option is for the driver to be able to see a door clearly marked “Reception” and signs on doors leading to dangerous areas such as loading docks to indicate “No pedestrian access / Autorised personal only”. There are designated pathways protected by barriers both in the yard and in the building. It is necessary for blue collars staff to enter areas where MHE is operating – Fulfillment area where warehouse staff picking goods in racking aisles, and it is restricted to those for whom it is essential to do so, and they have received specific prior training. The designation of specific pedestrian routes doesn’t mean that other risk reduction measures can be neglected: for example, high-visibility clothing should continue to be always worn.

Pathways and crossing points in warehouse. Pedestrian routes are clearly marked by floor markings and barriers. The markings include signage, in many cases on the floor, to show that this is a walkway. Raised kerbs also used as a deterrent to vehicles encroaching onto a pathway. Barriers are installed for motorised vehicles, used in the area, and the vehicle route is closer than 1 m. to the pedestrian zone or pathway. Floor markings are sufficiently used, in case of only manual pallet trucks applied, and there is a buffer zone of at least 1 m. between pedestrian and vehicle routes.

Barriers is used usually at entrance points. This helps to deter people from walking straight into a vehicle route without stopping and looking. Similarly, doorway entrances into the warehouse should never be opened up to a crossing point.

Green gates or markings are used to restrict exit points from pedestrian areas – any gates should open towards the pedestrian. Routes should be laid out so that they take the shortest safe route – a pathway which follows three sides of a square tempts people to ignore it and take a potentially hazardous short cut across the shortest route. A width of 600 millimetres is used for a pedestrian pathway. Crossing points also take the shortest reasonable route in Cross-docking area. Black and white zebra crossing style markings are the best way of showing such a route.

Forklift Routes. Cross-docking, in shipping and receiving bays, it wasn't possible to designate fixed routes for forklifts and other MHE. However, the space and practicalities do permit this, it is highly desirable, with separate lanes for travel in each direction. Routes are wide enough for the largest vehicle that uses them. There is also a part of cross-docking area in which forklifts should not be permitted to operate, such as visitor's platform (who may not be aware of the dangers) is admitted. Signs, barriers and floor markings used to identify these areas.

Warehouse Handling Equipment. The challenges of a 24/7 operations culture, together with an ageing workforce, demands for improved accuracy, shorter order lead times and a reduction in cost have galvanised manufacturers into producing handling systems that require minimal manual input and provide increased throughput levels. The key principles of materials handling in Maersk warehouse in choosing the correct equipment are:

- lower unit materials handling costs;

- reduce handling time;
- conserve floor space;
- prevent injuries to staff and reduce energy consumption.

It is essential for Maersk to consider all aspects of an operation in order to ensure that the most suitable equipment is specified and the best handling solution selected. Important factors include: the load and the means of transfer, e.g. type of pallet (for now the centre use 5 types); type of storage; type of operation; warehouse dimensions (height and travel distances); overhead obstructions; surfaces and gradients; working area; work environment: offices of white and blue collars and environmental pressures[81].

Despite a recent aperture of warehouse, it already recommended itself among operational flow distribution centres of the company. Using the best practices of warehousing & distribution, Maersk took the advantage of building a sustainable centre corresponding the international standards. As any other warehouse, it has some inconveniences, such a space capacity, which was significantly reduces after applying a traffic plan and layout. However, proficient usage of equipment allows to manipulate and store the goods with better effectiveness and accordance of requirements of the customers

[81] Maersk Logistics & Services Spain: Contract logistic coverage in EU. Warehousing and Distribution enhancement in SWE area

## COMPLIANCE WITH SUSTAINABLE REQUIREMENTS FOR ENVIROMENT

In recent years, environmental and waste issues have affected all companies, not only in logistics, but in any other sector. Recycling has become an everyday occurrence and carbon footprints are being left but not without trace. These issues have also become ingrained into corporate social responsibility, but how does this impact a Maersk warehousing?

Environmental legislation has made carbon the new currency in a carbon economy. This new economy means the company needs to be aware of its carbon footprints, where the emissions come from and how they can be reduced. Business outcomes are therefore entwined with environmental aims. Maersk accentuates that by stimulating resource efficient and low carbon action, contributing to green goals, including the lowering of carbon emissions, the development of low carbon businesses, increased energy security and job creation.

In 2018, Maersk has developed a new environmental strategy committed to the net zero target as recommended by the Committee on Climate Change. Reaching net zero greenhouse gas emissions requires extensive changes across all company areas: buildings have a key role to play. Warehouses and distribution centres currently contribute some 21% of global greenhouse gas emissions but this could double or even treble by 2050[8283]. Global greenhouse gas emissions from transport and logistics amount to 3.5 billion tonnes every

