P02

Backbone of Warehouse

E215 – Warehouse and Storage

SCHOOL OF ENGINEERING

Main Task of Warehouse

- **Storage:**
  - Goal: Improved storage density, while considering on-hand inventory and turnover of the items in pallet storage
- **Retrieval:**
  - Goal: High handling productivity, while considering capital investment

Storage Type

By Size of Storage items:

- Pallet
- Carton
- Loose/Piece/Small item

By Movement of Goods or Picker:

- Picker to Stock
- Stock to Picker

Pallet Storage Alternatives

Picker to Stock:

- Block stacking
- Pallet stacking frames
- Single-deep pallet rack
- Double-deep pallet rack
- Drive-in rack
- Drive-thru rack
- Pallet flow rack
- Push-back rack
- Mobile pallet rack
- Cantilever rack

Stock to Picker:

- Unit load AS/RS

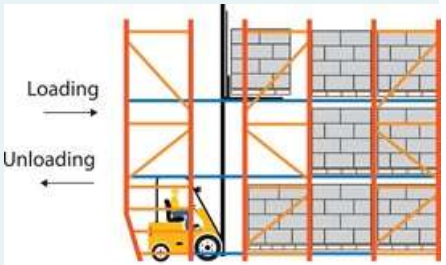
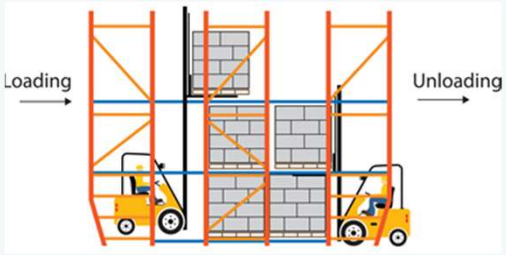
Pallet Storage – Picker to Stocks

Storage System	Features
Block Stacking 	• Last In First Out (LIFO) • Large quantities of single SKU products • Lane depth must be carefully determined • Low investment, easy to implement • Very flexible for floor space configuration • Stacking height is determined by acceptable safe limit, load stackability, pallet condition, floor loading restriction and so on • Disadvantage: “Honeycombing” – empty pallet spaces are created that can’t be utilized effectively • Items at the bottom can be crushed by the weight from above
Pallet Stacking Frame 	• Self contained steel units, frame attached to standard wooden pallet • Stacking of materials several load high • Lane depth must be carefully determined • Portable, easy for transportation • When not in used, can be disassembled, safe space • Can be leased – short term spike in inventory • Great protection during transportation • Disadvantage: “Honeycombing”

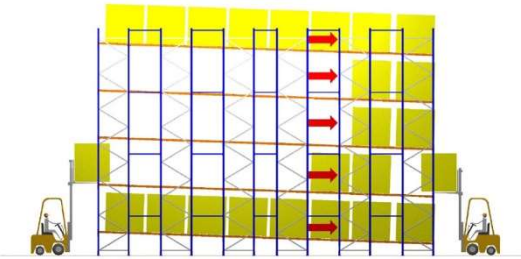
Pallet Storage – Picker to Stocks

Storage System	Features
Single-deep Pallet Rack 	• Immediate access to each load stored • Multiple SKUs stocked in the same vertical column • Stacking height not limited by stackability and/or crushability of loads • Loads can be of varying heights and widths. • Consider if 3-5 pallet loads of inventory for a SKU • Disadvantage: Too much space (50-60%) devoted to aisles
Double-deep Pallet Rack 	• Two pallet positions deep racks • Fewer aisles needed: 50% aisle space savings compared to single-deep • Consider if >5 pallets of inventory and when product is received and picked frequently in multiples of two pallets • Disadvantages: “Honeycombing” and double-reach forklift is required

Pallet Storage – Picker to Stocks

Storage System	Features
Drive-in Rack 	• LIFO • Usually for load that are fragile to stack • High density storage as there is no aisles • Enable a lift-truck to drive into the rack several pallet positions • Consider for small-medium velocity SKUs with >20 pallets in inventory • Disadvantages: “Honeycombing” and reduction of lift-truck travel speed to ensure safe navigation within the rack construction 
Drive-through Rack 	• It is accessible from both sides of the rack • Pallets are loaded at one end and retrieved at the other end • Same considerations for drive-in rack apply to drive-through rack

Pallet Storage – Picker to Stocks

Storage System	Features
Pallet Flow Rack 	• FIFO • Load is removed from the front of a storage lane, the next load advances to the pick face by gravity • High-throughput pallet storage and retrieval and good space utilization • Used for items with high pallet inventory turnover and with several pallets on hand • Need to consider different angle of incline based on weight of load
Push-back Rack 	• LIFO deep lane storage, 2~5 pallets deep • When load is placed into storage, the existing loads in the lane are pushed back into the lane • When load is removed from the front of a storage lane, the remaining load automatically advances in front by gravity • No need to use special type of lift truck • Lesser honeycombing as different SKU can be loaded vertically • Front loading only

