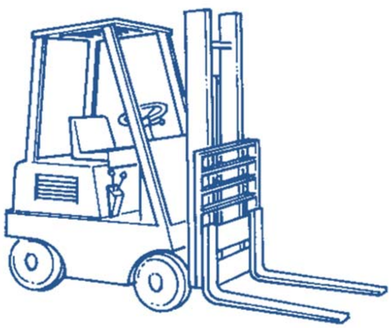
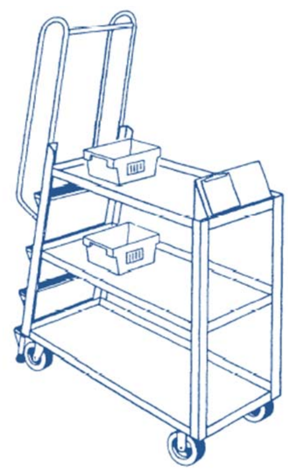
Storage and Retrieval Cycle

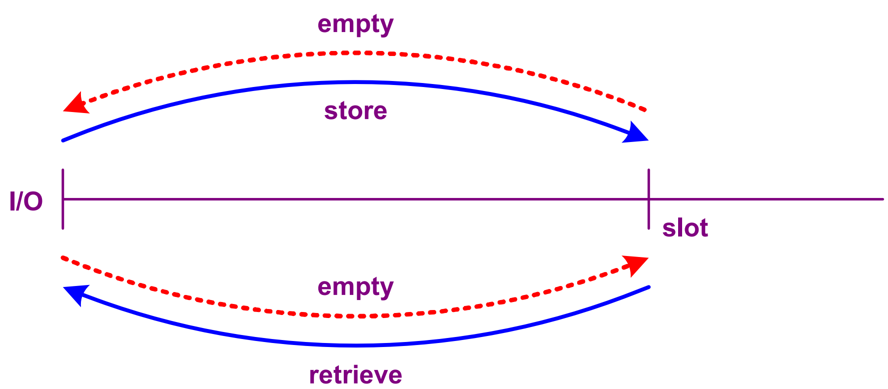
- A storage and retrieval (S/R) cycle is one complete roundtrip from an I/O port to slot(s) and back to the I/O
- Type of cycle depends on load carrying ability:
  - Carrying one load at-a-time (load carried on a pallet):
    - Single command
    - Dual command



  - Carrying multiple loads (order picking of small items):
    - Multiple command



Single-Command S/R Cycle



- Single-command (SC) cycles:
  - Storage: carry one load to slot for storage and return empty back to I/O port, or
  - Retrieval: travel empty to slot to retrieve load and return with it back to I/O port

Expected time for each SC S/R cycle:

$$t_{SC} = \frac{d_{SC}}{v} + t_L + t_U = \frac{d_{SC}}{v} + 2t_{L/U}$$

where

d_{SC} = expected distance per SC cycle

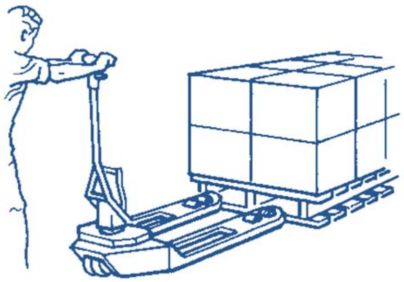
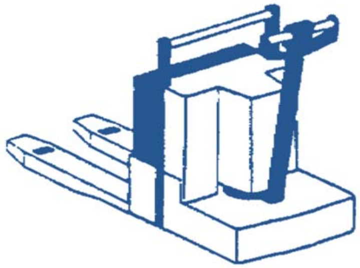
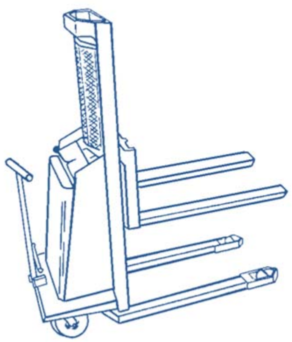
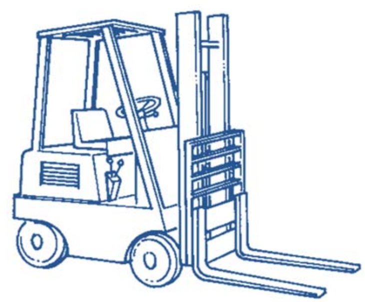
v = average travel speed (e.g.: 2 mph = 176 fpm walking; 7 mph = 616 fpm riding)