[82] Maersk Sustainability report 2021
[83] Maersk decarbonisation strategy 2050

year and A.P. Moller – Maersk's current emissions account for about 1% of all transport and logistics emissions and close to 0.1% of all global emissions. In 2021, several events and developments brought further urgency to our work on decarbonisation. First, the UN Intergovernmental Panel on Climate Change's 6th status report not only reiterated the need for eliminating GHG emissions but strongly emphasised that speed is of the essence to avoid irreversible effects of climate change. Second, due to supply chain congestions following the COVID-19 pandemic, our emissions from ocean transport grew and impacted the contract logistics vessel efficiency negatively. Third, the customer demand for green logistics solutions continues to grow. 2/3 of Maersk Top 200 customers have now set net zero or science-based targets and rely on company as logistics provider to enable them to reach their targets to decarbonise the logistics supply chains. This expectation was emphasised when nine of the world's largest cargo owners – who are also Maersk's customers either directly or indirectly – in the autumn of 2021 launched the Cargo Owners for Zero Emission Vessels (coZEV coalition) and publicly committed to requiring net zero operations of their shipping partners by 2040. Already in 2018, Maersk took leadership in the industry with a strong commitment to decarbonise its shipping operations by 2050 and develop scalable solutions to help the entire industry reduce its greenhouse gas footprint[84].

[84] Fuerst F., McAllister P. (2011) The impact of Energy Performance Certificates on the rental and capital values of commercial property assets., Energy Policy, 39 – p. 6610

As regulation and sustainability targets evolve the impact on warehouse design is expected to continue as developers strive to reach net zero goals. Occupiers of warehouse space can expect to see more sustainability features offered by landlords and developers and may have to factor in changes to operations which meet sustainability goals.

Over time, the sustainability agenda has broadened to embrace not just environmental issues but other social and governance factors. In this context, there is an emerging interest between Maersk and investors in developing warehouses or consolidation centres that provide enhanced building characteristics and amenities that address staff wellbeing. This interest largely reflects the increasing challenges that companies are facing in attracting and retaining labour for warehouses. One manifestation of this approach is the interest in securing the WELL Building Standard. The foundation WELL version 2 is based around 10 broad concepts: water; nourishment; light; fitness; movement; thermal comfort; mind; sound; materials and staff. Although WELL certification is very new in warehousing, with only one scheme certified in Europe and a further two globally.

Changes may also evolve outside of the warehouse environment, which will in turn impact the location of any company's future warehouse development. One such example is the current implementation of clean air zones in warehouse modules. Whilst approaches vary, and fulfillment and cross-docking areas are more stringent than others, potential exists to ban petrol and diesel vehicles from certain parts of the layout network.

Along the side, and at either end, are huge glass windows, allowing light into the warehouse. Not only is it thought to improve the wellbeing and productivity of workers, by making it a nicer environment, but it means the usage 56% less electricity in lighting the premises.

Maersk Logistics & Services expect warehouses such as this one to become common place in years to come due to increased legislation but also the fact that by investing in sustainability features means the building costs less to run in the long term. There are substantial opportunities within the warehousing industry to save energy, costs and reduce carbon by the simple implementation of existing, low-energy technology, especially a pragmatic and cost-effective actions. For example, lighting and heating are the core areas for energy- and carbon-saving focus. Spanish warehousing industry can save in excess of 145 million euros in energy costs and 1.4 million tonnes of carbon by making simple changes such increasing of usage the natural light.

Indeed, the legislation in contract logistics drives bit by bit to reduce the environmental impact and decrease the embodied $CO^2$ emissions. In this regard, Maersk represents the leadership in decarbonisation and green warehousing, by changing rapidly the requirements that follow to the international standards and allow to achieve the sustainable strategy.

## RISKS AND OPPORTUNITIES IN MAERSK WAREHOUSING FOR CONTACTS LOGISTICS

Risks are always present around any kind of workplace. Warehouse hazards are especially common in dynamic operations where there are a lot of

objects, movements and moving parts. As more operations are introduced, collisions are happening more likely. These collisions result to costly downtimes. Each downtime is more expensive as the scale of warehouse operations increases. In fact, scaling up the warehouse operations often means overhauling the entire risk and traffic management in the warehouse.

New risks and hazards continue to sprout as the warehouse operations scale up. As more goods are handled, increasing usage of both the horizontal and vertical space is required. As a result, risk management in warehouses requires a dynamic approach. For instance, white collars of Maersk does not have updated information about the risks and hazards present in the workplace. This happens when the operations in cross-docking area spread or take a new direction – arrival of a new client, too many containers to be discharged, fragile and heavy goods are now being handled.

In the above scenario, the risk management manual and safety practices in the workplace are now outdated. The documents remain the same but warehouse white and blue collars now are getting exposed to new kinds of hazards and risks. That's why one of the first steps in risk management is consulting the employees. They are in the frontlines. They're the ones most familiar with the safety and health risks present in the workplace. When operations change or scale up, the staff will be the one to first notice the new risks.

Maersk and CTC[85] employees work hand in hand in identifying the things or potential events that may harm people. Some of those common things and events are:

- The physical work environment itself;
- Equipment, materials and substances used or present in or within the vicinity of the workplace;
- The work tasks and how these are performed;
- The interaction between Maersk and CTC employees and equipment, for example during loading and unloading.