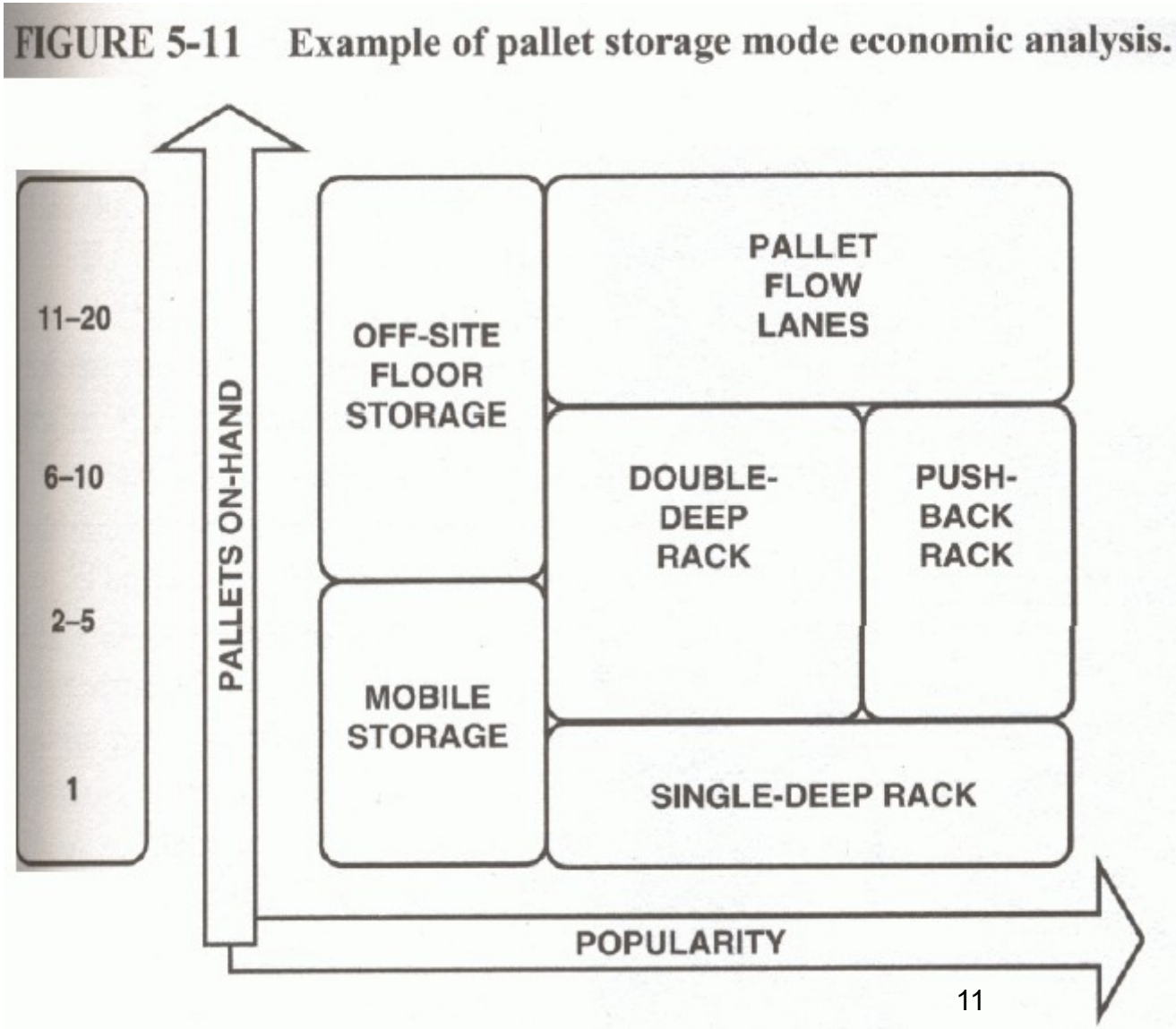
Pallet Storage – Picker to Stocks

Storage System	Features
Mobile Pallet Rack 	• Single-deep pallet racks on wheels or tracks permitting an entire row of racks to move away from adjacent rack rows • <10% of space is devoted to aisles • Highest storage density of any pallet storage alternatives • Justifiable when space is scarce and expensive and for slow-moving SKUs with 1-3 pallets on hand • Disadvantage: Lowest productivity

Other Storage Type – Big Items

Storage System	Features
Cantilever Rack 	• No aisle frames to obstruct the storage of long or bulky items such as lumber, furniture, or tubing • Arm elevations are easily adjustable to accommodate any bundle size • Non palletized items, such as pipe, timber, carpet • Picker to stock
AS/RS 	• Automated Storage and Retrieval System • Unit Load AS/RS - Handle large load - Load are placed on pallets or pallet-sized containers • Good for high stock movement • Available for both palletized and non-palletized items • Highest installation cost • Similar types includes Vertical Lift, Vertical Carousels, Shuffle Technology • Stock to picker

Economic analysis of pallet storage systems



Pallet Storage Systems – Summary

Table 5.1 Pallet storage system comparison.

