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Title of the Dissertation Report

"Development of a Framework for implementation of a Lean Green Temperature Controlled (LGTC) Warehouse Management System (WMS)"

By

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Guided By

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Declaration by the Guide

This is to certify that the Mr. Supratim Mondal, a student of **MBA –LSCM, SAP ID 500051251** of **UPES** has successfully completed this dissertation report on "**Development of a Framework for implementation of a Lean Green Temperature Controlled (LGTC) Warehouse Management System (WMS)**" under my supervision.

Further, I certify that the work is based on the investigation made, data collected and analysed by him and it has not been submitted in any other University or Institution for award of any degree. In my opinion, it is fully adequate, in scope and utility, as a dissertation towards partial fulfilment for the award of degree of MBA/BBA/B.Sc.

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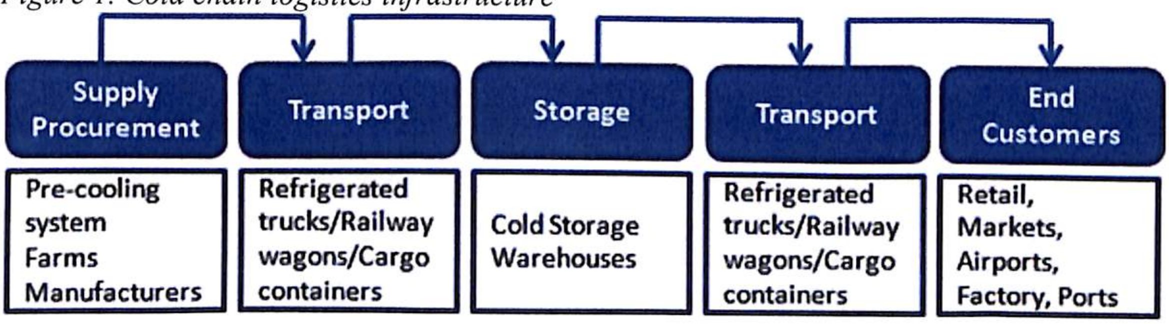
Chapter 1

Introduction

1.1 Introduction including background of the proposed Study:

Temperature Controlled Warehousing is a part of "Cold Chain Logistic System"; The Cold Chain refers to the transportation and storage of temperature sensitive products like perishable goods from the point of origin to point of consumption in the food supply chain. Cold chain process helps reducing spoilage, retains the quality of the harvested products and guarantees a cost efficient delivery to the consumer which can be transported over long distance and can be preserved beyond the life of the product. Different products require different temperature level maintenance to ensure their integrity throughout the travel process. For instance, the most common temperature standards are "banana" (13 °C), "chill" (2 °C), "frozen" (-18 °C) and "deep frozen" (-29 °C). Staying within this temperature is vital to the integrity of a shipment along the supply chain. Any deviations from the prescribed temperature limits will damage the goods in the transit. Figure 1 below shows a typical cold chain logistics infrastructure.

Figure 1. Cold chain logistics infrastructure



1.1.1 The complete Cold chain logistics system consists of:

Cold Storages: This part of logistics consists of acquiring products from the point of origin and storing them in temperature controlled environment for the further transit to the point of consumption or point of sale.

Refrigerated Carriers: Refrigerated Carriers form the primary distribution in a Cold Chain process. The main aim is continuous maintenance of in-transit required temperature. Failure in this part will be a major setback to the whole process.

Packaging: It can be viewed as the Value added service in the Cold Chain process. It contains adhering to the various specifications and packaging the products.

Warehousing: Warehousing forms the secondary distribution system of the Cold Chain process. After transportation of the products, they need to be stored in a cold storage unit from where they can deliver to the clients based on their requirements.

Management Information Systems (Traceability and Tracking etc.): Throughout the transit of the goods, there should be continuous monitoring of the temperature and efficient supply chain management system should have tracking systems in place to trace the products and vehicles in transit to avoid any malfunctions. A company must maintain proper RFID (Radio - Frequency Identification) and Data logger systems to excel in this area

(Source: *Adapted from* *Innovative Solutions for Implementing Global Supply Chains in Emerging Markets(DOI: 10.4018/978-1-4666-9795-9.ch011)*

1.2 Background

To understand the challenges, opportunities, and issues pertaining to cold storage development, it is useful to understand the needs of cold storage operation and the current cold storage infrastructure and supply.
Cold storage is an important element of the food distribution network. In order to attract customers, cold storage must effectively integrate with food and natural resource-based product suppliers, must coordinate with the global transportation system, and must be cost-effective and competitive. In addition, profitable cold stores must have sufficient inventory to capitalize on economies of scale which characterize cold storage construction and operation.

1.2.1 Inventory Estimation

The first step in designing a successful cold store is estimating expected inventory or demand for cold storage in order to determine necessary capacity. In general, estimates of inventory are based on an input source and the inflow and outflow of that input. In the case of a cold store designed primarily for seafood, storage inputs are a function of several variables, including expected monthly fish landings, proportion of landings sold fresh versus frozen, processed yield, and the storage period for each frozen and deep frozen product.

1.2.2 Sources of Inventory

For a business that depends on relative stability, seafood presents significant challenges due to the highly seasonally and annually variable nature of fish harvests. In many cases, reasonable calculations can be made of annual landings, but there is a high degree of uncertainty regarding the size of future landings for any given fisheries product.

1.2.3 Inventory Dissipation

While it is necessary to know the quantity of landings or processed product in order to estimate total inventory demand, these data are not sufficient to estimate demand. The second component of inventory demand is an estimate of how quickly product will flow out of storage, that is, the rate of inventory dissipation. The rate of inventory dissipation is dependent on a wide array of factors, and typically differs for each species and product form. The rate of inventory dissipation also has implications for the quality of inventory when sold. For example, the quality of fatty fish generally deteriorates more quickly than leaner fish while in frozen storage which can reduce its value. Past research has shown that the decisions and factors affecting the inventory dissipation rate are not dissimilar to those driving non-renewable resource extraction, where the rate of dissipation fluctuates with in market prices. In the case of planning for cold store development, the rate of inventory dissipation is based on a series of assumptions and expectations that lead to an expected dissipation rate that (for planning purposes) is fixed. In general, the planned rate of inventory dissipation for seafood should be sufficient to clear inventory of a given species before the next season begins.

1.2.4 Constructing the Appropriate Cold Store

Many economic factors determine the cold store design appropriate for a given situation. In some cases, the best economic solution is not to build a cold store. In other cases, the best option will be the construction of a large, low temperature, state-of-the-art facility. Some items to consider include demand for a cold store, expected species mix of inventory, and the cost of using an existing cold store. Demand for a cold store takes into account such variables as whether the cold store is publicly available, or whether it integrates with a seafood processor. If a cold store is publicly available, the demand for that cold store will depend on factors such as competition with other cold stores in the area, the ability of that cold store to effectively integrate with transportation networks, and sources of inventory in the area. If a cold store is integrated with a processor, then demand for that cold store can be more easily determined, being purely a function of that processor's operations.

The mix of species and respective market demand influences the choice of holding temperature since the shelf life of certain species is more affected by holding temperature than others. The quality of fatty fish generally deteriorates more quickly in frozen storage than lean fish, but the rate of deterioration is slowed as temperature decreases. If fatty fish with high relative demand are held in storage, one might optimally design a low temperature cold store to preserve quality, or alternatively, subdivide the cold store into several rooms of different holding temperatures to accommodate the temperature needs of different products.

Other factors that determine appropriate cold store design include economies of scale and need to access stored inventory. In some cases, operators may not be concerned with access to stored inventory and may optimally design a facility that accommodates a first in – first out (FIFO) approach where inventory is tightly stacked, there are no aisles dividing the storage area, and inventory is delivered in the front and removed from the back. Other cold stores may be designed with multiple aisles to facilitate a selective approach for turning over inventory, necessitating a larger facility to accommodate aisle space.

1.2.5 Cold Storage Cost

Cost data were gathered from several engineers and cold store designers for cold stores ranging from 640 to 375,000 cubic feet, and from –40 to -10° F. Costs considered include refrigeration equipment, building, refrigeration energy, foundation, racking, and sprinklers. One important note is that there are costs of cold storage that are not explicitly associated with construction and operation. This price differential is viewed as a cost since the value of frozen inventory is worth considerably less than the value of that inventory if it was sold fresh. This cost is included as an opportunity cost in the analysis since the lost opportunity of selling the product fresh is reflected in lower profits.

1.2.6 Capital Cost

The capital cost of a cold store building can be divided into two major parts: the cost of the cold storage box, or the building cost without refrigeration equipment, and the refrigeration equipment. Other costs include the cost of land, foundation, racking, lights, utility installation, and sprinkler system.

The cost of a cold storage box is best described in cost per cubic feet, which generally decreases as the size of the cold store increases. In the smaller size ranges cost per cubic foot decreases rapidly as size increases, but as size gets larger, the rate of decrease in cost per cubic foot declines. Although cost per unit volume always decreases, the total cost of the box always increases as it becomes larger.

The predicted cost of a cold storage box is calculated using statistical models. In the example below, a log-linear spline regression was used, where the "knot" in the regression occurs at –20° F. Temperature generally affects the cost of the cold store box by necessitating differences in insulation and ceiling design for maintaining different temperatures. According to cold storage designers, the cost of a cold storage box increases rapidly at temperatures below –20°. Designs below this temperature begin to push the technological bounds of cold storage design, whereas design temperatures between –10° and –20° vary little in cost.

1.3 Purpose of the Study

Our study is to develop a framework for lean warehouse Management System for deep frozen SKU.

A framework implementation of a lean warehouse Management system needs multi criteria approach to Development of FLARG System.