For instance, in the corporate office, warehouse hazards occur as well. These are related to the chairs, desks, shelves, papers, computers, printers and other office equipment. Even if most of the equipment and the staff are stationary most of the time, warehouse risks are still present.

What makes warehouses unique in general (and potentially more dangerous and hazardous) is that there are a lot of movements. Both the people and equipment are in constant motion especially during busy operations and tight deadlines. Perhaps the only stationary things are the shelves and racks. The drivers, non-drivers and forklifts are all in constant motion. Boxes, goods and packages are also being constantly pulled out or put in. Those movements and the constant interaction among people, objects and equipment drastically increase the complexity of warehouse operations.

[85] CTC EXTERNALIZACIÓN S.L.U. is a logistic company provides a solutions for warehousing & distribution. Well known and recognised in Spain. For Maersk, CTC appears as a handling operations vendor in the warehouse who is responsible of all operations take place.

In other words, walking around the warehouse and inspecting equipment, racks and shelves is not enough to identify the risks present in the workplace. We also have to take into account for the movement, traffic and interaction in the area. Indeed, movement brings the complexity level of warehouse operations to a high level. In this case, various scenarios can occur in all these steps:

- Receiving and unloading goods and packages from suppliers, customers and manufacturers;
- Transferring the goods onto pallets for later storage (short-term for cross-docking and fulfillment for long-term storage);
- Storing the goods in appropriate physical and temperature conditions;
- During customer orders, picking the products from the warehouse racks and then preparing them for transport – VAS services: wrapping, packing, palletising, labeling;
- Loading the goods into the vehicles so they can be delivered to the customers;

Each step presents risks and hazards because movements and interactions are always there. For example, receiving and unloading the goods make the forklifts tip over. Loading the orders into the vehicles also presents risks. This is because of the lifting and driving required.

CTC employees should inform Maersk office about the risks and hazards present in the warehouse, whether there's movement or none. It's a

continuous and dynamic approach to identifying risks so that safety procedures will also be regularly updated.

Eliminating the hazards is the best way to make the workplace safe. For instance, slippery surfaces will sooner or later cause accidents no matter how careful the workers are. Eliminating the hazard is the best way to prevent accidents. In this case, removing the slippery surfaces or getting rid of the events that lead to slippery surfaces would work. Another effective way of dealing with risks is by isolating the hazard from people. For example, barriers, gates and rails are often installed to restrict human access to certain areas of the plant.

More effective ventilation system also has been installed so the concentration of chemical fumes won't get too high in warehouse. PPE[86] such as helmets, hard hats, gloves, protective eyewear are effective at limiting employee's exposure to a hazard.

Indeed, any kind of hazards can be prevented in warehouse workplace by good communication between Maersk and CTC employees as well as adequate usage of machinery and equipment. However, not only the human factor has a crucial role in risks, but the company also takes into account the possible ways of hazards. The best way to avoid them is to start the construction of warehouse using best quality materials and on a final or operational stage, secure the zone where risks can occur likely.

[86] Personal Protective Equipment

Among the risks, warehousing gives the opportunities for W&D sector. Currently, Maersk is now at a stage where the challenges within the supply chain are necessitating a change of mindset amongst warehouse operators, with automation and robotics being considered a viable and at times necessary alternative to large amounts of labour. This is now being seen globally. The following list is not exhaustive but details the number of challenges being faced by Maersk today and those likely to be faced in the future. One of the biggest challenges is the growth in e-commerce. This is already resulting in the following[87]:

- smaller, more frequent orders;
- shorter order lead times;
- next-day delivery should be the norm;
- same-day delivery in certain circumstances;
- increase in door-to-door delivery;
- increase in personalisation of items;
- a greater proliferation of product lines or SKU;
- a requirement for accurate information in real time – TARIK system;
- the need to achieve the perfect order to ensure competitiveness;
- a requirement for lower overall inventory and overall cost reduction;
- an increase in the cost of land;
- increasing labour costs;
- a shortage of skilled labour;

[87] Maersk virtual library. Sustainable supply chain among transformations

- a shortage of management knowledge and expertise;
- security of products;
- traceability of items;
- cold chain storage and distribution (the first Maersk cold store warehouse in Iberia planning to be opened in Q2 2023);
- a greater need for systems integration – ERP systems with WMS and TMS[88];
- the growth in cloud-based systems and the reluctance in some quarters to accept them – especially in terms of data security;
- local and global regulations and protectionism;
- sustainability demands – pressure for more environmentally friendly warehouses;
- more buzz words such as Industry 4.0, M to M and the Internet of Things;
- dealing with extraneous events such as the COVID-19 pandemic.

New technology is continually being introduced and concepts such as fully automated warehouses, carbon-neutral deconsolidation centres, hybrid lorries, robotics, drones, voice, vision and optically guided warehouse operations are all in the various stages of development in Maersk.

Thus, what are advantages of the warehousing of the future? In contract logistics? First, it's revolutionary product is 3D printing or additive manufacturing – what effect will this have on the warehouse of the future? Will

[88] Transport Management System

the company actually need warehouses in their current form? Could this lead to the demise of maintenance stores? This section will look at the likely role of the warehouse in tomorrow's supply chain, what it might look like and the new technology which will be adopted.