Pallet Rack Type	Load Always on Aisle	Percent Loads on Aisle	Rotation	Damage	Ease of Handling Variable-Sized Loads	Ease of Installation	Ease of Reconfiguration	Special Vehicle Required	Same Face for Store and Retrieve
Floor storage	No	10–40	LIFO	Medium	High	Easy	Very high	No	Yes
Single-deep rack	Yes	100	Random	Low	Medium	Easy	High	No	Yes
Single-deep narrow aisle	Yes	100	Random	Low	Medium	Easy	High	Yes	Yes
Double-deep rack	No	50	LIFO	Medium	Medium	Easy	Medium	Yes	Yes
Drive-in rack	No	10–30	LIFO	High	Low	Moderate	Low	No	Yes
Push-back rack	Yes	20–50	LIFO	Medium	Medium	Moderate	Low	No	Yes
Pallet-flow rack	Yes	10–30	LIFO	Medium	Low	Difficult	Very low	No	No
Mobile pallet rack	No	10–20	Random	Low	Medium	Difficult	Very low	No	Yes

Small Item Storage Alternatives

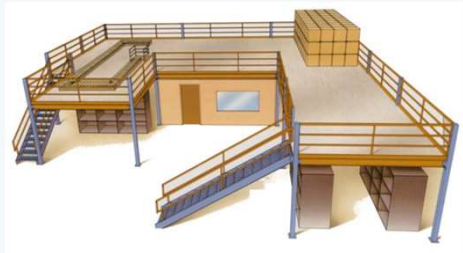
Picker to Stock:

- Mezzanines
- Static Shelving
- Carton Flow Rack

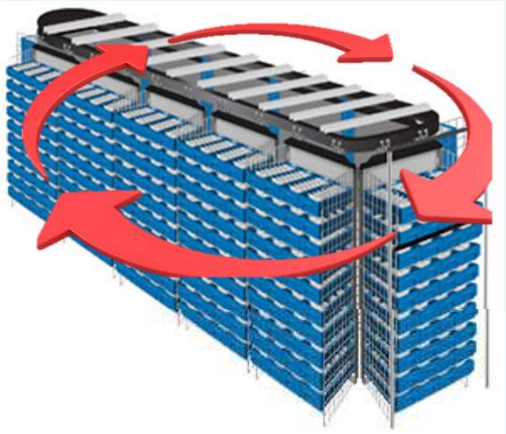
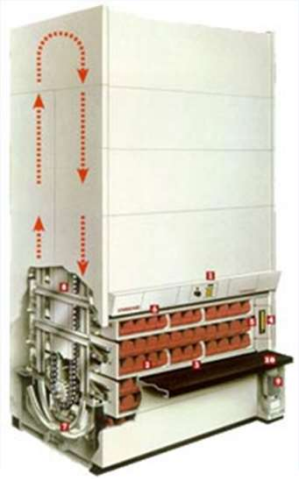
Stock to Picker:

- Horizontal Carousels
- Vertical Carousels
- Vertical Lifts
- Mini load ASRS

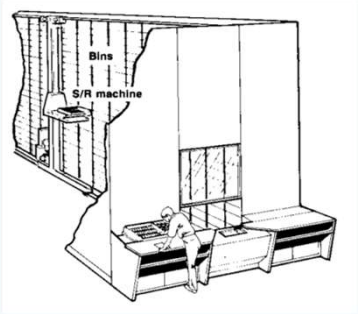
Small Item Storage – Picker to Stock

Storage System	Features
Static Shelving 	• Commonly used for slower, lower-volume picking • Non-palletized items • Typically shallow (300 – 400mm deep) • Some are customizable e.g. number of shelves, height of shelves etc. 
Mezzanines  	• Nearly twice as much material can be stored in the original square footage • Cost: $10-$20 / ft2 (approximate) • Key implementation issue: Slot the products so that most of the picking activity takes place at the floor level • Properly constructed to take the appropriate storage • Ensure there is space for lift, conveyor, forklift

Small Item Storage – Stock to Picker

Storage System	Features
Horizontal Carousels 	• Length from 15 ft to 100 ft, and height from 6 ft to 25 ft • Items with a high cube movement should not be stored in carousels because too many replenishments would have to be made • Disadvantage: Expensive: $40,000-$70,000 per carousel unit
Vertical Carousels 	• Vary in height from 8 feet to 35 feet • Advantage: Excellent item protection and security; Only one shelf of items is exposed at one time • Disadvantage: Expensive: $100,000 

Small Item Storage – Stock to Picker

Storage System	Features
Vertical Lift  	• extractor (elevator) travelling vertically between front and rear storage section • Storage capacity: up to 90,000 pounds • Height from 12 feet to 40 feet • High storage density to optimize space and increase productivity • Vertical Lifts are modularized • Can be integrated to the current storage system • Implemented gradually in stages • Mostly to optimize the height of a warehouse • Use where lands are scarce and expensive
Mini Load AS/RS 	• Pick Rate: 40-200 picks/person hr • Length from 40 to 200 feet and height from 8 feet to 50 feet • Cost: $150,000-$300,000 /aisle (approximately) • S/R machine: 500 feet/minute horizontal speed and 120 feet/minute vertically • Shuttle Technology