Flexible: To accommodate increase in volume of SKU for Temp. Controlled Warehouse.
Lean: Lean Temperature Controlled Warehouse – Minimisation of wastages.
Agile: To accommodate variety of SKU's.
Resilient: To enable Temperature Controlled Warehouse to meet exigency.
Green: To develop a green framework.

1.3.1 Problem Statement:

Temperature controlled warehouse suffers from the problem of "variable usages to energy consumption ratio, "Proper storage solution", "optimizing space utilization" and "inventory Management".

1.3.2 Need for the research:

At present solutions are generic in nature and based on floor area utilization. Temperature controlled Warehouse needs to be relooked from the perspective of cost of cooling, use of energy and discharge of pollutants. Hence Research/Study is required to develop a decision framework implementation for lean green temperature controlled warehouse.

1.3.3 Objective:

1. The aim of the study is to propose a durable, scalable and optimally utilization framework for temperature controlled warehouse solution.
2. To maximize the throughput of the warehouse.
3. To suggest remedial and mitigation plans to minimize waste and energy consume.
4. To suggest a framework indicating the return of implementing lean green temperature controlled warehouse system.
5. To suggest scalable and Smart solution.

1.4 Research Hypotheses:

Research questions in this study is "what is the best warehousing solution for deep frozen material that satisfy the criteria – space optimization, waste minimization and green implementation.

Chapter 2

1.3 Review of Literature:

2 **Maarten L. A. T. M. Hertog et. al. (2014)** concluded that Many current commercial warehouse management systems offer fragmented solutions and lack the ability to adopt a holistic perspective to supply chain integrity owing to an absence of information-sharing channels and the necessary tools to obtain relevant environmental data. Given a global need to increase transparency and responsiveness, reduce lead times and enhance security in the perishable food chain, the shift from FIFO to FEFO strategies has gathered significant traction. Most conventional systems estimate shelf life based on an onsite approach and a handover of information which, in many cases, is not based on the actual supply chain history to which the product was exposed.

3 **Pawel Zajac (2017)** on "Zero energy buildings in the logistics warehouse systems" concluded that energy consumption in a warehouse is not always the most important goal. The superior goal is always the efficient handling of the flow of goods. In many cases we may agree to extensive automation, often energy-consuming, instead of short handling time and correct picking. In various situations, however, it is worth taking into account the energy consumption of a warehouse facility.

4 **Sichao Lu & Xifu Wang (2016)** concluded that If the cold chain is broken, the damage it causes would be irreversible. Therefore, timeliness and responsiveness is of vital importance for the food cold chain management. In this paper,we proposed an intelligent solution which is based on the IoT, the cloud computing, and the artificial intelligence. Through the cloud-based IoT platform, the cold chain logistics provider can develop core competencies of awareness and visibility.With these competencies, risks such as temperature violation and route deviation could be detected timely or prevented proactively, and various unexpected incidents could be responded as soon as possible, which contribute to a better quality control of perishable food products and improve customer satisfaction. By leveraging the artificial intelligence, an enhanced decision support can be achieved to reap more economic value.

Chapter 3

RESEARCH DESIGN, METHODOLOGY & PLAN

3.1 RESEARCH METHODOLOGY:

1. A case based Approach.

    1.1. Identifying Guiding Principle of warehouse solution:
    1.2 Identifying the permissible capacity of the warehouse.
    1.3 Identifying plausible utilization of the permissible capacity.
    1.4 Identifying the business growth rate.
    1.5 Carry out Sensitivity.

2. Identifying Engineering solution /Technological implementation to meet the Guiding Principle.

To develop basic framework design for LGTC (Lean Green Temperature Controlled) warehouse, we need to get the preliminary data as stated,

    2.1.1 Customer Business Activity Analysis :
    2.1.2 Required Storage/Inventory Capacity :
    2.1.3 Objective for investments in Storage System :
    2.1.4 Design Objective:
    2.1.5 Through-put Consideration
    2.1.6 SKU Information
    2.1.7 Warehouse Information
    2.1.8 Storage System Consideration
    2.1.9 Material Handling Equipment

3. Compute Return of Investment.
4. Recommendation.

3.2 SOURCES OF DATA:

Case base study.
Data was collected from two sources namely:

i. An existing temperature controlled warehouse of sea food company (YHL)
ii. An existing temperature controlled warehouse of seafood processor Company (BML)

3.3 Research Design:

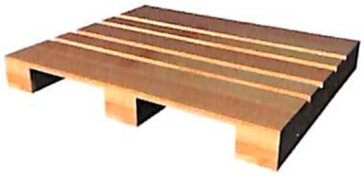
Warehouses for storage of frozen foods are one of the largest energy consumers among the food industry. Increasing energy costs have been driving this vital sector of the industry to look for better practices and technologies so as to reduce its energy use. The major challenge in this sector is lack of suitable energy consumption benchmark data. Most of the available benchmarking studies are survey-based, which though, give a broad outline of energy consumption of one warehouse compared to the other, are limited in determining potential for improvements, if best known industrial practices are applied. Moreover since individual warehouses differ in operating conditions, size and location, comparing two different warehouses becomes mostly inappropriate. These limitations in survey-based studies necessitated development of a theoretical benchmark which provides an achievable expectation for a given warehouse. Thus to design factors needs to maximize the internal storage capacity of every energy controlled warehouses to get the maximum utilization of cold storage area.

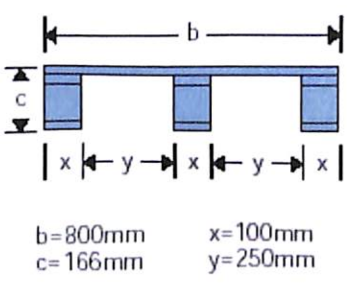
3.3.1 Key Component to develop the Storage :

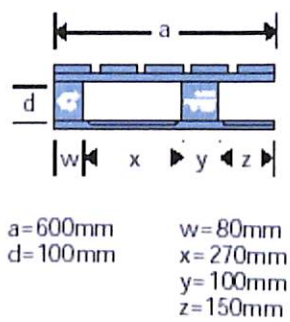
Wooden Pallet: A pallet is the structural foundation of a unit load which allows handling and storage efficiencies. Goods or shipping containers are often placed on a pallet secured with strapping, stretch wrap or shrink wrap and shipped. Temperature controlled warehouses usually use wooden pallets instead of Metal or Plastic for Green approach for the frozen and deep frozen foods and avoid hazardous contaminations.

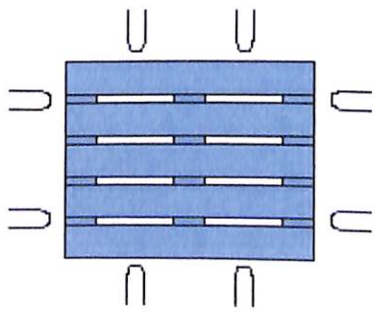
PALLETS

2 Way Open Pallets

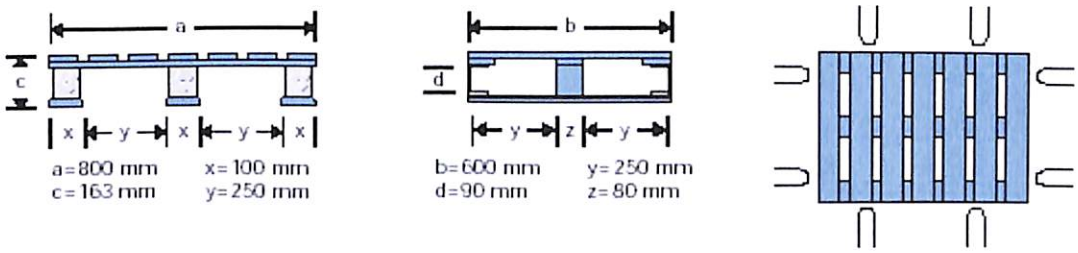




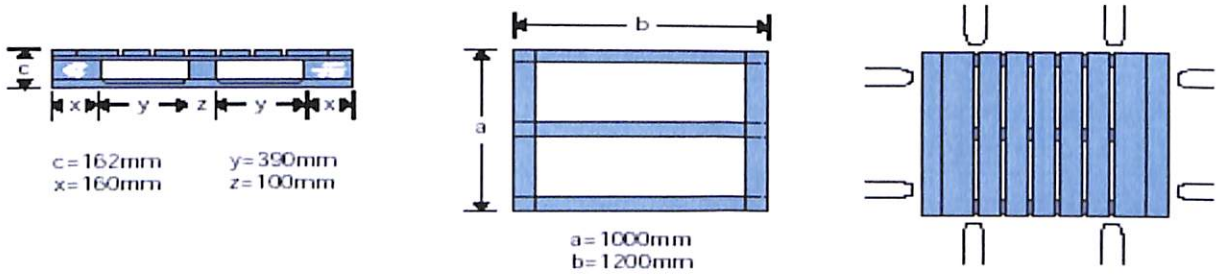




4 Way open Pallets



2 Way Closed Pallets



Pallet RACKING: Pallet racking is a material handling storage aid system designed to store materials on pallets (or “skids”). Although there are many varieties of pallet racking, all types allow for the storage of palletized materials in horizontal rows with multiple levels. Stacker, ,Reach Trucks or Forklift trucks are usually required to place the loaded pallets onto the racks for storage. Since the Second World War, pallet racks have become a ubiquitous element of most modern warehouses, manufacturing facilities, retail centers, and other storage and distribution facilities. All types of pallet racking increase storage density of the stored goods. Costs associated with the racking increases with increasing storage density. Temperature controlled warehouses usually use pallet packing to use the elevated warehouse height and maximize the storage space.

