MATERIAL TRANSPORT EQUIPMENTS

1- Industrial Trucks
2- Automated Guided Vehicles,
3- Monorails and other rail guided vehicles
4- Conveyors
5- Cranes and hoists

See Table 10.1 for Summary of Features

Industrial Trucks:

Powered (self propelled) — See Figure 10.2

Non-Powered Hand trucks "pushed or pulled by human workers"

Relatively low quantity and low move distances

See Figure 10.1

Walkie trucks
- battery powered
- equipped with wheeled forks
- no place for workers to ride on the vehicle
- truck is steered by a worker using a control handle in front of the vehicle.
- speed limited to 5km/hour. normal walking speed.

Rider forklift trucks
- a place for worker to sit and drive the vehicle. "operator"

450kg – 4,500kg. Capacity
- high reach capability for accessing pallet loads on high rack systems.
- capable of operating in narrow aisles with high density storage racks.
- internal combustion vs. electric motors

Towing tractors
- to pull one or more trailing carts over relatively smooth surfaces.
- large amount of material between major collection and distribution areas
- Runs between these points are fairly long.
- Internal combustion vs. electric motors.

Especially used in air transport operations for moving baggage and air freight in airports.

Two-wheel limited to lighter loads.

Multiple Wheel

Pallet trucks
- have two forks for pallets
- a lift mechanism to lift & lower the pallet
- small diameter wheels
- insert fork into the pallet, elevate the load, pull the truck to its destination then lower the pallet and remove forks.

Dollies
Wheel Configuration fixed vs. caster-type

Automated Guided Vehicle Systems:

- a system that uses independently operated, self propelled vehicles guided along defined pathways.
- Powered by on-board batteries (8-16 hours of operation before recharging)
- Distinguishing feature, compared to rail guided vehicle systems and conveyor systems, is that the pathways are unobtrusive.
- is appropriate where different materials are moved from various load points to various unload points. "in batch production/mixed model production"
- first agv was operated in 1954 (by A.M. Barrett, Jr.) using an overhead wire to guide a modified towing truck pulling a trailer in a grocery warehouse. Followed commercial ones.
  - 1973, VOLVO, swedish carmaker, use agvs to serve as assembly platforms for moving carbodies. Later, Volvo entered into AGV business and marketed their unit load AGVs to other car maker companies.

Improvements - refinements:
- vehicle guidance and navigation,
- on-board vehicle intelligence and control,
- overall system management
- safety.

3-categories:

See Figure 10.3

Driveless trains
- pulls one or more trailers to form a train.
- First type introduced still widely used.
- without intermediate pickup & dropoff points.

Pallet trucks
- for palletized loads
- a worker loads the vehicle drive to the guide path, programs its destination and then it automatically proceeds to the destination for unloading
- two pallets up to thousands of kg.
- Fork-lift AGV with significant vertical movement.

Unit-load carriers
- moving unit loads from one station to another.
- equipped with automatic loading and unloading of pallets or totepans. "powered rollers, moving belts, mechanized lift platforms"

light load, assembly line AGV up to 250 kg. to carry partially completed subassembly

Vehicle Guidance Technology

- Inbedded guide wires
- Paint strips
- Self Guided vehicles
  - latest guidance technology
  - sensors, GPS systems ...

See Figure 10.4

Vehicle Management and Safety

Traffic Control

- On-board sensing
  - detects the presence of other vehicles and obstacles ahead on the guide path.
- Zone Control
  - no vehicle is permitted to enter a zone if that zone is already occupied by another vehicle

See Figure 10.5

Vehicle Dispatching

- On-board control
- remote call stations
- Central Computer Control

Safety Rule: travelling speed is slower than the normal walking pace of a human.
Acquisition distance (5 to 15 cm) automatic stopping feature.
Obstacle detection
Surrounding bumper (30 cm)

Monorails and other rail guided vehicles:

Fixed rail system
- One rail (monorail) suspended overhead
- two parallel rails

- pickup electrical power from an electrified rail (No charging required)
- Routing variations: - switches
  - turntables
- before 1900 overhead monorail trolleys were used in slaughtered animals were hung from meat hooks attached.
  Henry Ford got the idea for assembly line.

Conveyor Systems:

Movement of relatively large quantities between specific locations over a fixed path.

- Non-powered: Manual push/gravity
- Powered (using chains, belts, rotating rolls)

implemented by a track system
- in the floor
- above the floor
- overhead

- Roller / Skate Wheel Conveyors (lighter weight) as a portable equipment for load & unload truck trailers at shipping/receiving docks. See Figure 10.6
- Belt conveyors See Figure 10.7
  - endless loop
  - Chain - Slat - in floor tow line - overhead trolley, power and free overhead trolley - cart on track
    See Figure 10.8 Figure 10.9 See Figure 10.10
  - screw conveyors - vibration based - vertical lift conveyors - chutes, ramps, tubes ...