Examples of Racking & Storage System at Supply Chain Innovation Lab

Single-deep Pallet Rack

Vertical Leanlift

Static Shelving

Pallet Storage Systems – Summary

Table 7.1 Summary Characteristics of Alternative Broken-Case Picking Systems

						Picking Rates (lines/person hour)				
Method	Feet Cubic Feet of Inventory of Inventory Housed per Square Foot of Floor Space	Maintenance Requirements	Item Security and Protection	Reconfiguration Flexibility	Ergonomics	General	Cart	Tote	ASRS	Wave
Bin shelving	1.0–1.2	Low	Low	High	Low	15–500	20–100	80–250	15–80	200–500
Carton flow rack	0.7–0.9	Low	Low	High	Low	20–600	2–125	100–300	20–100	300–600
Storage drawers	1.8–2.5	Low	High	High	Medium	10–150	15–80	60–150	10–50	N/A
Horizontal carousels	0.8–1.3	Medium	Low to medium	Medium	Medium	50–250	N/A	N/A	N/A	N/A
Vertical carousels	5.0–7.0	Medium	Very high	Low	High	35–200	N/A	N/A	N/A	N/A
Miniload ASRS	4.0–5.0	Very high	Very high	Low	High	30–150	N/A	N/A	N/A	N/A
Automated dispensing	—	Very high	Medium	Low	Medium	500–2000	N/A	N/A	N/A	N/A

Material Handling and the Equipment

What is Material Handling?

The art and science involving the moving, packaging, and storing of substances in any form.

American Society of Mechanical Engineers (ASME)

What is Material Handling Equipment (MHE)?

Material handling equipment is all equipment that relates to the movement, storage, control and protection of materials, goods and products throughout the process of manufacturing, distribution, consumption and disposal

(Material Handling Institute)

Types of MHE

- Pallet jacks
- Walkie stackers
- Counterbalanced lift trucks
- Straddle trucks
- Straddle reach trucks
- Sideloader trucks
- Turret trucks
- Automated storage and retrieval system (AS/RS) machines

Selecting the Right MHE

- When selecting MHE, the following factors should be considered:
  - Budget
    - It must be within the budget approved for the purchase
  - Aisle Width
    - This is the width required by the MHE. Some MHE require bigger aisle compared to others. Bigger aisle width means less storage space in the warehouse.
  - Lift Height
    - Depends on how high the racks are in the warehouse. MHE must be able to reach the highest rack.

Selecting the Right MHE (cont.)

- Lift Weight
  - This depends on the goods that are stored in the warehouse. MHE must have the lifting capacity to handle the goods. E.g. you cannot get a MHE with lifting capacity of 200kg to operate in a warehouse which handles goods of 500kg.
- Lift Speed
  - This depends on how high the racks are in the warehouse. In a warehouse with very high racks, lifting speed becomes important, as the faster the lifting speed the less time it is required to retrieve the goods.
- Travelling Speed
  - This is important if the warehouse is big. A slow travelling MHE will take a long time to cover a big warehouse.

Types of MHE

Type of MHE	Features
Pallet Jacks 	• The simplest MHE • Used to move pallets • Main advantage is low cost (least among all the MHEs) • Disadvantages: - Unable to lift pallet to a rack - Manual - Slow speed
Walkie Stackers 	• Operator steers from a walking position behind the vehicle • Can stack up to 3 loads high • Offers both pallet retrieval/putaway • Can work outside warehouse, example: truck loading/unloading • Low cost • Used when low throughput, short travel distances, low vertical storage height and low cost requirements • Disadvantage: Short distances

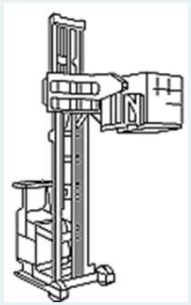
Types of MHE

Type of MHE	Features
Counterbalanced Lift Trucks  	• Commonly known as Fork Lift • Counterbalance in the back of the truck to stabilize loads carried and lifted • Gas or battery powered • Offers both pallet retrieval/putaway • Can work outside warehouse, example: truck loading/unloading • < 25 feet height reach • Cannot reach/store double-deep • Longer range than Walkie stackers • Benchmark vehicle for all other pallet retrieval vehicles • Disadvantage: - Wide turning radius required to turn the vehicle in an aisle, (requires aisle width of 11-12 ft) - However, this is not a problem in block stacking, drive-in and drive-thru rack and pallet stacking frames

Types of MHE

Type of MHE	Features
Straddle Trucks  	• Requires less aisle width (8-10 feet) than counterbalanced truck • Disadvantage: Outriggers have to be driven into the rack • Disadvantage: Lower loads compared to counterbalance trucks 
Straddle Reach Trucks 	• Requires less aisle width (8-10 feet) than counterbalanced truck • Reach capability with a scissor reach mechanism • Outriggers don't have to be driven into the rack • Reach truck: Allows the forks to be extended to two-deep with a special extended fork 