Other advances include the Internet of Things, Industry 4.0 and Machine-to-Machine communication where everything from camera systems to automation equipment is totally integrated into a WMS or WCS[89]. Conveyors (where they'll be applicable) and storage racks could eventually link to each other, the computer systems, and various personal devices in an advanced warehouse. No need to re-enter data or introduce middleware – the machines will communicate directly with each other.

One other piece of technology is 3D printing or additive manufacturing. 3D printing was originally developed as an automated method of producing prototypes. Although there are several competing technologies, most work on the basis of building up layers of material, sometimes plastic, ceramics or even metal powders, using a computer-aided design. Hence, it is referred to as an additive process; each layer is printed' until a three-dimensional product is created. 3D printing is already very good at producing products, even with moving parts, which previously would have required the assembly of multiple components, and that by eliminating the assembly phase there will be huge savings for the supplier in terms of labour costs. 3D printing-based production can also reduce or eliminate storage, handling and distribution costs.

[89] Warehouse Control System

Warehouse staff will be able to print a required item at home providing they have the scanned image or the blueprints of the product itself.

Global and national company's zones warehouses as well as forward deconsolidation centres will potentially become unnecessary. In some cases, a huge amount of redundancy is built into supply chains to enable parts to be dispatched in a very short time schedule to get machines up and running again as fast as possible.

The service parts logistics industry will be either transformed or decimated by 3D manufacturing or perhaps, both. With small 3D printing machines available, operations in remote locations or even in an engineer's wagon will only need electronic libraries of designs available to them on a local computer. They can then call up the design of the spare part required and immediately print it. Defective parts could simply be scanned in 3D, fixed in the computer's memory and the new part printed. The implications for maintenance warehouse's inventory are clear. A recent research of contact logistics considers that the 3D printing market is estimated to grow between 200 billion and 510 billion euros by 2025, it will not become a substitute for mass-production but a complementary process.

Maersk implies the following advantages of jumping to 3D production in the future for warehousing and distribution[90]:

[90] Maersk Warehousing & Distribution strategy 2022

- lower number of production steps to design, prototype and produce highly complex and/or customised products;
- faster delivery time through on-demand and decentralized production strategies;
- lower logistics and production costs: reduced shipping and storage costs, potential elimination of import/export costs through localised production, elimination of new production tools and molds and costly modifications to factories;
- higher sustainability and efficiency in production through using the least amount of material and energy in production.

The trends in contract logistics can change their paths certainly. The companies use a new technology to make a process of production and distribution less impactable and efficient for supply chain. Even implementation of the new technologies is started to enter to the warehousing, Maersk is taken to its strategy of contract logistics the ways to advance the compliance of good's movement. Even in the current warehouse in Barcelona, it is observable improvements such the usage of exoskeletons, for example, to discharge the containers with heavy goods.

# CONCLUSION

Warehouses are the nodes in logistics networks. Within the network design their number and locations influence the need for transportation. But they also have a footprint from their building and the activities in and around the warehouse. The environmental impact is usually classed into two main parts: construction and operations.

Green warehousing design and build is regarded as being the gold standard, delivering a range of environmental and potentially financial benefits. As warehouses increasingly become centres of economic activity it is important to recognise the impact on the local environment and community. Environmental initiatives related to warehouse operations have the potential to offer ‘green and gold’ benefits. Reducing light and heating bills, for example, also reduces carbon emissions.

The balance between capital building costs and operational costs depends on the price of energy. When energy prices are low there is less incentive to buy/lease a higher specification warehouse.

The emissions in the construction phase are often in a compromise with the operational emissions. More insulation in the construction means more energy is embedded in the building but less is consumed during its daily operations and as a consequence the anticipated durability of a warehouse building is a crucial component in this compromise. Although much of the energy consumption is determined at the design stage of the warehouse, the warehouse’s energy consumption and its environmental impact can also be

reduced to some extent later through the installation of energy- and water-saving technology, for example in updating temperature control, LED lighting systems, solar panels etc.

Warehouses aren't necessarily built or run by a single company that owns the stored products inside them. Contract logistics service providers or tenants investors may own the building and use it for more than one client. Different interests and priorities between these stakeholders may lead to less than optimal solutions. Warehouses also fall into the social dimension of the triple bottom line as they are places of employment. The wellbeing of the workforce therefore must also be part of sustainability considerations.