Conveyor Operations:

- Continuous
  - ∥c
  - belt, roller, skate-wheel overhead trolley, slat conveyors.
- Asynchronous (stop & go motion)
  - overhead power-and-free trolley to destination.
  - in-floor towline
  - Cart-on-track conveyors
  - Roller & Skate wheel
  - – accumulate loads
  - – temporary storage
  - – allow for differences in production rates
  - – smooth out production
  - – accomodate different conveyor speeds.

Conveyors:

- Single direction
  - one way flow of operation
  - roller, skate-wheel belt, chain in floor gravity conveyors.
- Continuous loop
  - See Figure 10.11
  - overhead trolley "closed loop" collection of empty carriers
- recirculating ∥ provides storage function

Cranes and Hoists: over 100 tons capacity.

- horizontal movement (x, y axis)
  - transport the load horizontally to the the desired destination.
- vertical movement (z axis)
  - lifts the load
  - – a mechanical device that is used to raise and lower the loads.
  - See Figure 10.12

- Manual, electric or pneumatic motor driven.

- Bridge cranes 36.5 m height 100 tons See Figure 10.13
- Gantry cranes "vertical legs" 46 m height 100 tons
- Jib cranes

composed of one or more fixed pulleys, rope/cable/chain! a hook (attaching device)
Mechanical advantage!

- Double gantry crane
- Half gantry crane
- Cantilever gantry crane

See Figure 9.2

Wall-mounted 180°
Column-mounted (floor mounted) 360°
upto 5 tons

Analysis of vehicle based system:

Delivery cycle:
- load at pickup station
- travel to dropoff station
- unload at dropoff station
- empty travel to pickup station.

Delivery cycle time per vehicle

$$T_C = T_L + \frac{L_d}{V_C} + T_u + \frac{L_e}{V_C}$$

L_d: travel distance between pickup & dropoff station

L_e: empty travel distance

T_L: time to load

T_u: time to unload

ignores losses due to:
- reliability (Availability) A
- traffic congestion T_J → waiting at intersections, blocking of vehicles, waiting for load/unload.
- others

$$AT = 60_{min} \cdot A \cdot T_J \cdot E$$

- AT: (available time min/hour)
- A: Availability
- T_J: traffic factor
- E: Worker efficiency

Rate of deliveries per vehicle (deliveries per hour/vehicle)

$$R_{dv} = \frac{AT}{T_C}$$

Workload (specified flow rate of deliveries)