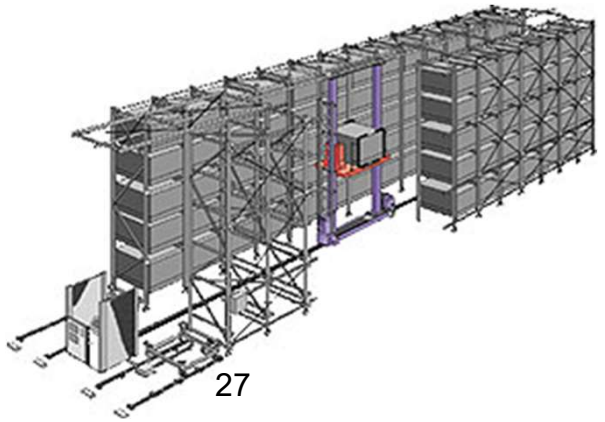
Types of MHE

Type of MHE	Features
Sideloader Forklift Trucks  	• Loads and unloads from one side • No need to turn in the aisles • Very narrow aisle (VNA), around 6.5 ft • Need guidance system to travel within VNA • Access loads up to 40ft high • Disadvantage: - Need to enter the correct end of the aisle - More complexity in truck routing (Turret trucks solve this problem)
Turret Trucks 	• Forks rotate to allow for side loading and, since truck itself does not rotate during stacking, the body of the truck can be longer to increase its counterbalance capability and to allow the operator to sit • Can function like a sideloader for picking pallet-size load • Can lift the operator to rack above ground level for picking item

Types of MHE

AS/RS Machines

- AS/RS for pallets: Unit load AS/RS
- A storage system that uses fixed-path storage and retrieval (S/R) machines running on one or more rails between fixed arrays of storage racks
- Travel vertically and horizontally simultaneously
- AS/RS machines are costly
- Systems are often quite tall and sometimes support the building shell that contains them.



Types of MHE

AS/RS Machines

- Single command vs dual command
  - Single command cycle:
    - The S/R machine will only retrieve or store the bin in that cycle. After the retrieving or storing, it will go back to the home (I/O) location to wait for the next command.
  - Dual command cycle.
    - The S/R machine picks up the load and travel to the storage location to put down the load. Thereafter, the machine travels to the retrieval location to recover the load. Finally, it travels back to the I/O location to deposit the load. This process is commonly described as *dual command order picking.*