Selective pallet racking is a common pallet racking system in use today. Selective pallet racking systems typically come in one of two configurations: a **roll formed**, or clip-in configuration, and a **structural** bolt-together configuration.

1. **Roll formed** selective rack is most commonly manufactured in a "teardrop" style (so named as the holes on the column of the upright are shaped like a teardrop). Pallets then rest on the horizontal load beams that are held in place by mounting clips. Because

the clips on teardrop configurations can be quickly moved, the shelves can be easily adjusted to different heights to accommodate various load sizes. This is convenient for a warehouse that needs to store a wide variety of product sizes.

2. **Structural** pallet rack systems are very similar to roll formed pallet rack systems except the horizontal load beams are attached to the uprights with bolts and have much greater weight-bearing capacity. The bolt fixings make this a form of adjustable shelving - racks can be constructed, reconfigured, and dismantled and reused as necessary.

Structural pallet racking can be designed into the structure of the building itself, so that the upright columns are simultaneously used to support the roof of the storage facility, in which case the structural pallet rack uprights replace the storage building's vertical support I-beams. This system is a rack supported building.

Selective pallet rack systems provide easy accessibility to all products at all times - important if the inventory is rapidly depleted and restocked (called quick turnover). A selective pallet rack system is commonly used in a "big-box" distribution application, as well as in retail store inventory rooms, cold storage applications, wholesale stores, etc.

Common components of selective rack include the following:

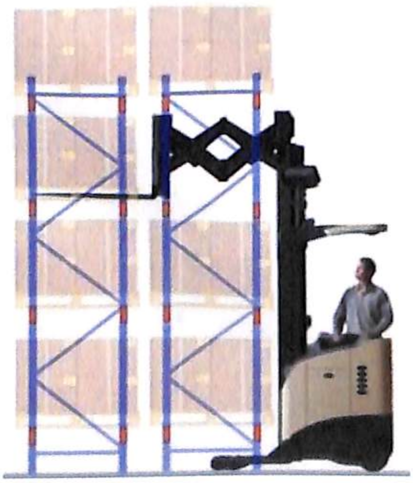
1. **Load beams** (also called step beams or box beams).
   - Most **step beams** are roll formed members with a 1⅝" step along the top inside edge. This step is used to hold any load support components such as pallet supports or wire decks.
   - **Box beams** have no inset step, instead have four flat sides like a box. All load beams typically mount onto an upright frame column with integral rivets or hooks. Some systems utilize an extra clip or bolt to lock the beam to the upright.
   - **Structural beams** are hot formed structural C shapes with connecting clips at either end. Structural load beams are generally used with structural uprights but can be used with standard roll formed uprights. Structural load beams offer heavier weight capacities than step beams or box beams.
2. **Upright frames** (also called upright columns or **uprights**) vary in size and design depending on load requirements, and styles. The most common upright column is produced by roll forming flat coil stock steel into a modified "C" shape with returns. This style is often referred to as open-back roll-formed columns. Holes or slots are punched during manufacturing up and down the column at standard intervals so that the load beams can be mounted into the upright columns. Upright frames can also be constructed utilizing structural C shapes for columns. Structural uprights have an increased weight capacity over roll formed uprights.
3. **Diagonal braces** and **horizontal braces**, commonly referred to as upright frame lacing is usually welded between two upright columns to form selective upright frames. The lacing may be bolted to the columns in some cases.
4. **Pallet supports** are roll formed channels that are placed front to back between the load beams to support pallets.
5. **Timber decking** comes in two forms: close boarded and slated. Close boarded decking provides a solid 'floor' to a level of racking while slatted is formed by rows of timber and acts as a permanent pallet.
6. **Wire decking** is commonly used as a safety measure on selective pallet rack to prevent pallets or the products stored on them from falling through the rack structure. Wire mesh decking comes in various thicknesses and mesh dimensions. Wire mesh construction also allows for easy identification of shelf contents and prevents dirt and other debris from accumulating on the shelves because of the holes in the mesh. Most wire mesh decking has U-shaped channel supports, also known as struts, to support the load. With this **waterfall decking**, the wire mesh extends across the top and down the front of the beam to provide more support, and is more desirable in the marketplace. **Reverse waterfall decking** can provide containment of a loose product to prevent the product from falling behind the rack system. **Lay-in decking** rests inside the step of the beam, and wire mesh does not waterfall over the beam. Some types of decking are

manufactured with solid metal instead of wire mesh. Even though the solid decking provides a greater distributed weight capacity, it is discouraged by fire inspectors because sprinkler systems cannot spray through the shelves to levels below.

7. **Footplates**, also known as footpads or baseplates, are at the base of columns and serve as anchors to give the rack more stability: anchor bolts are inserted through the baseplate's holes to attach the column to the concrete floor. Footplates are made of thicker steel and in some geographic locations, they must be of a certain size and seismic rating. Footpads increase the pallet rack's overall stability and weight-bearing capacity.
8. **Shims** are used when the uprights are resting on uneven floors; the shims, equal in size to the base of the uprights, are installed beneath the uprights to level the rack.
9. **Row spacers** are sometimes used if uprights are arranged in back-to-back rows; the spacers are mounted between adjacent columns to ensure that the rows are kept straight and to give the pallet racks even more strength and steadiness.
10. **Wall ties** may be used for further support if the uprights are arranged in a row along a wall.
11. **Column protectors**, also known as post protectors, are protective shields that can be installed around the base of an upright to minimize damage where forklifts might hit the upright. Damage to the base of a column can weaken the entire frame and could cause it to collapse. Column protectors are made of various materials such as polyethylene, ductile iron casting, and other durable materials.
12. **Guard rails** are installed to increase protection for upright columns and for human safety when platforms or steps are attached to pallet racks.

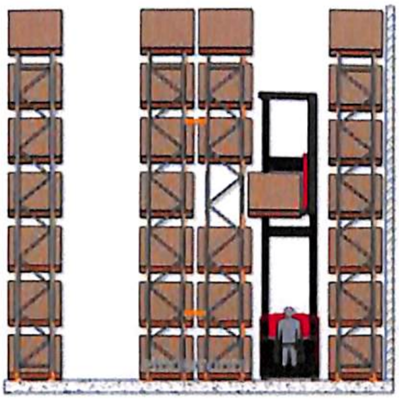
Selective Pallet Racking :

Double Deep Racking

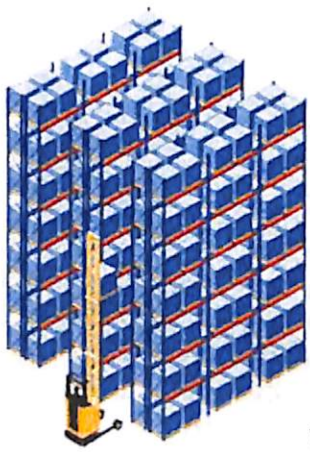


VNA : **Very narrow aisle** otherwise known as **VNA**, is the use of selective pallet racking in a tighter configuration to provide maximum space utilization within a storage facility. These systems typically operate in conjunction with wire-guided or rail-guided reach-truck systems. A wire-guided system consists of a wire embedded in the concrete floor that provides tracking for the reach-truck. A rail-guided system consists of angle iron bolted to the floor down the length of each row. Typically, the angle iron is 4" by 3" and ¼" - ⅜" inches thick. A distinct advantage of a narrow aisle pallet racking is fast picking without large aisles which results in improved use of space. When there is limited space, a compact storage method is ideal. Fully adjustable system flexibility and space saving aisles can be manipulated as one to give the greatest amount of pallet storage locations.

Aisle width : 2.7 –3.1 Mts.



Narrow Aisle Rack



Very Narrow Aisle Rack (VNA)

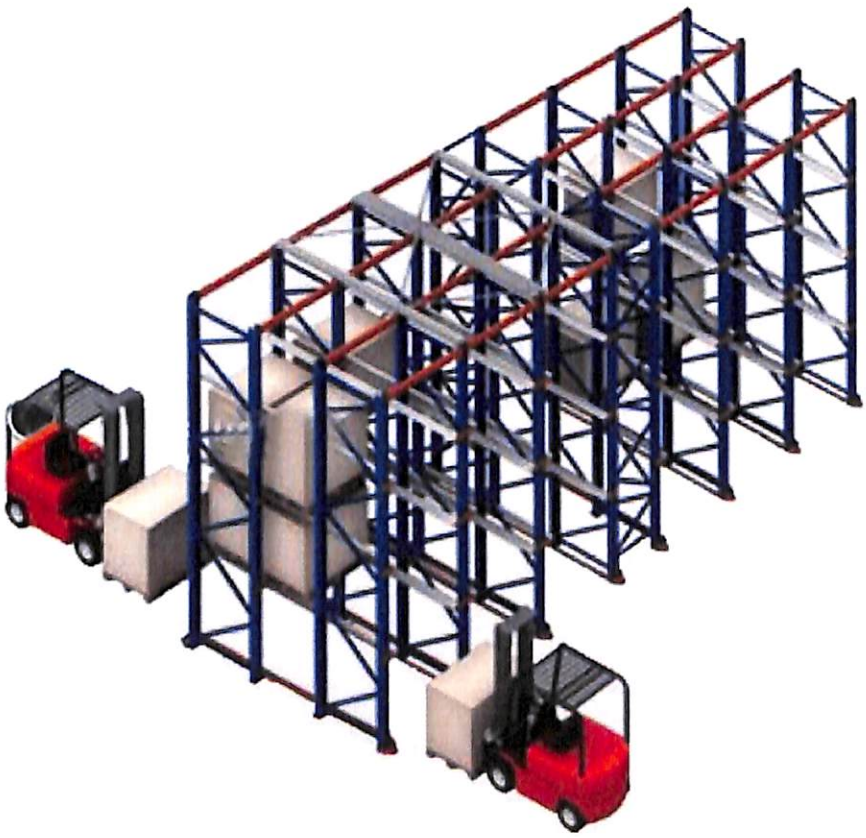
Aisle widths around 2.2 Mts

Aisle widths around 1.7 Mts.