t_L = loading time

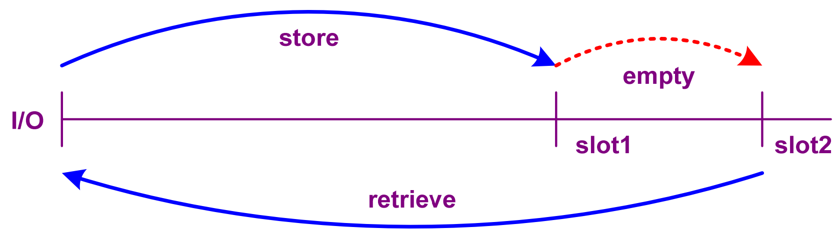
t_U = unloading time

$t_{L/U}$ = loading/unloading time, if same value

Industrial Trucks: Walk vs. Ride

Walk (2 mph = 176 fpm)	Ride (7 mph = 616 fpm)
	
Pallet Jack	Pallet Truck
	
Walkie Stacker	Sit-down Counterbalanced Lift Truck

Dual-Command S/R Cycle

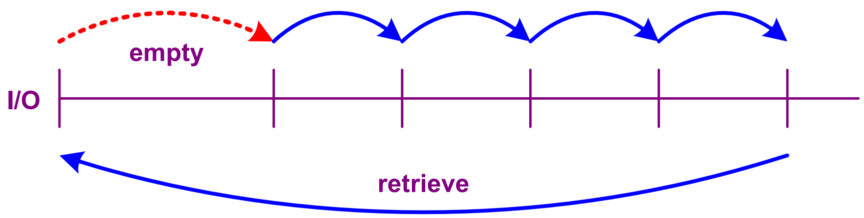


Expected time for each SC S/R cycle:

$$t_{DC} = \frac{d_{DC}}{v} + 2t_L + 2t_U = \frac{d_{DC}}{v} + 4t_{L/U}$$

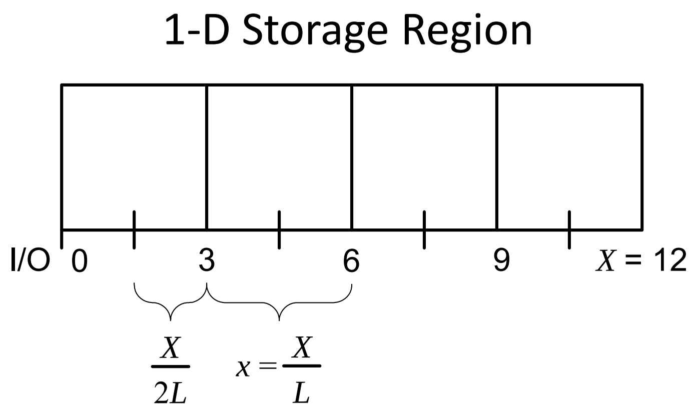
- Dual-command (DC):
- Combine storage with a retrieval:
  - store load in slot 1, travel empty to slot 2 to retrieve load
- Can reduce travel distance by a third, on average
- Also termed task “interleaving”

Multi-Command S/R Cycle



- Multi-command: multiple loads can be carried at the same time
- Used in case and piece order picking
- Picker routed to slots
  - Simple VRP procedures can be used