Types of MHE

AS/RS – An Illustration

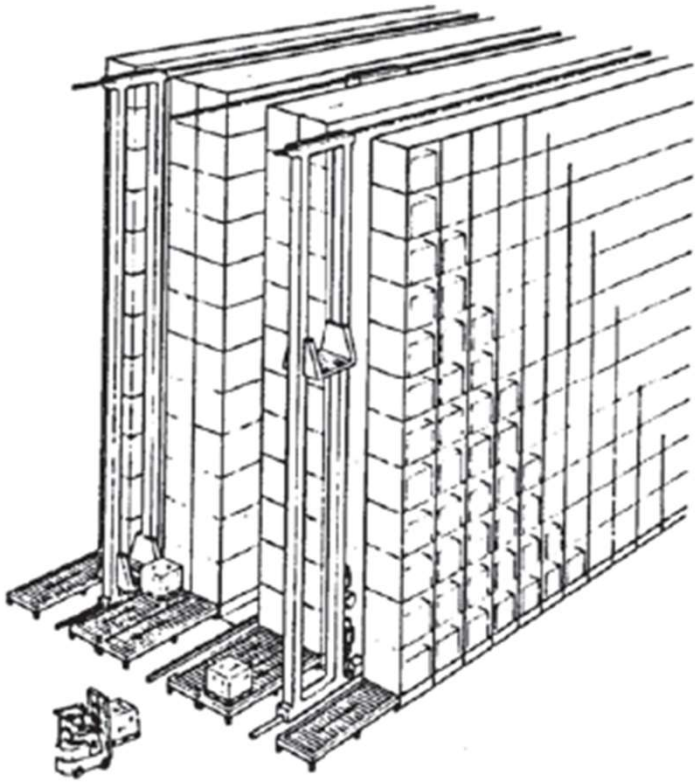


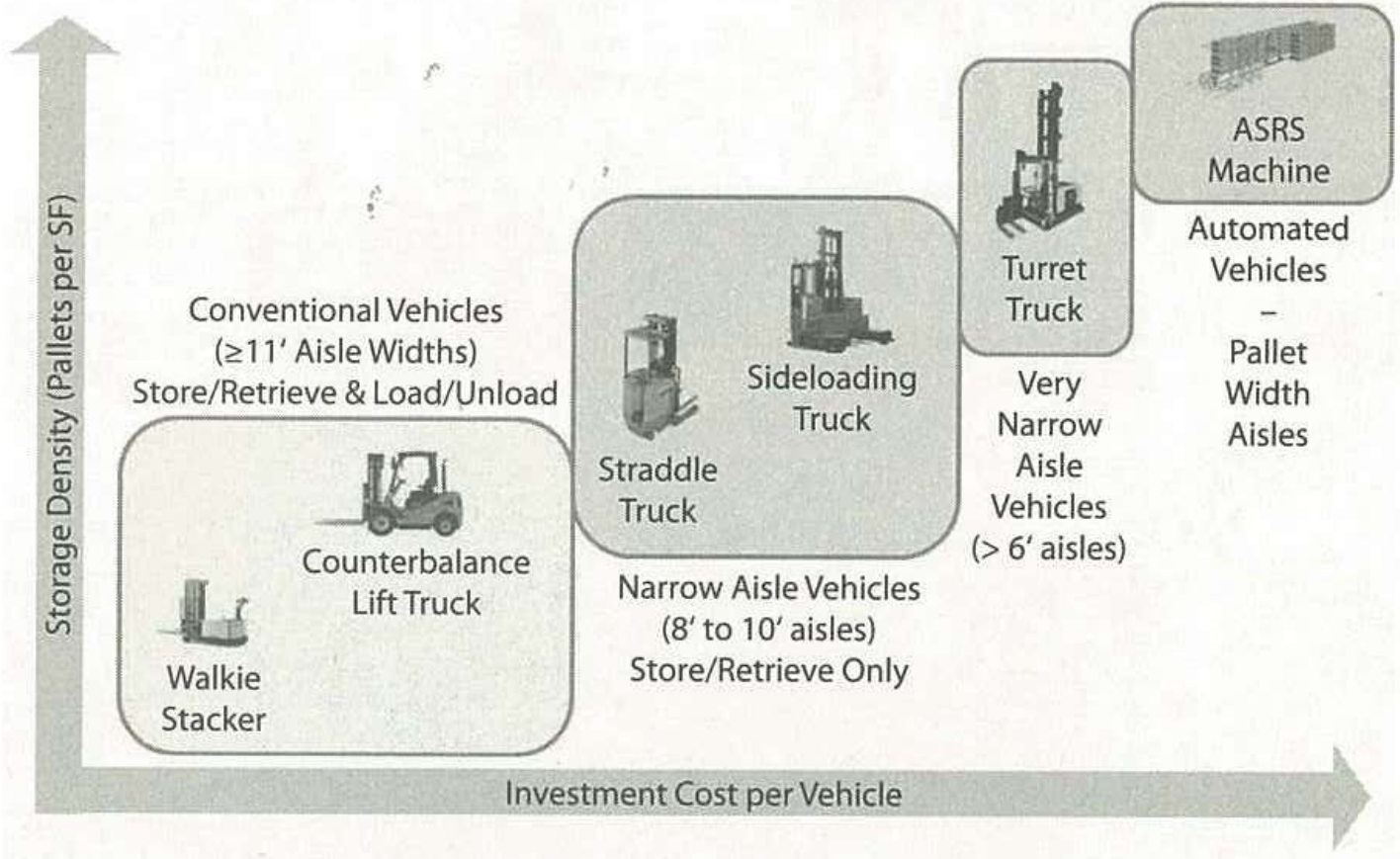
Figure 12.11: An automated storage and retrieval system (adapted from "Warehouse Modernization and Layout Planning Guide", Department of the Navy, Naval Supply Systems Command, NAVSUP Publication 529, March 1985, p 8–17.)