Companies invest to construct more warehouses so that they can obtain a competitive advantage in the market and to gain money. Therefore, financial considerations to build a warehouse and financial expectations from the operations inside are paramount during the design process. However, increasing awareness and consciousness on the environment to leave a livable world for the future generations have not only forced governments to make regulations but also stressed companies to be socially and environmentally responsible. So, companies, especially the ones that cause more damages to the environment or human safety and health, will be involved in actions to preserve natural resources and to provide healthier and comfortable workplaces. Considering the rise of global logistics in the last decades, warehouse and distribution centres have become on the front view from the perspective of sustainable facilities. While new constructions will have to face with stricter governmental regulations, governments will have to

encourage existing warehouses to renovate their facilities in compliance with new standards. For instance, enhanced capital allowances in the EU has provided tax relief to warehouses that implement energy saving technologies in their buildings. In the Spain, 22% of the warehouses built before 2008 was renovated with respect to energy-saving measures. Therefore, HVAC equipment upgrades, roof replacements and insulation upgrades hold a significant potential to reduce energy consumption in existing warehouses. For new constructions, determining a good location and following an appropriate green certification system will be more viable day by day to achieve sustainable warehouses. Additionally, European Foundation for Quality Management (EFQM) model criteria may be used as a road map to make the warehouses sustainable from the perspective of warehouse management.

As a result of this analysis, the author allots the following elements for sustainable warehousing:

1. Optimal locations in a proximity to the main transport intermodal hubs;
2. Efficient layout, making the most of storage space and maximizing the throughput of fulfillment and cross-docking operations;
3. Energy efficiency through the advantages of natural light and energy management systems;
4. Implemented WMS and TMS to efficient operations running;
5. RACKS, to increase the capacity of storage goods and avoid the hazards in warehouse;
6. Sustainable climate control with efficient temperature regulations;

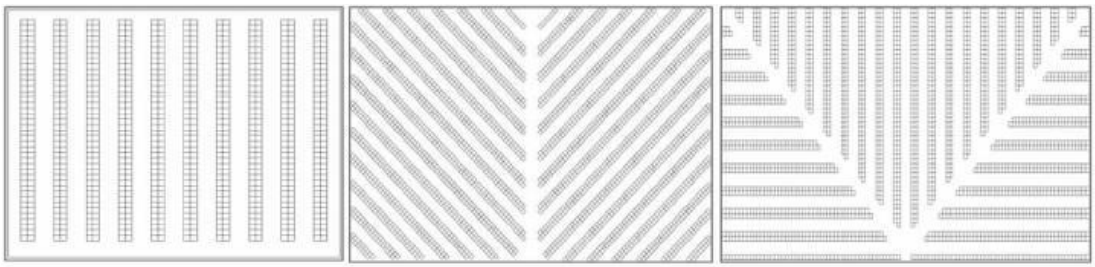
7. Solid recycling of material, smart packaging, distinct reuse of pallet and reducing the onset of additional wastes.
8. Preventive maintenance to avoid any kind of risks, hazards or breakdowns in machine-failure or operations involved.

Maersk warehouse in Barcelona is a first huge project of the company in SWE area. In was opened in January 2022 and it is a pilot for a company's strategy in contract logistics – warehousing and distribution. Despite the dimensions (8.000 $m^2$ which is quite narrow side for warehouse), it already recommended itself among other warehouses located in ZAL thank to company's soaring sustainable demands and operations quality running. Although, the warehouse still has to seek the enhancement in terms of efficiency of productivity and sustainability via better communication and explanation of cost-effective consumption of energy, recycling materials to its employees as well as to outsourcing company regarding and such a matter, educate the transport drivers to reduce the embodied $CO_2$ emissions by turning out the engine of lorries while waiting the register or queuing for load / unload.

Being certified by LEED as a gold warehouse in the construction and equipment stages (gained 78 points), the warehouse should prove its efficiency on operational level to gain the platinum status. It's a first logistic centre among the Maersk warehouses less than 2 years durability certified so quickly. Moreover, it'll be the first warehouse as well to be certified by WELL certification regarding sustainable and mental health of its employees. Certainly, company will continue to amend and improve the strategy of

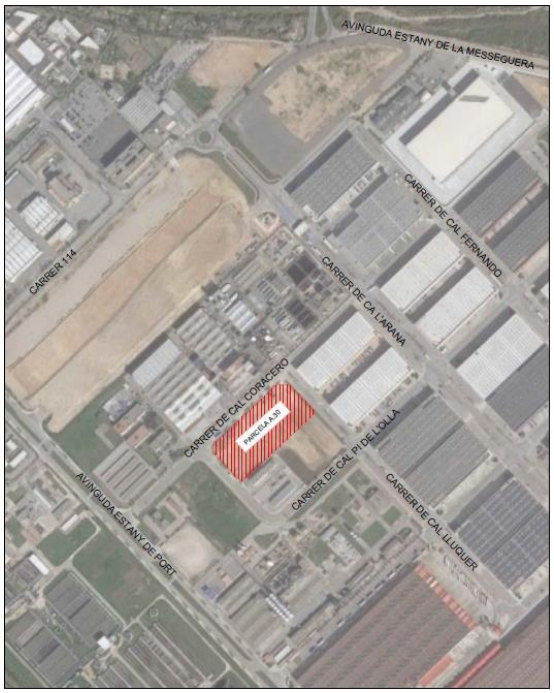
warehousing and distribution by using the sustainable practice to reduce the environmental impact and minimising production of wastes and energy consumption.