1-D Expected Distance



$$TD_{1-way} = \sum_{i=1}^{L}\left(i\frac{X}{L}-\frac{X}{2L}\right) = \frac{X}{L}\sum_{i=1}^{L} i - \frac{X}{2L}(1)$$

$$= \frac{X}{L}\left(\frac{L(L+1)}{2}\right) - \frac{X}{2L}(L)$$

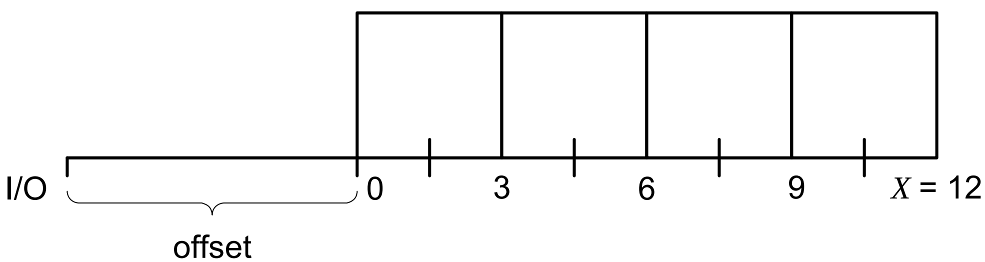
$$= \frac{XL+X-X}{2} = \frac{XL}{2}$$

$$ED_{1-way} = \frac{TD_{1-way}}{L} = \frac{X}{2}$$

$$d_{SC} = 2(ED_{1-way}) = X$$

- Assumptions:
  - All single-command cycles
  - Rectilinear distances
  - Each slot is region used with equal frequency (i.e., randomized storage)
- Expected distance is the average distance from I/O port to midpoint of each slot
  - e.g., [2(1.5) + 2(4.5) + 2(7.5) + 2(10.5)]/4 = 12

Off-set I/O Port



$$d_{SC} = 2(d_{\text{offset}}) + X$$

- If the I/O port is off-set from the storage region, then 2 times the distance of the offset is added the expected distance within the slots

2-D Expected Distances

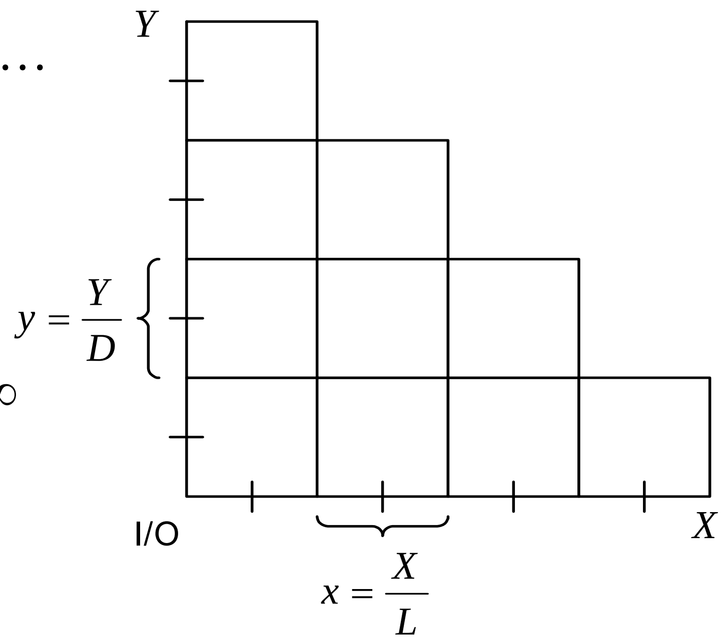
- Since dimensions *X* and *Y* are independent of each other for rectilinear distances, the expected distance for a 2-D rectangular region with the I/O port in a corner is just the sum of the distance in *X* and in *Y*: $d_{SC}^{rect} = X + Y$
- For a triangular region with the I/O port in the corner:

$$TD_{\text{1-way}} = \sum_{i=1}^{L} \sum_{j=1}^{L-i+1} \left[\left(i\frac{X}{L} - \frac{X}{2L} \right) + \left(j\frac{X}{L} - \frac{X}{2L} \right) \right] = \cdots$$