Many types of pallet storage racks are available with different designs to fulfill specific functions or create specific advantages. To create the ideal pallet racking system, several considerations should be taken into account:

- Desired storage density
- Floor space and building height
- Placement of building doors and columns
- Inventory accessibility
- Inventory rotation
- Item/load size and weight
- Optimal storage design
- Cost of materials and installation

Drive – In Rack: Drive-in and **drive-through** (sometimes spelled Drive-thru) are storage rack configurations that allow the forklift to drive directly into the lane of stacked rows (called a bay). The difference between a drive-in and a drive-thru pallet rack system is simply whether the bays have an entry at only one end, or at both ends. Drive-in rack systems use a common entry and exit, while drive-thru systems have entry points at either end of the bay. Because a drive-in racking system has only one entrance, it uses what is called a LIFO (last in, first out) storage method. With only one entrance, the last pallet put into a row is necessarily the first one to be taken out. A drive-thru storage system, with two different entry points, can also use a FIFO (first in, first out) storage method. With a FIFO system, pallets are loaded in one end and are pushed back to the other end, where they are then at the front of the row on the opposite side. The first pallet put into such a row is the first one taken out at the other end. This system is advantageous for material with an expiration date or wherever shelf life is a major concern.

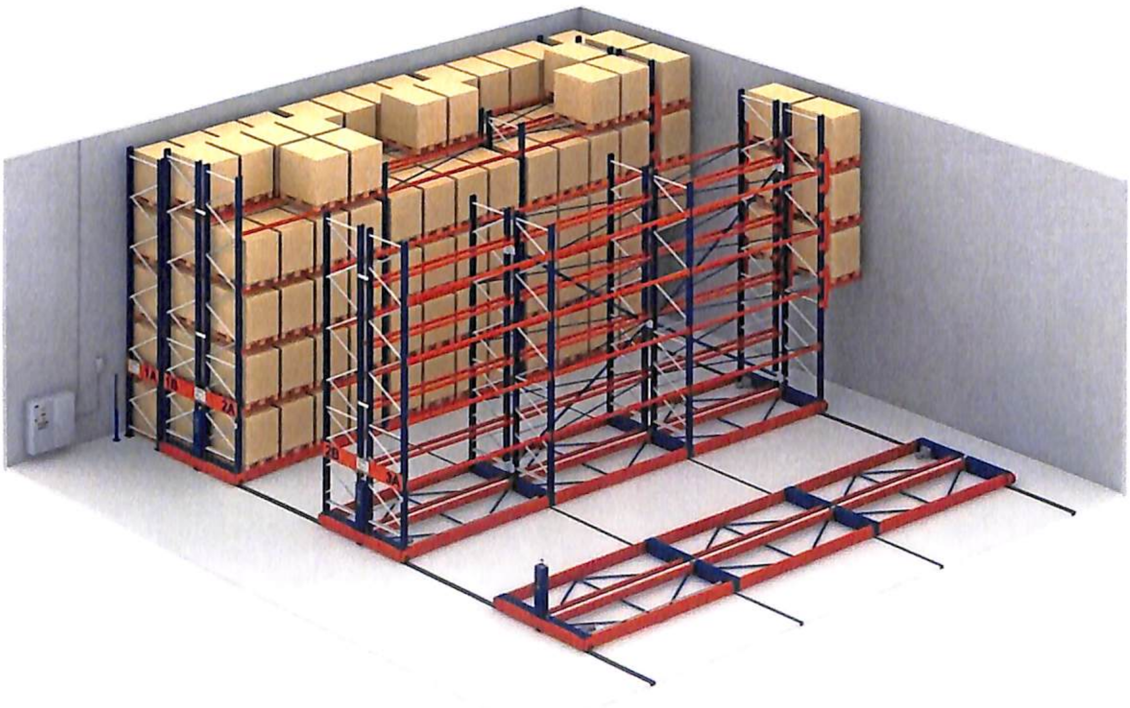


Mobile Rack : Compact mobilized pallet racks (also known as motorized mobile pallet racks or mobile industrial rack system),[3] are designed to maximize the use of warehouse storage space. This can reduce your pallet storage area in half, or double the capacity of your pallet rack storage in the same floor area. It allocates space by converting static access aisles into productive storage space. By mounting rows of pallet racks onto heavy-duty rolling carriages and positioning them on floor tracks. Rows of pallet racks (up to 96' long) move sideways along the floor tracks creating a movable floating access aisle. Typical warehouse storage facilities may have dozens of static access aisles but only one or two forklifts capable of accessing stored materials. This reduces the number of access aisles to match the velocity requirements of your storage area. Rows of pallet racks are moved by pushing a button or by remote control, which opens access aisles when and where they are needed.

Mobilized storage system has helped many organizations reduce or eliminate new building construction costs, auxiliary warehouses, building expansions, and decrease ongoing operational costs (lighting, energy, insurance) by redistributing the use of their storage floor space.

Some disadvantages of high density pallet storage systems are; less access to all stock at any given moment (although if the stored product is all the same, it should not matter), and the expense of such systems. Selective pallet rack systems are considerably less expensive per pallet position than their higher density counterparts. In most medium to large facilities, however, high density pallet rack systems are essential, since they provide the efficiency of time and high cost facility space is better optimized.

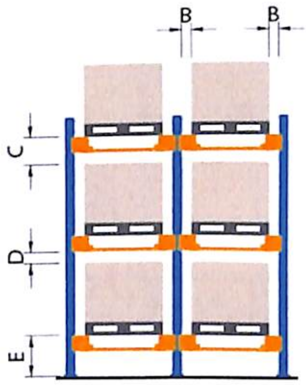
Identifying the brand of racking systems is important to order compatible shelving or resell the racks. It is possible to differentiate between the many pallet rack brands by looking at the shape of the vertical beams, increments of height adjustment and the shape of the holes on the vertical beams.

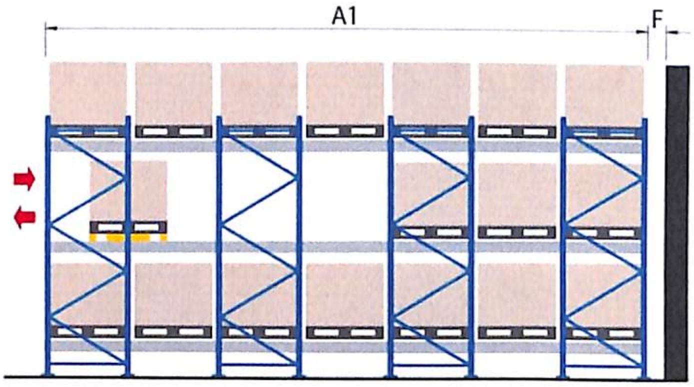


Isometric View of motorized mobile pallet rack

Shuttle Racking System: Pallet Shuttle Racking systems are high density pallet storage systems that utilize depth to increase capacity. This system uses a Battary operated radio shuttle to move the pallet in every depth of the racking. These systems also called Radio-Shuttle System or Pallet Shuttle systems. The pallet shuttle system often has complex motion and braking systems to control the speed of the moving pallet shuttle. Pallet flow racking systems are either a FIFO (first in, first out) or a LIFO (last in, first out) storage system. If the system is loaded from the back and unloaded from the front, it is FIFO; if the system is loaded and unloaded from the front it is a LIFO system.

SHUTTLE RACKING PARAMETERS



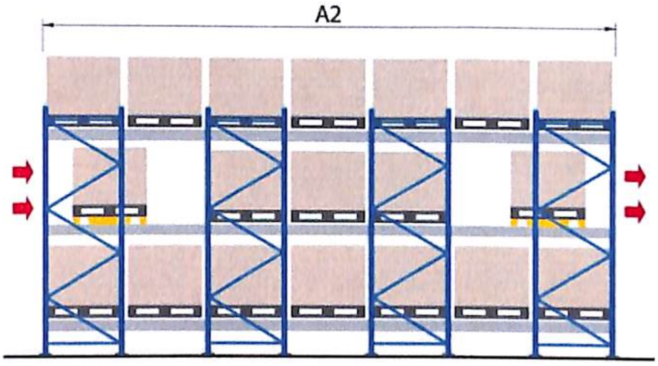


Depth of LIFO

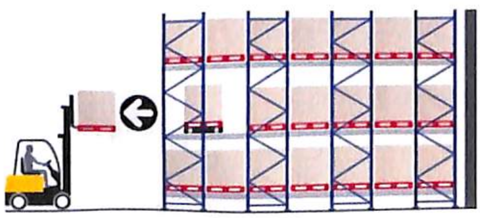
A1 = 300 + (n x (Pallet Depth+20) mm.

Depth of FIFO

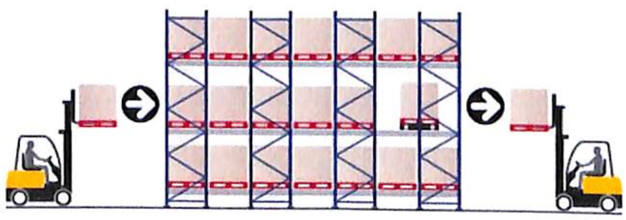
A2 = 300 + (n x (Pallet Depth+20) + 300



B = 75 mm. (minimum clearance)
C = 335 mm. (minimum clearance)
D = 60 mm. (minimum clearance)
E = 400 mm. (Lowest level)
F ⩾ 150 mm.