## Annex 1 – TYPES OF LAYOUTS IN CONTRACT LOGISTICS



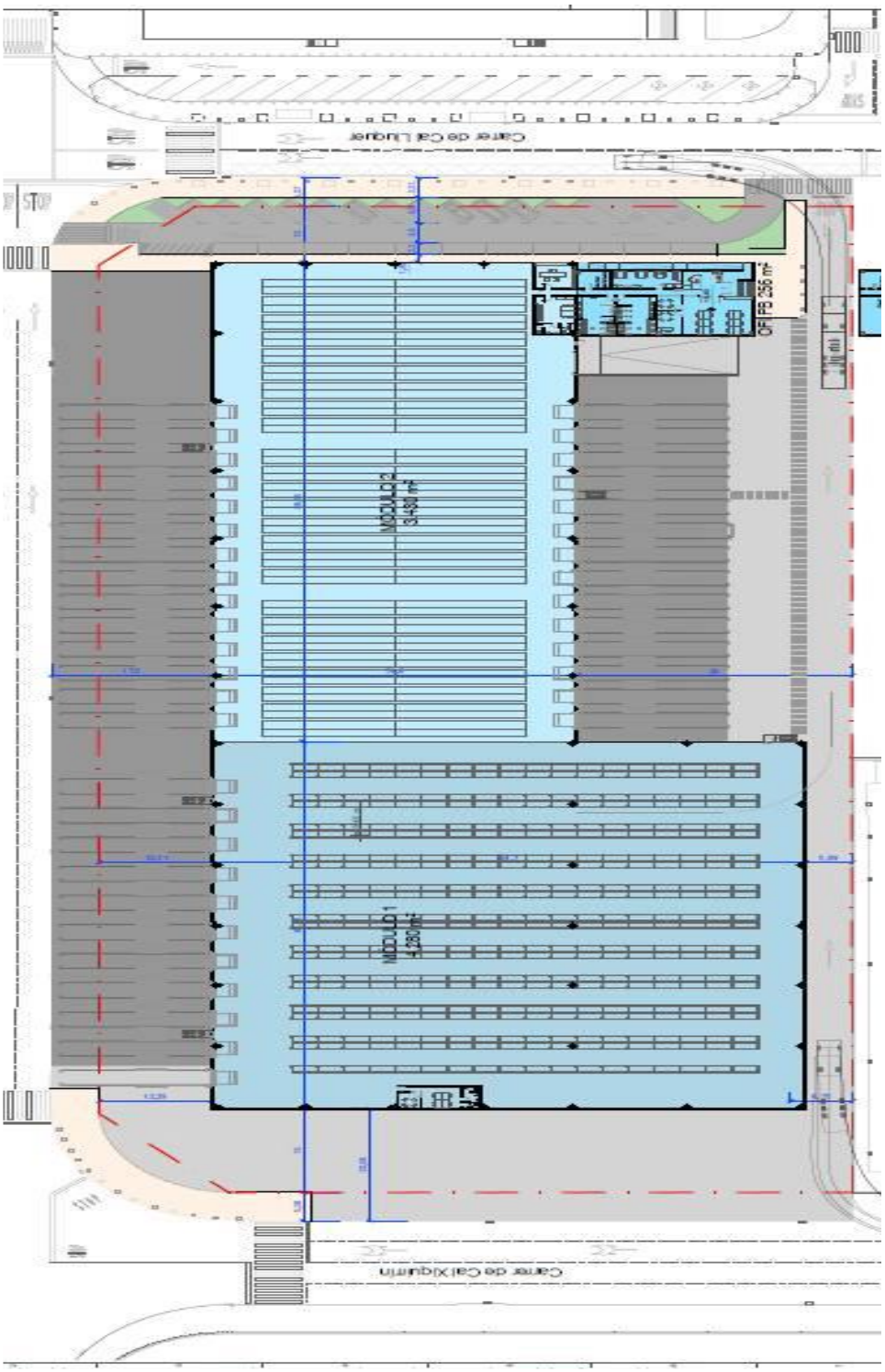
(a) Conventional (b) Chevron (c) Fishbone