$$= \frac{X}{6}\left(2L^2 + 3L + 1\right)$$

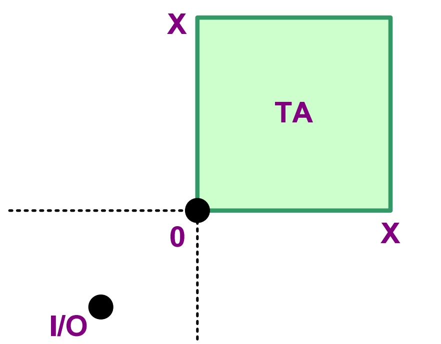
$$ED_{\text{1-way}} = \frac{TD_{\text{1-way}}}{\frac{L(L+1)}{2}} = \frac{2}{3}X + \frac{X}{3L} = \frac{2}{3}X, \quad \text{as } L \to \infty$$

$$d_{SC}^{tri} = 2\left(\frac{2}{3}X\right) = 2\left(\frac{1}{3}X + \frac{1}{3}Y\right) = \frac{2}{3}(X+Y)$$



I/O-to-Side Configurations

Rectangular

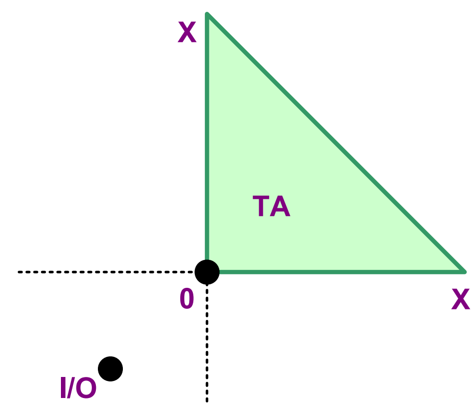


$$TA = X^2$$

$$\Rightarrow X = \sqrt{TA}$$

$$\Rightarrow d_{SC} = 2\sqrt{TA}$$

Triangular



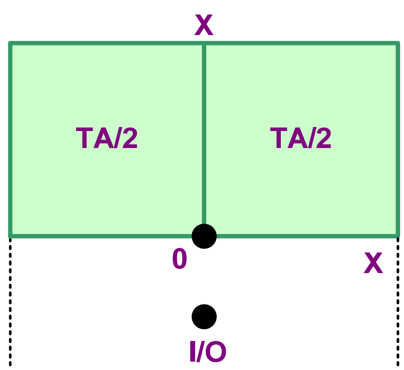
$$TA = \frac{1}{2} X^2$$

$$\Rightarrow X = \sqrt{2TA} = \sqrt{2}\sqrt{TA}$$

$$\Rightarrow d_{SC} = \frac{4}{3}\sqrt{2}\sqrt{TA} = 1.886\sqrt{TA}$$

I/O-at-Middle Configurations

Rectangular

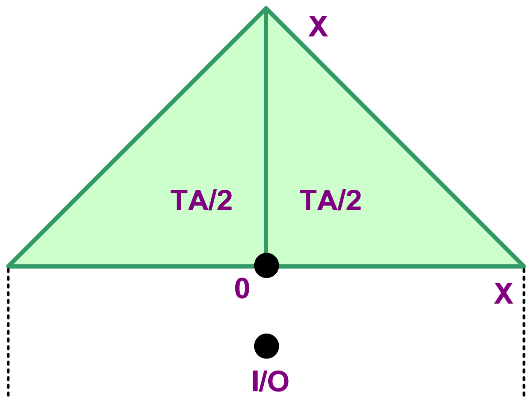


$$\frac{TA}{2} = X^2$$

$$\Rightarrow X = \sqrt{\frac{TA}{2}} = \frac{\sqrt{TA}}{\sqrt{2}}$$

$$\Rightarrow d_{SC} = \sqrt{2}\sqrt{TA} = 1.414\sqrt{TA}$$

Triangular



$$\frac{TA}{2} = \frac{1}{2}X^2$$

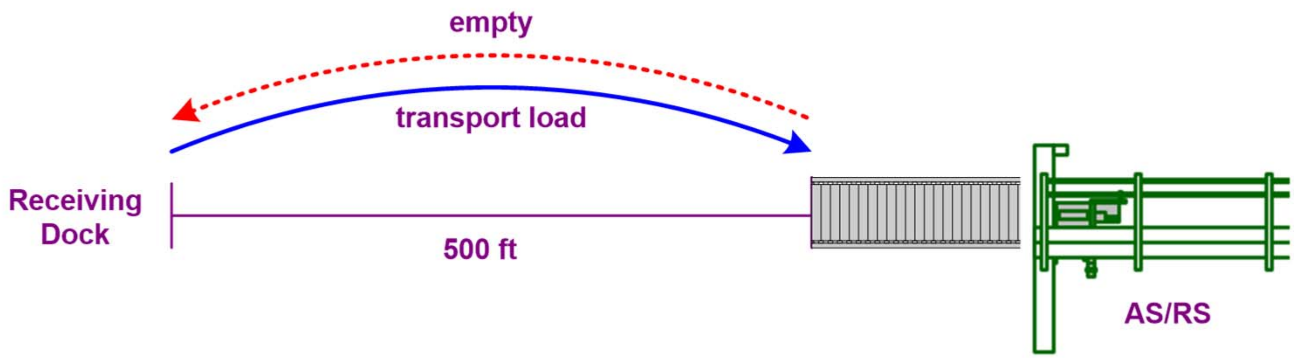
$$\Rightarrow X = \sqrt{TA}$$

$$\Rightarrow d_{SC} = \frac{4}{3}\sqrt{TA} = 1.333\sqrt{TA}$$

Example 3: Handling Requirements

Pallet loads will be unloaded at the receiving dock of a warehouse and placed on the floor. From there, they will be transported 500 feet using a dedicated pallet truck to the in-floor induction conveyor of an AS/RS. Given

a. It takes 30 sec to load each pallet at the dock