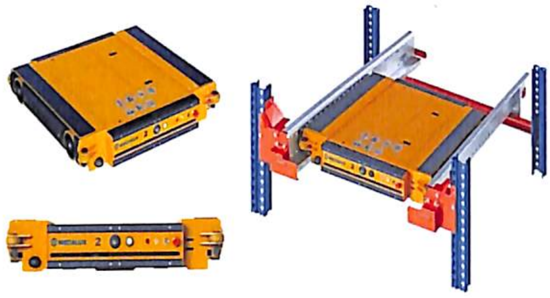


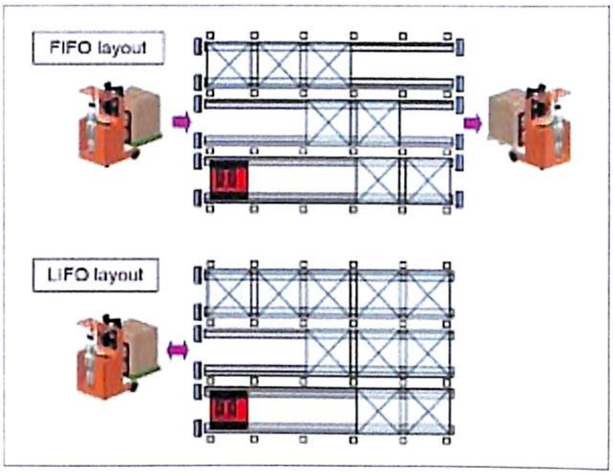
Last-In, First-Out (LIFO)



First-In, First-Out (FIFO)

Radio- Shuttle System





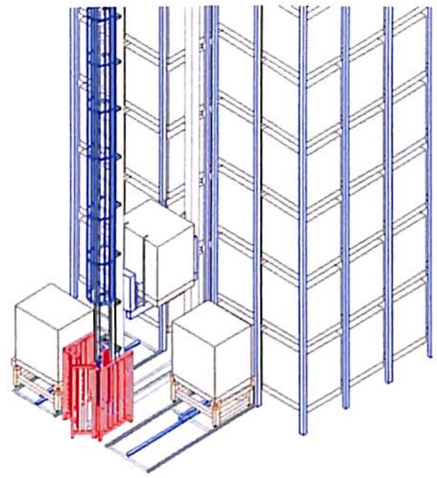
UNDERSTANDING Pallet Racking :

Selective Pallet Racking	• 100% Accessibility. Low investment. • MHE investment low. • Adoptive to different pallet / load shape.
Double Deep Racking	• 50% accessibility. MHE investment is high. • Gives good density but location utilization low compared to SPR
Narrow Aisle Racking	• High density, less aisle requirement. • High investment in MHE, flooring for VNA. • Good vertical height utilization.
Drive – In Racking	• Less SKU x high volume. Low location utilization. • Slower throughput, accident prone.
Shuttle Racking	• Improvement on Drive-in, deep lane, more SKU's. • High investment in MHE + Shuttle. • Faster throughput & safe.

ASRS : An **automated storage and retrieval system** (**ASRS** or **AS/RS**) consists of a variety of computer-controlled systems for automatically placing and retrieving loads from defined storage locations. Automated storage and retrieval systems (AS/RS) are typically used in applications where:

- There is a very high volume of loads being moved into and out of storage
- Storage density is important because of space constraints
- No value is added in this process (no processing, only storage and transport)
- Accuracy is critical because of potential expensive damages to the load

An AS/RS can be used with standard loads as well as nonstandard loads, meaning that each standard load can fit in a uniformly-sized volume. Standard loads simplify the handling of a request of an item. In addition, audits of the accuracy of the inventory of contents can be restricted to the contents of an individual metal box, rather than undergoing a top-to-bottom search of the entire facility, for a single item.




Major Component for AS/RS Consideration:

1. Space availability, height availability.
2. Cost of land & building.
3. Pallet locations planned.
4. Throughput.
5. Material handling, before & after ASRS.
6. Visibility & traceability of material.
7. Stand alone or integrated with production ?
8. ROI justification / other specific objectives ?

An efficient AS/RS system helps companies cut expenses by minimizing the amount of unnecessary parts and products in storage, and improving organization of the contents of a warehouse. Due to automated processes, it also allows for more storage space due to high-density storage, narrower aisles, etc.

Automation reduces labor costs while lowering workforce requirements and increasing safety.

Modeling and managing the logical representation of the physical storage facilities (e.g. racking, etc.). For example, if certain products are often sold together or are more popular than others, those products can be grouped together or placed near the delivery area to speed up the process of picking, packing and shipping to customers.

Enabling a seamless link to order processing and logistics management in order to pick, pack, and ship product out of the facility.

Tracking where products are stocked, which suppliers they come from, and the length of time they are stored. By analyzing such data, companies can control inventory levels and maximize the use of warehouse space. Furthermore, firms are more prepared for the demands and supplies of the market, especially during special circumstances such as a peak season on a particular month. Through the reports generated by an AS/RS system, firms are also able to gather important data that may be put in a model for it to be analysed.

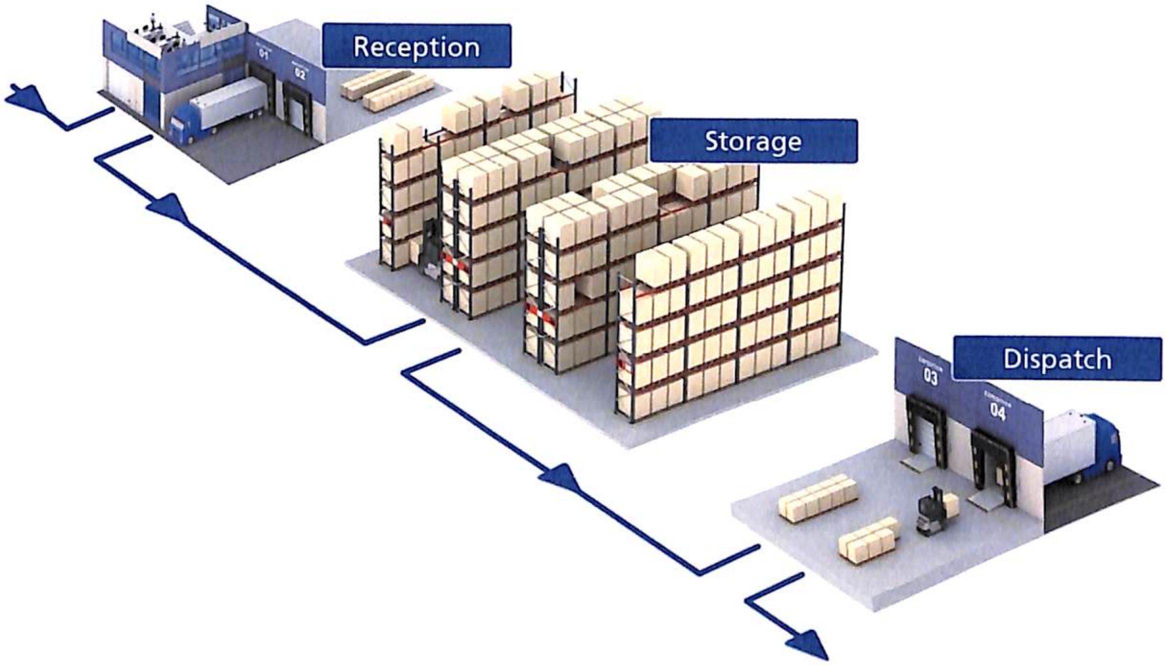
MHE (Material Handling Equipment)

When deciding what material handling equipment to use, it is important to take into account the general characteristics of the equipment types available in the market. Different material handling equipment used for warehouses material conveying, storing and retrieval. For cold storage application we consider all Trucks specially constructed for temperature controlled environment.

Comparasion chart of Stacker, Reach Truck, Aisle Master vs Turret Reach Truck						
Sr. No.	Description	Units	Stacker	Reach Truck	Aisle Master	Turret Reach Truck
1	Type		Stand on	Sit On	Sit On	Sit On
2	Palle Type		Open	Open/Close	Open/Close	Open/Close
3	Fork Type		Fixed	Adjustable		
4	Aisle Space	mm	2800	3100	2200	1650
5	Throughput	Pallet / Hr	8 to 10	16 to 18	14 to 16	22 to 24
6	Guide Rail		N/A	Optional	N/A	Required
7	Operation		Equipment required to move 90 Degree every time		Only mast Articulates	Fork mounted Turret moves
8	Steering		Tiller Arm	Steering type		
9	Over head Guard		N/A	YES		
10	Basic Capacity	kg	2000	2000	2000	1500
11	Lift height available	mm	6500	12000	12400	9500
12	Capacity @ max	Kg	800	800	900	700
13	Flooring		Levelled (RCC)	Levelled (RCC)	Levelled (RCC) & Rough Terrain	Levelled (Tremix)
14	Application		Indoor	Indoor	Indoor & Outdoor	Indoor
15	Pictures					

WMS: A **warehouse management system** (**WMS**) is a software application designed to support and optimize warehouse functionality and distribution center management. These systems facilitate management in their daily planning, organizing, staffing, directing, and controlling the utilization of available resources, to move and store materials into, within, and out of a warehouse, while supporting staff in the performance of material movement and storage in and around a warehouse.