# Annex 2 – MAERSK WAREHOUSE LOCATION ZAL EL PRAT

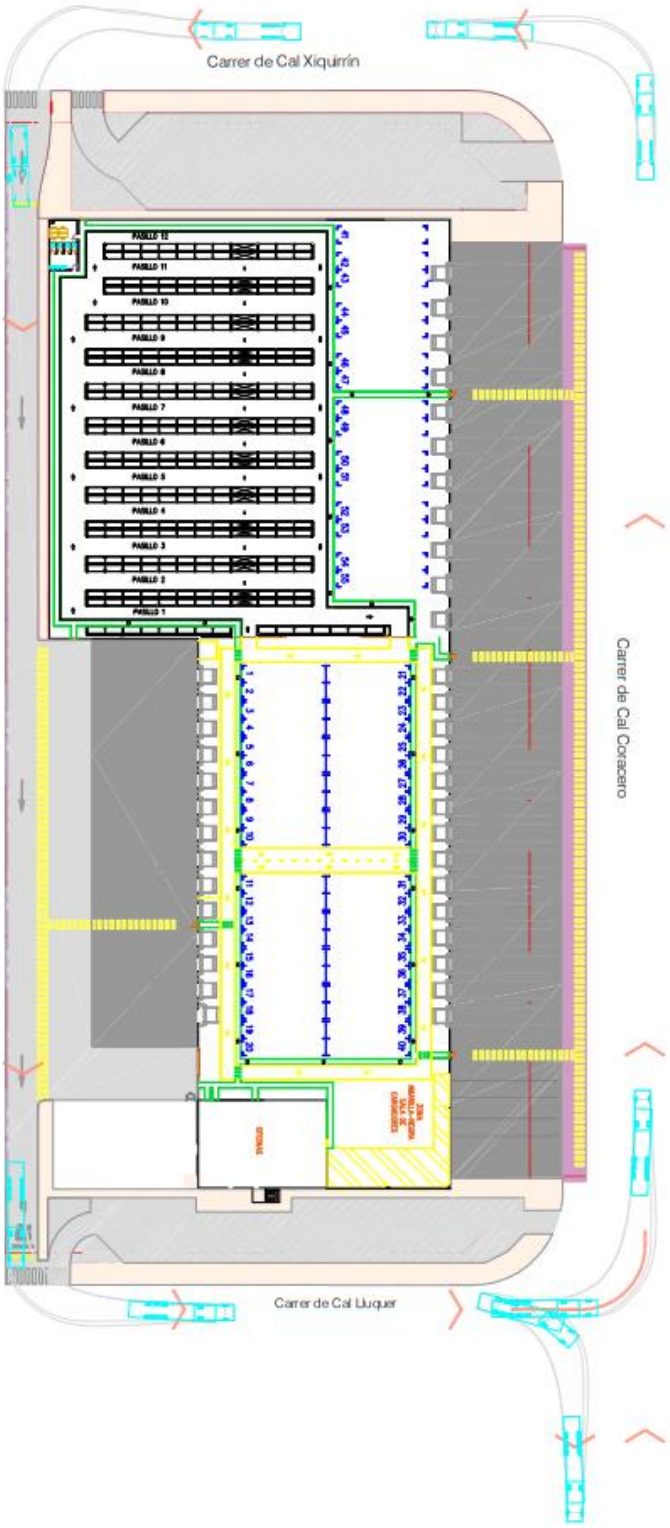



## Annex 3 – MAERSK WAREHOUSE LOAD / UNLOAD FACES

## Annex 4 – MAERSK FLOW WAREHOUSE MODULES



# Annex 5 – MAERSK WAREHOUSE LAYOUT



## REFERENCES


Adrien-Kirby A.J., Hoejmose S.U. (2018) Socially and environmentally responsible procurement: a literature review and future research agenda of a managerial issue in the 21st century. Journal of Purchasing and Supply Management, 18 (4), p. 232–242

Ahmed D. Sundaram D., Tan K-S., Sustainable Warehouse Management., Electronic Source: https://www.researchgate.net/publication/247927242

Akkucuk U. (2018) Handbook of Research on Supply Chain Management for Sustainable Development, IGI Global. ISBN: 9781522557579 – Chapter 12: Lean and Sustainable Warehousing.

Baker P. (2010) The Principles of Warehouse Design, 3rd edition., The Chartered Institute of Logistics and Transport in the UK

Baker P. (2012) The Environmental Impact of Warehouses., Proceedings of the Logistics Research Network Conference

Blanchard D. (2021) Supply Chain Management Best Practices, Third Edition, John Wiley & Sons, Inc. – Chapter 8: Distribution and Warehousing – Going with the Flow.

Blanchard D. (2008) How to Build a Lean-Green Warehouse Network, IndustryWeek, p.64–65.

Browne M., McKinnon A., Whiteing A. (2012) Green Logistics: Improving the environmental sustainability of logistics, 2nd edition, Kogan Page

Brodin H. Kohn C. (2005) Centralized distribution systems and the environment: how increased transport work can decrease the environmental impact of logistics. International Journal of Logistics Research and Applications, 11 (3), p. 229–245

Carter C.R., Rogers D. S. (2008) A framework of sustainable supply chain management theory., International Journal of Physical Distribution & Logistics Management, 38 (5), p. 360–387

Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC. Electronic Source: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32012L0027&from=EN

Directive 2009/31/EC of the European Parliament and of the Council of 23 April 2009 on the geological storage of carbon dioxide and amending Council Directive 85/337/EEC, European Parliament and Council Directives 2000/60/EC, 2001/80/EC, 2004/35/EC, 2006/12/EC, 2008/1/EC and Regulation (EC) No 1013/2006. Electronic Source: https://eur-

lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009L0031&from=EN

Directive EU 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources. Electronic source : https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L2001&from=EN

European Green Deal: Commission proposes transformation of EU economy and society to meet climate ambitions. Electronic source: https://ec.europa.eu/commission/presscorner/detail/en/ip_21_3541

Fabbri M., Glocker J., Schmatzberger S., Rossini A.V. (2020) A guidebook to European Building Policy. Key legislation and initiatives. Buildings Performance Institute Europe (BPIE). – p. 1-50