b. 30 sec to unload it at the induction conveyor
c. There will be 80,000 loads per year on average
d. Operator rides on the truck (because a pallet truck)
e. Facility will operate 50 weeks per year, 40 hours per week



Example 3: Handling Requirements

1. Assuming that it will take 30 seconds to load each pallet at the dock and 30 seconds to unload it at the induction conveyor, what is the expected time required for each single-command S/R cycle?

$$d_{SC} = 2(500) = 1000 \text{ ft/mov}$$

$$t_{SC} = \frac{d_{SC}}{v} + 2t_{L/U} = \frac{1000 \text{ ft/mov}}{616 \text{ ft/min}} + 2\left(\frac{30}{60}\right) \text{min/mov}$$

$$= 2.62 \text{ min/mov} \quad = \frac{2.62}{60} \text{ hr/mov}$$

(616 fpm because operator rides on a pallet truck)

Example 3: Handling Requirements

2. Assuming that there will be 80,000 loads per year on average and that the facility will operate for 50 weeks per year, 40 hours per week, what is the minimum number of trucks needed?

$$r_{avg} = \frac{80,000 \text{ mov/yr}}{50(40) \text{ hr/yr}} = 40 \text{ mov/hr}$$

$$\begin{aligned} m &= \lfloor r_{avg} t_{SC} + 1 \rfloor \\ &= \left\lfloor 40\left(\frac{2.62}{60}\right) + 1 \right\rfloor = \lfloor 1.75 + 1 \rfloor \\ &= 2 \text{ trucks} \end{aligned}$$

Example 3: Handling Requirements

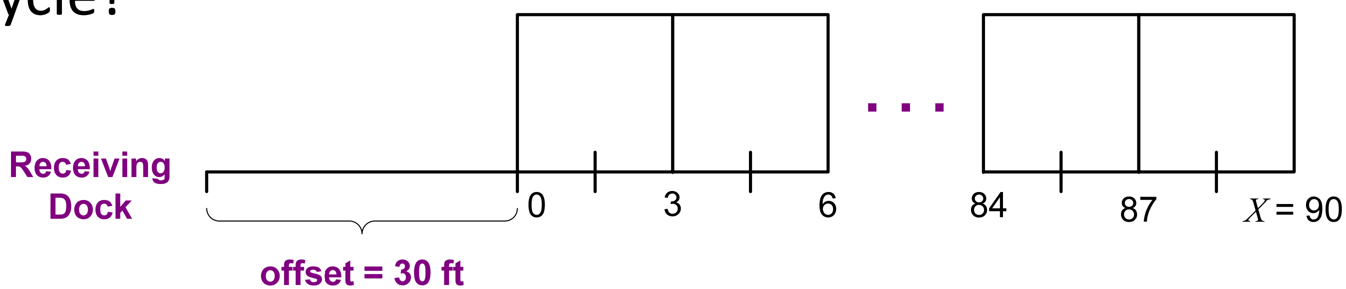
3. How many trucks are needed to handle a peak expected demand of 80 moves per hour?