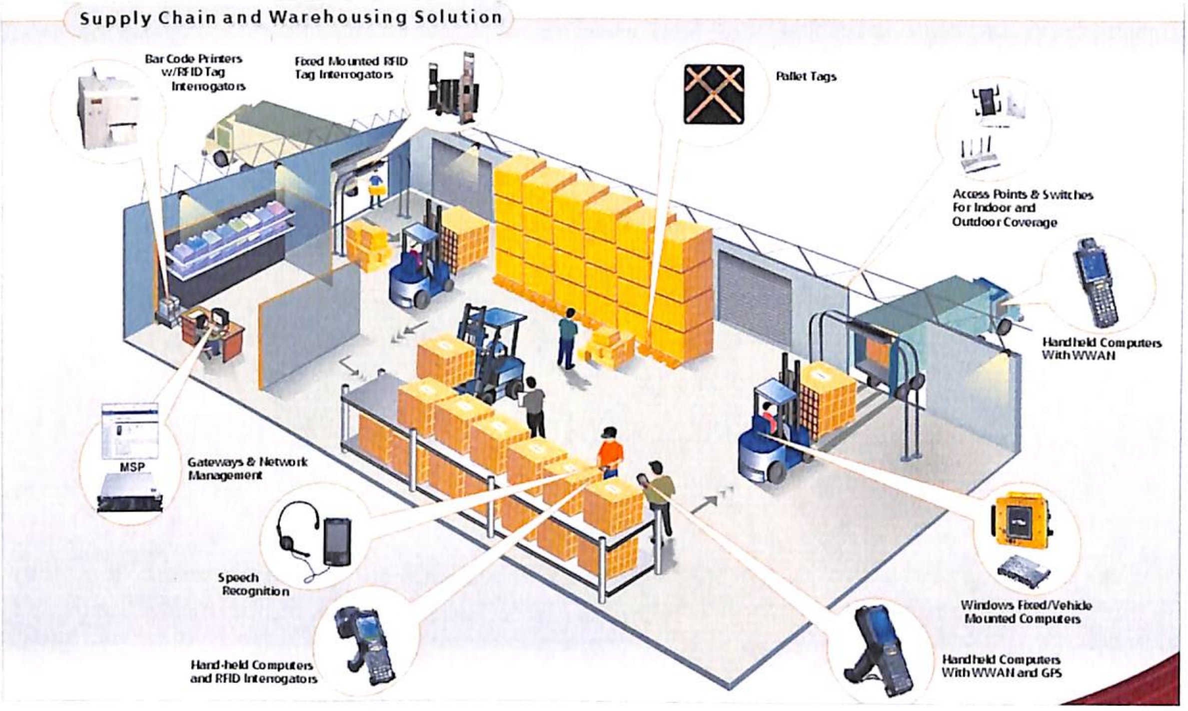
Warehouse management systems support warehouse staff in performing the processes required to handle all of the major and many minor warehouse tasks such as receiving, inspection and acceptance, put-away, internal replenishment to picking positions, picking, packing, value added services, order assembly on the shipping dock, documentation, and shipping (loading onto carrier vehicles). A warehouse management system also helps in directing and validating each step, capturing and recording all inventory movement, and status changes to the data file.



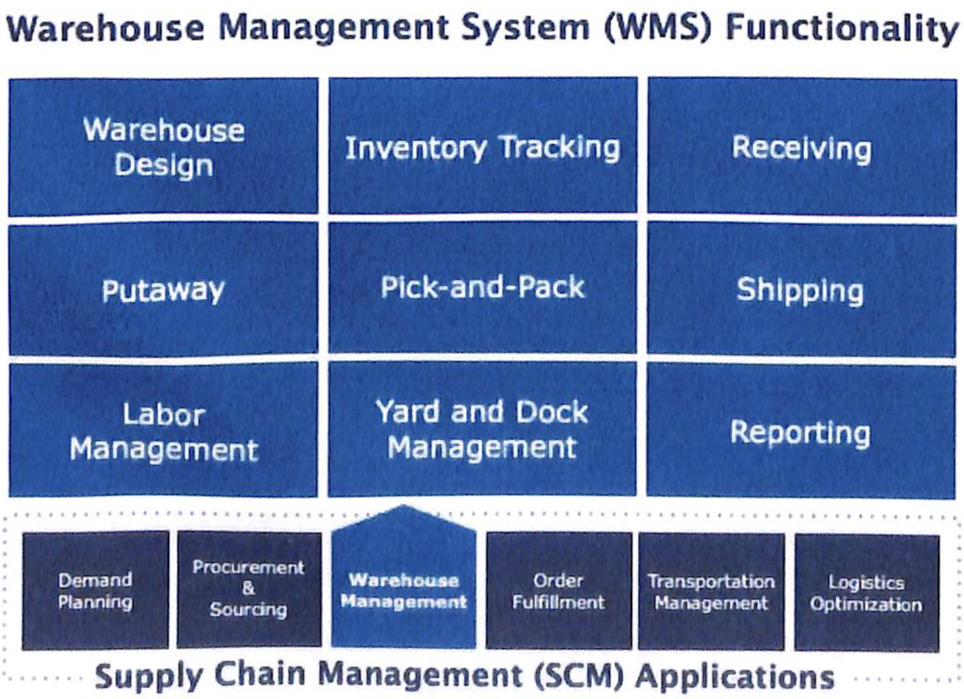
A warehouse management system usually represents the central unit in the software structure of a warehouse. The WMS receives orders from the overlying host system, mostly an ERP system, manages these in a database and, after appropriate optimization, supplies them to the connected conveyor control systems.

This becomes clear when you look at the processes necessary for e-commerce: as soon as a customer places an order on a website the information is passed along via the business host computer (mostly an ERP system) to the WMS. All necessary steps to manage this order, pick the ordered items, etc., are then processed within the WMS. Afterward, information is sent back to the business host computer to support financial transactions, advance shipping notifications to customers, inventory management, etc.

FUNCTIONAL LAYOUT OF WMS System.



A modern WMS will connect to a variety of communication technologies (radio frequency), automatic ID technologies (barcode, RFID, etc.), mobile computers, and occasionally automated material handling (conveyors and sortation) and storage equipment (carousels, automatic storage and retrieval, etc.).



Chapter 4

Finding & Analysis:

2.1 Data Collection and Analysis

Data was collected from two sources namely:

iii. An existing temperature controlled warehouse of sea food company (YHL)
iv. An existing temperature controlled warehouse of seafood processor Company (BML)

4.1.1 Case Study Case Study 1: Sea food processing warehousing requirement of YanHua Limited (YHL)

YHL is into business of marine products and sells in domestics as well as international markets. The specification of the stock keeping units (SKU), and storage requirements are as:

Survey Question: Design Shortcomings

Mr. Rashid Ansari, the warehouse manager of YHL stated that the current warehousing solution described above lacks from the following shortcomings:

i. The space was insufficient during certain period of time
ii. The space remained underutilised during certain period of time
iii. The energy consumption per unit load varied over time
iv. The maintenance cost per unit load varied over time
v. YHL had to resort to outsourcing of warehouse space and in some occasion could not meet customer requirement.

SKU and storage requirements

Packaging: Cartons in Pallets

Dimension (l x B x h in mm): 1200x1000x 1500

Pallet Load: 1000 Kg

Temperature requirement: 0 to -20°C

Inventory flow: LIFO(50% Pallet Selectivity required)

Space Restriction: Yes

Conventional Solutions (by existing warehousing solution providers)

Criteria: 1. Cost; 2. Inventory Flow; 3. Dimension; 4. Temperature requirement
Design Approach

Minimize Cost (C_i), where i = Type of warehouse : Temperature controlled i = 1, else 0

Subject to

Dimension (m^3) = α , say α = 1200x1000x 1500

Pallet Load (kg) = β, say β = 1000 Kg

Temperature requirement (°C) = γ; say, γ = 0 to -20°C

Inventory flow: LIFO

Space Restriction: Φ , say Φ = (l'=10m x b'=10m x w'=10m; 1000 m^3)

DATA SOURCES :

	BLOCK I (Considering one Block)
WH Length	**41654 mm**
WH Width	**27183 mm**
WH Height	**10900 mm**
Proposed Storage Area Length (l)	**40320 mm**
Proposed Storage Area Width (b)	**22100 mm**
Proposed Storage Area Height (h)	**9500 mm**
Single Working Aisle LIFO	**3133 mm**
Considered Maintenance Aisle	**1700 mm**

Solution

If MHE = Reach Truck
Aisle width = 3100 mm
Cost = INR 2500000
Else If MHE = Aisle Master
Aisle width = 2200 mm
Cost = INR 3200000
Else If MHE = VNA Truck
Aisle width = 1650 mm
Cost = INR 3500000

1. MHE Stacker will not be considered, as last loading level is 7800 mm.
As if ,
Last loading level H1
Stacker lift Height H2 .... H2 > H1

If rack type = Selective Pallet Racking Density per m^3 for pallet dimension = 1.8
Cost = INR 2500
Else If rack type = Drive-In Shuttle ,Density per m^3 for pallet dimension = 1.8
Cost = INR 3600