AS/RS Machines - Assumption

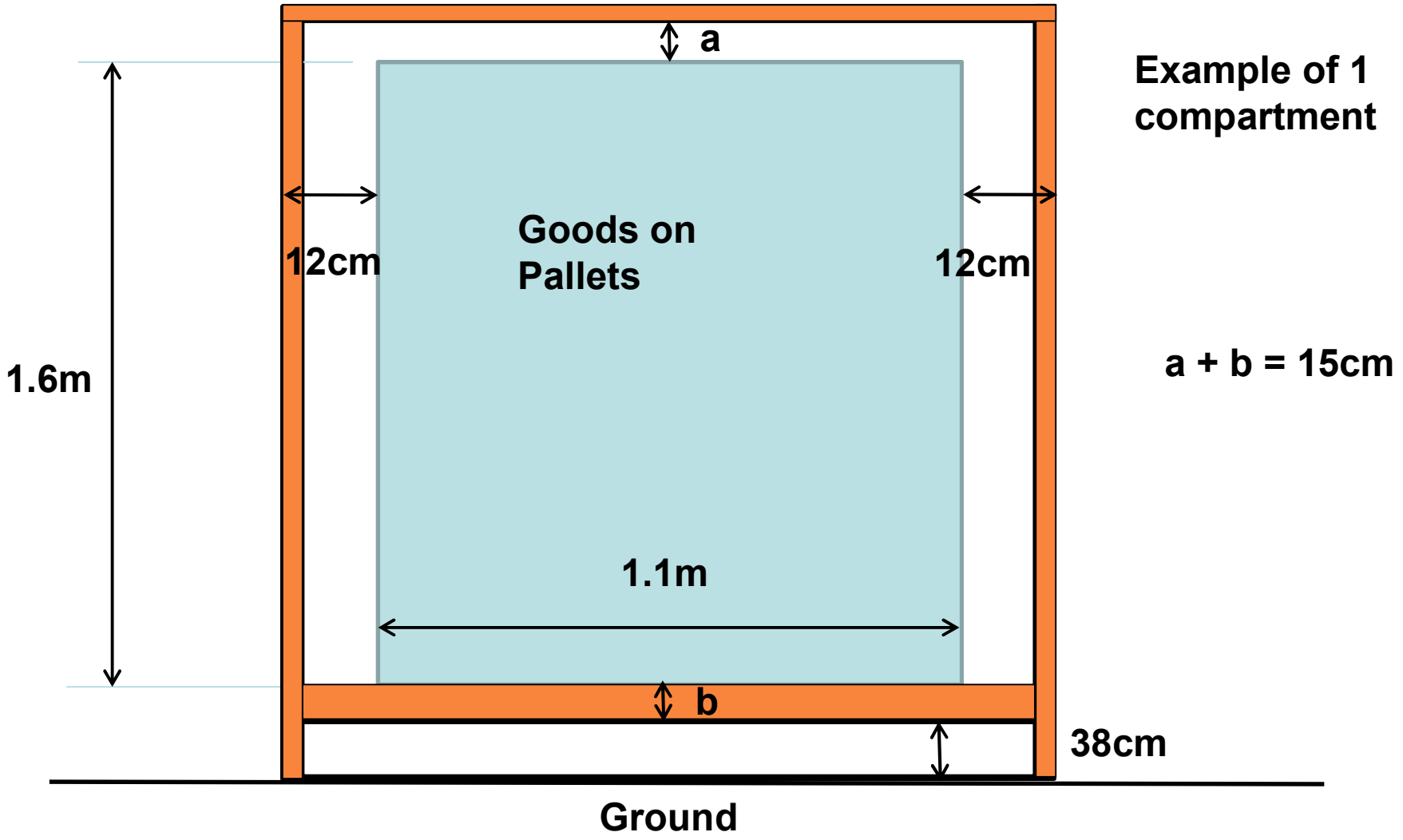
- Based on the model by Bozer and White (1984), the travel time of the AS/RS system is based on the following assumptions:
  - The rack is considered to be a continuous rectangular pick face where the I/O point is located at the lower left-hand corner
  - The S/R machine operated either on a single or dual command basis, ie, multiple stops in the aisle are not allowed.
  - The rack length and height, as well as the S/R machine speed in the horizontal and vertical directions are known.
  - The S/R machine travels simultaneously in the horizontal and vertical direction. In calculating the travel time, constant velocities are used for horizontal and vertical travel.
  - Randomized storage is used. That is, any point within the pick face is equally likely to be selected for storage or retrieval.
  - Pick-up and deposit (P/D) times associated with load handling are ignored. The P/D time is generally independent of the rack shape and the travel velocity of the S/R machine. Furthermore, given the load characteristics, the P/D time is usually deterministic.

Pallet Handling Systems – Summary

Figure 5.27 Pallet handling systems comparison.



Worksheet Question 20



Worksheet Question 20

- Total rows = 16 x 2 = 32 rows of racks
- Usable height 16.5m
- No. of compartments that can be fitted into a height of 16.5m is:
  - (16.5-0.38) / (1.6 + 0.15) = 9.21
  - Therefore the maximum number of compartments is **9** for a vertical height of 16.5m.
- No. of compartments that can be fitted into a width of 55m is:
  - 55 / (1.1 + 0.24) = 41.04
  - Therefore the maximum number of compartments is 41 for a horizontal length of 55m.
- Total number of pallets = 9 x 41 x 32

  = **11,808**

Worksheet Question 20

For the calculation of the throughput:

- Length of the rack (L) is taken to be 55m.
- Height of the rack (H) is taken to be 16.5m.
- Let SC be the travel time under a single command cycle.
- Let DC be the travel time under a dual command cycle.
- Given vertical velocity (S_v) is 37m/min(SC) & 30m/min(DC).
- Given horizontal velocity (S_h) is 95m/min(SC) & 75m/min(DC).
- Let T_v be the time taken for the S/R machine to travel to the furthest end vertically. ($T_v = H/S_v$)
- Let T_h be the time taken for the S/R machine to travel to the furthest end horizontally. ($T_h = L/S_h$)

Worksheet Question 20

- Calculation of the SC throughput:
  - SC = $[(1/3) \times b^2 + 1] \times Q$

Where

- b = Min $\{T_h/Q, T_v/Q\}$
- Q = Max $\{T_h, T_v\}$

- $T_h = L/S_h$ = (55)/95 = 0.5789min; T_h/Q = 0.5789/0.5789 = 1min
- $T_v = H/S_v$ = (16.5)/37 = 0.4459min; T_v/Q = 0.4459/0.5789 =0.7703min
- Q = 0.5789min
- b = 0.7703