$$r_{peak} = 80 \text{ mov/hr}$$

$$\begin{aligned} m &= \lfloor r_{peak} t_{SC} + 1 \rfloor \\ &= \left\lfloor 80\left(\frac{2.62}{60}\right) + 1 \right\rfloor = \lfloor 3.50 + 1 \rfloor \\ &= 4 \text{ trucks} \end{aligned}$$

Example 3: Handling Requirements

4. If, instead of unloading at the conveyor, the 3-foot-wide loads are placed side-by-side in a staging area along one side of 90-foot aisle that begins 30 feet from the dock, what is the expected time required for each single-command S/R cycle?



$$d_{SC} = 2(d_{\text{offset}}) + X = 2(30) + 90 = 150 \text{ ft}$$

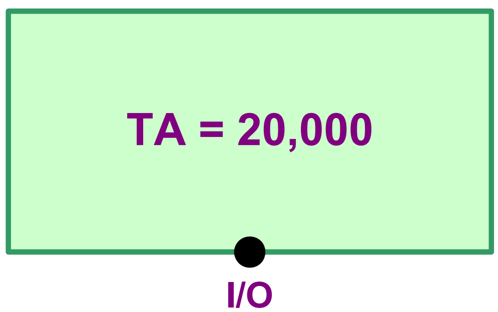
$$t_{SC} = \frac{d_{SC}}{v} + 2t_{L/U} = \frac{150 \text{ ft/mov}}{616 \text{ ft/min}} + 2\left(\frac{30}{60}\right) \text{min/mov}$$

$$= 1.24 \text{ min/mov} \quad = \frac{1.24}{60} \text{ hr/mov}$$

Estimating Handling Costs

- Warehouse design involves the trade-off between building and handling cost.
- Maximizing the cube utilization of a storage region will help minimize building costs.
- Handling costs can be estimated by determining:
  1. Expected time required for each move based on an average of the time required to reach each slot in the region.
  2. Number of vehicles needed to handle a target *peak demand* for moves, e.g., moves per hour.
  3. *Operating costs per hour of vehicle operation*, e.g., labor, fuel (assuming the operators can perform other productive tasks when not operating a truck)
  4. Annual operating costs based on *annual demand* for moves.
  5. Total handling costs as the sum of the annual capital recovery costs for the vehicles and the annual operating costs.

Example 4: Estimating Handing Cost



Expected Distance: $d_{SC} = \sqrt{2}\sqrt{TA} = \sqrt{2}\sqrt{20,000} = 200 \text{ ft}$

Expected Time: $$t_{SC} = \frac{d_{SC}}{v} + 2t_{L/U}$$
$$= \frac{200 \text{ ft}}{200 \text{ fpm}} + 2(0.5 \text{ min}) = 2 \text{ min per move}$$

Peak Demand: $r_{\text{peak}} = 75 \text{ moves per hour}$

Annual Demand: $r_{\text{year}} = 100,000 \text{ moves per year}$

Number of Trucks: $$m = \left\lfloor r_{\text{peak}} \frac{t_{SC}}{60} + 1 \right\rfloor = \lfloor 3.5 \rfloor = 3 \text{ trucks}$$

Handling Cost: $$TC_{\text{hand}} = mK_{\text{truck}} + r_{\text{year}} \frac{t_{SC}}{60} C_{\text{labor}}$$
$$= 3(\$2,500 / \text{tr-yr}) + 100,000 \frac{2}{60} (\$10 / \text{hr})$$
$$= \$7,500 + \$33,333 = \$40,833 \text{ per year}$$