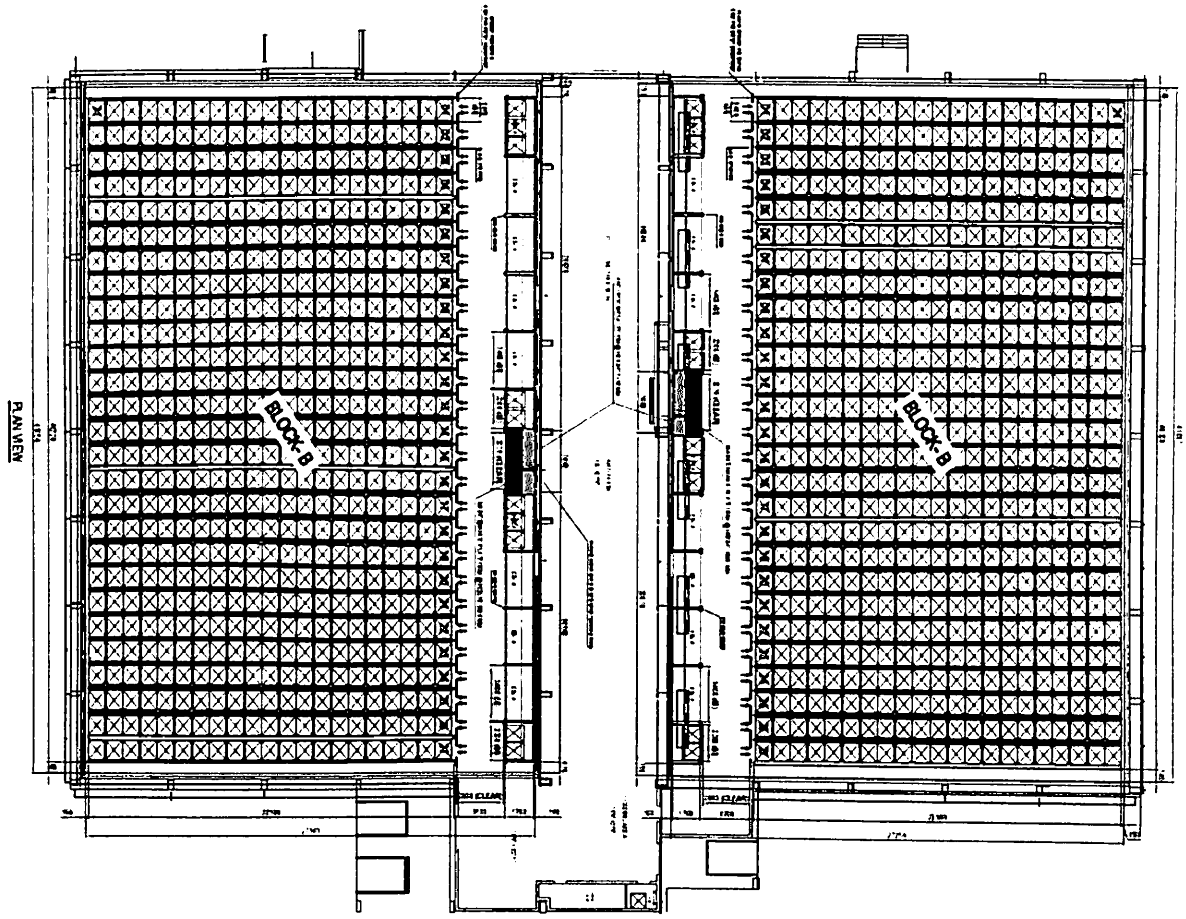


Fig 01: Proposed Shuttle Racking for YHL Cold storage Proposal: LIFO Pallet Flow

Thus Considering Drive In Shuttle Rack: Observation

Number of rows R= l' ÷ (l+ [2 x l"]), i.e., for every row of width b, there are 2 aisles on both sides of the row of width b"

Number of Columns C= b'÷ b

Thus, Number of rows R
R= l' ÷ (l+ [2 x l"])
= 40340 ÷ (1200+ [2 x 125]) [l = 1200 mm + 250{single side clearance 125 mm}]
= 27

Number of Columns C= b'÷ b
= 22100 ÷ 1050(b = 1000 mm + 50mm clearance)
= 21

Number of pallets per column N_C = h'÷ h
= 9500 ÷ 1850(h= 1500 mm + 350 mm clearance for shuttle run)
= 5

Number of pallets per row P_R= C x N_C = 21 x 5 = 105

Storage Capacity Φ' = [R x P_R] = [27 x 105] =2835 x(1.45l x1.05bx1.85h)

Non-revenue earning space = Φ - Φ' = 12177 – 7985 = 4191 m^3

Thus Considering Selective Rack: Observation

Number of rows R= l' ÷ (l+ [2 x l"]), i.e., for every row of width b, there are 2 aisles on both sides of the row of width b"

Number of Columns C= b'÷ b

Thus, Number of rows R
R= l' ÷ (l+ [2 x l"]
= 40340 ÷ (2250+ [2 x 2200]) [l = 1000 mm x 2(Back to Back) + 250{single side clearance 125 mm} Working aisle required 2200 mm]
= 06
Number of Columns C= b'÷ b
= 22100 ÷ 1200(b = 1000 mm + 50mm clearance)
= 18
Number of pallets per column N_C = h'÷ h
= 9500 ÷ 1750(h= 1500 mm + 250 mm clearance for shuttle run)
= 5
Number of pallets per row P_R= C x N_C = 18 x 5 = 90

Storage Capacity Φ' = [R x P_R] = [06 x 90] = 540 x(1.45l x1.05bx1.85h)

Non-revenue earning space = Φ - Φ' = 12177 – 1520 = 10657 m^3

PIC: LIFO Shuttle Racking

4.1.2 CASE STUDY II

CASE STUDY 2: SEA FOOD PROCESSING WAREHOUSING REQUIREMENT OF BEN MARINE LIMITED (BML)

BML is into business of marine products and sells only in international markets. The specification of the stock keeping units (SKU), and storage requirements are as:

SURVEY QUESTION: DESIGN SHORTCOMINGS

Mr. Ronit Guha, the warehouse manager of BML stated that the current warehousing solution described above lacks from the following shortcomings:

i. The space was insufficient during certain period of time
ii. The space remained underutilised during certain period of time
iii. The energy consumption per unit load varied over time
iv. The maintenance cost per unit load varied over time
v. YHL had to resort to outsourcing of warehouse space and in some occasion could not meet customer requirement.

SKU and storage requirements

Packaging: Cartons in Pallets

Dimension (l x B x h in mm): 1200x1000x 1500

Pallet Load: 1000 Kg

Temperature requirement: 0 to -20°C

Inventory flow: FIFO(78% Pallet Selectivity required)

Space Restriction: Yes

Conventional Solutions (by existing warehousing solution providers)

Criteria: 1. Cost; 2. Inventory Flow; 3. Dimension; 4. Temperature requirement
Design Approach

Minimize Cost (C_i), where i = Type of warehouse : Temperature controlled i = 1, else 0

Subject to

Dimension (m^3) = α , say α = 1200x1000x 1500

Pallet Load (kg) = β, say β = 1000 Kg

Temperature requirement (°C) = γ; say, γ = 0 to -20°C
Inventory flow: FIFO
Space Restriction: Φ , say Φ = (l'=10m x b'=10m x w'=10m; 1000 m^3)

DATA SOURCES:

	BLOCK II (Considering one Block)
WH Length	**29590 mm**
WH Width	**25100 mm**
WH Height	**11500 mm**
Proposed Storage Area Length (l)	**23350 mm**
Proposed Storage Area Width (b)	**23470 mm**
Proposed Storage Area Height (h)	**10350 mm**
Single Working Aisle LIFO	**2860mm**
Considered Maintenance Aisle	**1500 mm**

Solution
If MHE = Reach Truck
Aisle width = 3100 mm
Cost = INR 2500000
Else If MHE = Aisle Master
Aisle width = 2200 mm
Cost = INR 3200000
Else If MHE = VNA Truck
Aisle width = 1650 mm
Cost = INR 3500000

1. MHE Stacker will not be considered, as last loading level is 7800 mm.
As if, Last loading level H1
Stacker lift Height H2 .... H2 > H1
If rack type = Selective Pallet Racking Density per m^3 for pallet dimension = 1.8
Cost = INR 2500
Else If rack type = Drive-In Shuttle ,Density per m^3 for pallet dimension = 1.8
Cost = INR 3600

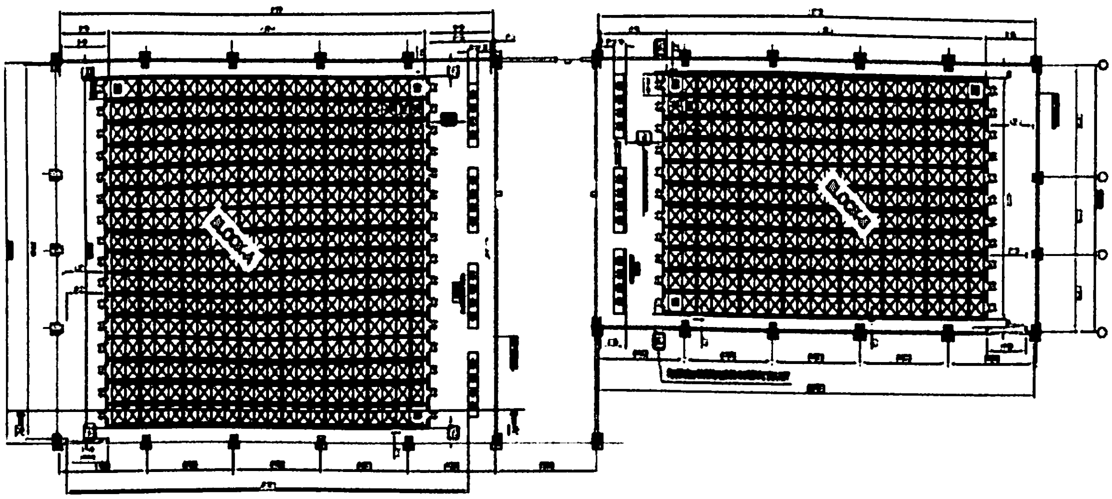


Fig 02: Proposed Shuttle Racking for BML Cold storage Proposal: FIFO Pallet Flow

Thus Considering Drive In Shuttle Rack: Observation

Number of rows R= l' ÷ (l+ [2 x l"]), i.e., for every row of width b, there are 2 aisles on both sides of the row of width b"