SC = $[(1/3) \times b^2 + 1] \times Q = [(1/3) \times 0.7703^2 + 1] \times 0.5789 = 0.6934$ min

Throughput for this system = (60/SC) x number of S/R unit
= (60/0.6934) x 16
= 1384 cycles/hr

Worksheet Question 20

- Calculation of the DC throughput:
  - DC = $(4/3 + b^2/2 – b^3/30) \times Q$

Where

- b = Min $\{T_h/Q, T_v/Q\}$
- Q = Max $\{T_h, T_v\}$

- $T_h = L/S_h$ = 55/75 = 0.7333min
  T_h/Q = 0.7333/0.7333 = 1
- $T_v = H/S_v$ = 16.5/30 = 0.55min
  T_v/Q = 0.55/0.7333 = 0.75
- Q = 0.7333min
- b= 0.75

DC = $(4/3 + b^2/2 – b^3/30) \times Q$ = $(4/3 + 0.75^2/2 – 0.75^3/30) \times 0.7333$
= 1.1737 min

Throughput for this system = (60/DC) x number of S/R unit
= (60/1.1737) x 16
= 818 cycles/hr

Worksheet Question 20

- Comparing Single Command and Dual Command

Single Command	Dual Command
1384 cycles/hr	818 cycles/hr
One operation per command, either retrieving or storing	2 operations per command, retrieving and storing
1384 operations/hr	1636 operations/hr, 18% more efficiency
Not need to balance retrieving and storing operation at any shift	May slow down either retrieve or storing operation as there is an imbalance

Worksheet Question 21

Palletized items:

	Requirement	Type of Storage / Racking System	Type of MHE
1	• Products required to be on FIFO basis • There's a constraint in the warehouse space (optimize the usage of warehouse would be desirable) • High movement rate • Many pallets on hand • Minimum level of security control on the products	Option 1: Pallet flow rack (if no of pallets on-hand > 11) Option 2: Narrow aisle single-deep rack	• Counterbalanced Lift Trucks • Straddle Trucks • Side-loader Forklift Trucks
2	• No FIFO requirement • Single SKU with bulk storage • Low investment needed • Minimum level of security control on the products	Off-site floor storage (block stacking)	• Counterbalanced Lift Trucks • Straddle Trucks

Worksheet Question 21

Palletized items:

	Requirement	Type of Storage / Racking System	Type of MHE
3	• No FIFO requirement • Optimize the usage of warehouse storage space would be desirable • Relatively high in the stock movement rate • Typically several pallets on hand	Option 1: Push-back rack Option 2: Single-deep rack	• Counterbalanced Lift Trucks • Straddle Trucks • Side-loader Forklift Trucks
4	• Requires high density of storage • Very low movement in the item (more for archiving purpose) • Justifiable in the investment of storage system in view of space scarcity	Mobile storage	• Counterbalanced Lift Trucks • Walkie stacker

Worksheet Question 21

Non-palletized items:

	Requirement	Type of Storage / Racking System	Type of MHE
5	• Non-palletized big and/or long items	• Cantilever rack	• Counterbalance Lift Truck with customized fork to handle long and bulky item
6	• Small items • Relatively low pick rate • Item requires high security • Cost of implementation is not an issue • Would like to optimize the usage of the height of the warehouse	Option 1: Vertical Carousels Option 2: Vertical Lift	• Picking cart

Today's Problem – Suggested Solution

Propose suitable racking/storage system for the warehouse. Factors to consider:

- Budget
- Types of products (size, shape, palletized, non-palletized…..)
- Storage density
- Movement of stocks (FIFO required?, required throughput?, etc)
- Level of security required

Today's Problem – Suggested Solution

Factors to consider in the selection of MHE for the warehouse:

- Budget
- Inbound and outbound operations at loading bay (example: forklift truck, pallet jack, walkie stacker,…)
- Storage racking system (putaway and picking)
  - Single deep/double deep racking?
  - Aisle width
  - Lift height / weight / speed
  - Travelling speed
- AS/RS system for fast moving small parts SKUs? (need to justify on the requirement and investment)

Today's Problem – Suggested Solution(s)

Requirements (Example)	Type of Storage / Racking System		Type of MHE
• Small items • High storage density • Low level of security • Average or slow throughout • Budget	1	• Static Shelving on Mezzanines	• Picking Cart
	2	• Carton flow rack	• Reach Trucks • Man-up forklift

Learning Outcome

- Identify and explore the different types of storage systems used in the warehouse for items of various sizes
- Analyze the pros and cons of the various storage systems
- Explain what is MHE and the various features of different MHEs
- Analyze and select suitable MHEs based on different considerations
- List the assumptions made in the travel time of the AS/RS system
- Compute the throughput of an AS/RS for both the single and dual command cycle.

E215 Warehousing and Storage Topic Flow