Ferrari C., Parola F., Morchio E. (2006) Southern European ports and the spatial distribution of EDCs. Maritime Economics and Logistics, 8 (1), p. 60–81

Fieldson R., Rai D., Sodagar B., X Hu. (2011) Assessment of $CO_2$ emissions reduction in a distribution warehouse. Energy, 36, p. 2271–2277

Frydendal J., Schmidt A. (2003) Methods for calculating the environmental benefits of “green' products” in (ed) C. Erdmenger. Buying into the Environment: Experiences, opportunities and potential for eco-procurement

Fuerst F., McAllister P. (2011) The impact of Energy Performance Certificates on the rental and capital values of commercial property assets., Energy Policy, 39, p. 6608–6614

Futch M. (2017) Rise of the Warehouse Robots, Material Handling & Logistics, p. 13–15.

Klassen R.D., Krause D.R., S. Vachon. (2009) Special topic forum on sustainable supply chain management: introduction and reflections on the role of purchasing management., Journal of Supply Chain Management, 45 (4), p. 18–24

Grant D.B., Trautrims A., Yew Wong C. (2015) Sustainable Logistics and Supply Chain Management, Revised Edition., Kogan Page Limited. – Chapter 4: Sustainable Warehousing.

Handfield R.B., Melnyk S.A., Walton S.V. (2012) The green supply chain: integrating suppliers into environmental management processes. International Journal of Purchasing and Materials Management, 2012, 34 (2), p. 2–11

HP. (2016) Supply chain responsibility: Our approach. HP Development Company, L.P.

Johnson E. (2009) Charcoal versus LPG grilling: A carbon-footprint comparison. Environmental Impact Assessment Review, 29 (6), p. 370–378

Jones D.T., Hines P., Rich N. Lean logistics., International Journal of Physical Distribution & Logistics Management, 27 (3/4), p. 153–173

Maersk Sustainability report 2021. – p. 17-35

Maersk Warehousing & Distribution strategy 2022. – p.18-43

Maersk decarbonisation strategy 2050 (only internal usage)

Maersk Logistics & Services Spain: Contract logistic coverage in EU. Warehousing and Distribution enhancement in SWE area. – p. 67-76

Maersk virtual library. Sustainable supply chain among transformations

Maersk web site. Maersk opens its logistics center for South Western Europe at port of Barcelona (ZAL Port). Electronic Source: https://www.maersk.com/news/articles/2022/01/21/maersk-logistics-center-for-south-western-europe-at-port-of-barcelona

Maersk web site. Optimise your supply chain operations with Maersk's warehousing facility in Barcelona. Electronic Source: https://www.maersk.com/news/articles/2021/12/27/supply-chain-operations-with-maersk-warehousing-facility-in-barcelona

Maersk Warehousing and Distribution services in Europe. Electronic Source: https://www.maersk.com/local-information/europe/warehousing-and-distribution/services

Manners-Bell J. (2017) Supply Chain Ethics—Using CSR and Sustainability to Create Competitive Advantage. Kogan Page Limited – Chapter 07: Sustainable Warehousing and Distribution.

Minghini J. (2016) How to Control Warehouse Storage Costs, Material Handling & Logistics, p. 24–26.

Morton R. (2004) Adapting to an Adaptive Supply Chain., Logistics Today, p. 14–15.

Office of Public Sector Information. (2020) Guide to PAS 2050. How to assess the carbon footprint of goods and services. ISBN 978-0-580-64636-2, London.

Richards G. (2022) Warehouse Management – The Definitive Guide to Improving Efficiency and Minimizing Costs in the Modern Warehouse, Fourth Edition., Kogan Page Limited

Sinden G. (2010) The contribution of PAS 2050 to the evolution of international greenhouse gas emission standards. International Journal of Life Cycle Assessment, 14, p. 195–203

Secretaría de Estado de Energía. (2021) Estrategia de Almacenamiento Energético. ISBN: 978-84-18508-43-1, Madrid

The Guardian (2011) Facebook builds "green" data centre in Sweden. Electronic source:

https://www.theguardian.com/environment/2011/oct/27/facebook-green-datacentre-sweden-renewables

Trunick P.A. (2005) How to Design a Cost-Effective DC., Logistics Today, p. 42–45.

Regulation EU No 1227/2011 of the European Parliament and of the Council of 25 October 2011 on wholesale energy market integrity and transparency. Electronic source: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32011R1227&from=EN

UN Department of Economic and Social Affairs. Industrial Development for the 21st Century: Sustainable development perspectives, United Nations digital library, New York, 2007. Electronic Source: https://digitallibrary.un.org/record/598441

World Economic Forum. Supply Chain Decarbonization: The role of logistics and transport in reducing supply chain carbon emissions. World Economic Forum, Geneva, 2009. Electronic Source: https://www3.weforum.org/docs/WEF_LT_SupplyChainDecarbonization_Report_2009.pdf

World Economic Forum (2009). The Global Competitiveness Report 2009–2010. Geneva. Electronic source: https://www3.weforum.org/docs/WEF_GlobalCompetitivenessReport_2009-10.pdf