Number of Columns C= b'÷ b

Thus, Number of rows R

R= l' ÷ (l+ [2 x l"])

= 29590 ÷ (1000+ [2 x 175]) [l = 1000 mm + 175{single side clearance 175 mm}]

= 22

Number of Columns C= b'÷ b

= 25100 ÷ 2200(b = 1200 mm + 1000mm clearance)

= 11

Number of pallets per column N_C = h'÷ h

= 10350 ÷ 1850(h= 1500 mm + 350 mm clearance for shuttle run)

= 5

Number of pallets per row P_R= C x N_C = 11 x 5 = 55

Storage Capacity Φ' = [R x P_R] = [22 x 55] =1210 x(1.45l x1.05bx1.85h)

Non-revenue earning space = Φ - Φ' = 7975 – 3408 = 4567 m^3

Thus Considering Selective Rack: Observation

Number of rows R= l' ÷ (l+ [2 x l"]), i.e., for every row of width b, there are 2 aisles on both sides of the row of width b"

Number of Columns C= b'÷ b

Thus, Number of rows R

R= l' ÷ (l+ [2 x l"]

= 29590 ÷ (2250+ [2 x 2200]) [l = 1000 mm x 2(Back to Back) + 250{single side clearance 125 mm} Working aisle required 2200 mm]

= 06

Number of Columns C= b'÷ b

= 22100 ÷ 1200(b = 1000 mm + 50mm clearance)

= 18

Number of pallets per column N_C = h'÷ h

= 9500 ÷ 1750(h= 1500 mm + 250 mm clearance for shuttle run)

= 5

Number of pallets per row P_R= C x N_C = 18 x 5 = 90

Storage Capacity Φ' = [R x P_R] = [06 x 90] = 540 x(1.45l x1.05bx1.85h)

Non-revenue earning space = Φ - Φ' = 7975 – 1520 = 6455 m^3

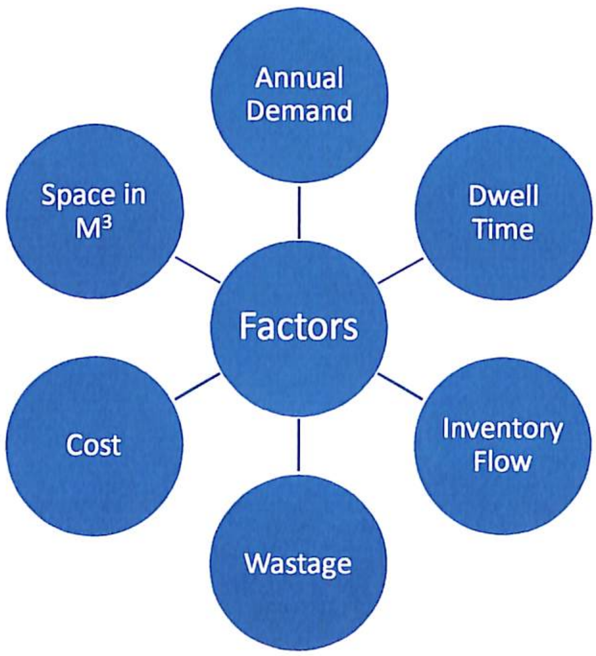
PIC: FIFO Shuttle Rack

INTERPRETATION OF RESULTS:

1.5 Lean – Green Warehouse: A proposed framework

5.1.1 THE PROPOSITIONS

The problems stated by the managers of the warehouses show that the current warehouse solution was based on cost minimisation without consideration of annual throughput and dynamic energy consumption. The annual throughput is a function of space available and dwell time of a unit SKU. Thus, based on the literature survey and outcomes of the case studies the significant factors for considerations include:



The Annual Throughput (A_T) $= \frac{([(\mathbf{l' \, x \, b' \, x \, h'})]\mathbf{x} \, \grave{\lambda} \mathbf{x365})}{\boldsymbol{DT}}$

[l'x b'x h'] represents the required storage space in m^3 per unit. This space is dependent on number of units arriving per day

and

DT or dwell time represents the stay time of each pallet (a SKU unit)

A_T can be increased with decrease of DT (the dwell time). Thus, the companies have to decide on the average dwell time of an unit cargo in the warehouse.

However, the firm has to consider the future rate of flow of cargo into the warehouse. If À is the expected number of pallets received per day (the arrival rate),

If [l'x b'x h'] x À = Φ', then

$A_T = = \frac{([(\Phi')]x\,365)}{DT}$; assuming that the warehouse is operational all 365 days. .... (1)

In equation 1, DT reduces the annual throughput, hence if arrival rate À increases in future, then the additional requirement can be met either by reducing DT and or expanding warehouse provided such expansion is feasible.

Thus, the **proposition 1** of the framework :

> ***If there is space restriction***
> ***Then DT is the guiding factor for enhancing annual throughput***
> ***Else expansion is also feasible***

If there is space restriction, the aisle width can be reduced with the type of MHE (material handling equipment), but has cost consideration. The cost comparison is shown in table 1 below:

Equipment	Width (MM)	Height(MM)	Cost(INR)
Stacker	2800	6500	1200000
Reach Truck	3100	12000	2500000
Aisle Master	2200	12400	3200000
VNA	1650	9400	3500000

The height (h')of the warehouse is limited by MHE.

Thus A_T can be increased with use of MHE at given cost.

Thus, the **proposition 2** of the framework :

> ***The annual throughput*** **A_T is decided by the firm**

Even if there is no space restriction, The space wastage can be reduced with use of MHE but at a given cost. Certain MHE requires less space for movement but are costlier than other ones as depicted in table 1

Thus, the **proposition 3** of the framework :

The type of MHE impacts the storage capacity of a warehouse i.e., the A_T

Different types of MHE consume varied energy.

Thus, the **proposition 4** of the framework :

The type of MHE impacts the consumption of energy and the cost of warehousing

The dimensions of pallets impact the type (and size) of racks.

Thus, the **proposition 5** of the framework :

The type of racks impacts the cost of warehousing

The inventory flow i.e., whether FIFO, LIFO or SIRO, will impact the rows in a warehouse. Table 2 shows the row alignment for different inventory flows:

FLOW	Row alignment	Storage density
FIFO	Aisle on both sides of row	High
LIFO	Aisle on single side	High
SIRO	Intermediate Pick aisle	Low

Thus, the **proposition 6** of the framework :

The inventory flow impacts the storage capacity and cost of warehousing.

This in turn affects the A_T

The density of storage minimizes the wastage of space, higher the storage higher the maintenance cost

Thus, the **proposition 7** of the framework :

The density of storage impacts the storage capacity and cost of warehousing.

This in turn affects the A_T

The cooling requirement increases with volume of warehouse. The volume of warehouse includes storage space, aisle space, and other space, i.e., the total space. That is, higher the non-storage space, higher the energy consumed per unit load.

Thus, the **proposition 8** of the framework :

The density of storage impacts the energy utilisation. Lesser energy utilisation helps achieve green objectives.

That is, makes warehouse solutions sustainable

Chapter 6 :

CONCLUSION & SCOPE OF FUTURE WORK

The Optimization Model

Minimize $Z = (\Phi - \Phi') \times C_O$ .... (2)

Equation 2 shows that the objective function is to minimize the utilization of space such that the opportunity cost (C_O) is minimized.

Φ represents the total available space in m^3, That is:

$\Phi = [l \times b \times h]$, where $[l \times b]$ is area of land available in m^2; and

h is the height available subject to the type of MHE installed

Φ' represents the total required space in m^3, given the required arrival rate À units per day. Each unit having a dimension = l'x b'x h'. That is:

$\Phi' = [l' \times b' \times h'] \times À$

The above minimization of objective function Z is subject to

$\Phi > \Phi'$ .... (3)

$(P_R \times C_R) + (EQ_N \times C_E) + (E_U \times C_U) < C_T$ ....(4)

Where C_R = Cost of Racks

C_E = Cost of MHE

C_U = Cost of Energy Consumed

P_R = No. of Row of Pallet Racking

EQ_N =No. of Equipment

E_U = Per Unit/Pallet Energy Consumed

Revised WMS should include Green WMS Sub- Module & Lean Warehouse Sub-Module:

1. Green WMS Sub- Module:
   1.1 This Module should capture real time data to provide information on green-based warehouse management system.
   1.2 The KPI's includes :
      i) Energy Consumption (En)/Unit Load
      ii) A = 'A' – Suggest Energy Consumption / Annual Throughput, Should be less than or Equal to compared to the design throughput is based on the stay time (Dwell Time) of the unit Load in the warehouse.
      iii) In event of increased stay time/ unit = the energy Consumption will go up.
      iv) In addition, even if the dwell time is as per the design level fewer number of unit load will lead to increase the Energy Consumption.

Designed GI (Green Indicator) = EC/ATD = R

$$ATA < ATD$$

$$EC/ATA = R1, \text{ Where } R1 > R$$

As Example, EC = 1000 Kw/ 1000 Unit Load ,

R = 1 Kw per unit Load.

Where R1 > R , of actual is 800 Since DT increased,

$$R1 = 1000 \text{ Kw} / 800$$

$$R1 = 1.25$$

$$R1 > R$$

Similarly, ATA can be less if Demand is less, Where again R1 > R.

Designed LI (Lean Indicator) = $\frac{ATA}{ATD}$

LI lies between 0 to 1

If LI ≤ 0.8 , The Warehouse needs to check why demand is falling.

Decision making framework will be developed to help managers to take customized decisions on Warehousing Solutions.

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