$$WL = R_f T_C$$

Number of vehicles required

$$n_C = \frac{WL}{AT} = \frac{R_f T_C}{R_{dv} \cdot T_C} = \frac{R_f}{R_{dv}}$$

Example 10.1 — Figure 10.15

$L_d = 110\,m$ $\quad T_L = 0.75\,min$ $\quad R_f = 40$ del/hour

$L_e = 80\,m.$ $\quad T_a = 0.50\,min$ $\quad v = 50\,m/min$

$A = 0.95$

$T_j = 0.90$

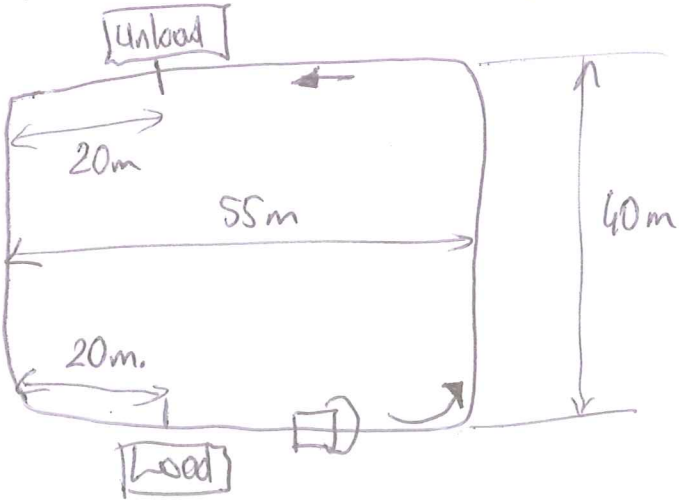
$E = 1.00$

$$T_C = 0.75 + \frac{110}{50} + 0.50 + \frac{80}{50} = 5.05\,min$$

$$WL = 40 * 5.05 = 202\,min/hour$$

$$AT = 60(0.95)(0.90)(1.0) = 51.30\,min/hour\text{-}vehicle$$

$$n_C = \frac{202}{51.30} = 3.94\ vehicles \Rightarrow n_C = 4\ vehicles.$$



Example 10:2: weighted average! Figure 10.16

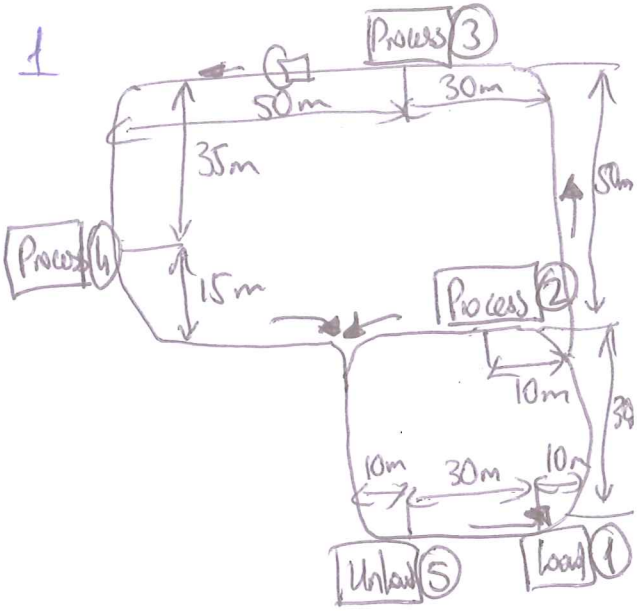
$$L_d = \frac{9(50)+5(120)+6(205)+9(80)+2(85)+3(170)+8(85)}{9+5+6+9+2+3+8}$$

$$L_d = \frac{4360}{42} = 103.8\,m$$

L_e is more difficult to compute, it depends on dispatching and scheduling methods used.

if returns back to station 1

	1	2	3	4	5
1	—	9/110	5/200	6/115	—
2	—	—	—	9/80	
3	—	—	2/35	3/150	
4	—	—	—	8/235	
5	—	—	—	—	



$$L_e = \frac{9(110)+5(200)+6(115)+9(80)+2(235)+3(150)+8(235)}{42}$$

$$= \frac{990+1000+690+720+470+450+1880}{42}$$

$$= \frac{6200}{42} = 147.62\,m$$

Conveyor Analysis

Single Direction Conveyors

See Figure 10.11a

- single direction
- powered
- one load station at the upstream end
- one unload station at the downstream end
- parts, cartons, pallet loads, other unit loads.
- operates at a constant speed v_c

$$T_d = \frac{L_d}{v_c}$$

T_d — Delivery Time (min)

L_d — length of conveyor between load & unload stations (m)

v_c — conveyor velocity (m/min, ft/min)

Flow rate depends on loading rate of load station.

$$R_f = R_L = \frac{v_c}{S_c} \leq \frac{1}{T_L}$$

R_f — material flow rate (pcs/min)

R_L — loading rate (pcs/min)

S_c — center to center spacing of materials (m/part, ft/part)

T_L — loading time (min/pcs)

$R_L = \frac{1}{T_L}$ → is determined by ergonomic factors

However, it is set by R_f.

$$T_U \leq T_L$$

T_U — unloading time (min/pcs)

otherwise accumulation of unloaded parts or dumped onto the floor!

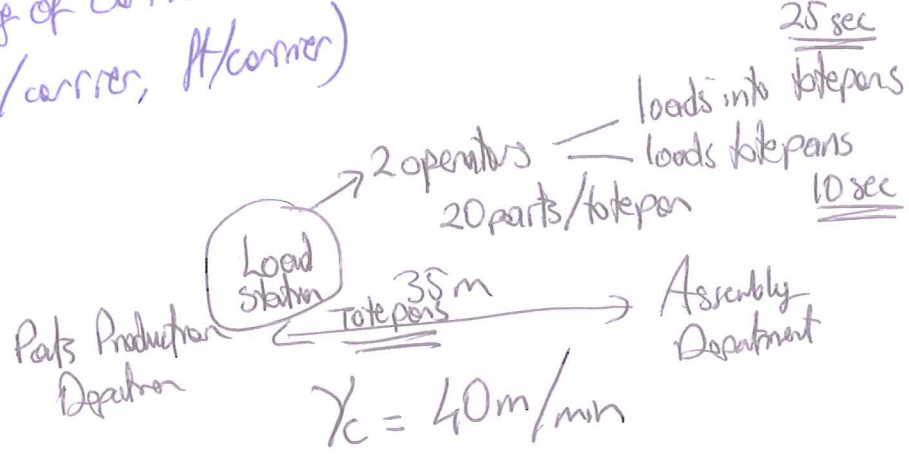
$$R_f = R_L = \frac{\gamma_c}{s_c} \leq \frac{1}{T_L} \quad , \quad T_u \leq T_L$$

If n_p parts exist in a carrier rather than a single part,

$$R_f = \frac{n_p \cdot \gamma_c}{s_c} \leq \frac{1}{T_L}$$

- R_f: flow rate (parts/min)
- n_p: number of parts per carrier
- γ_c: center-to-center spacing of carriers (m/carrier, ft/carrier)
- T_L: loading time per carrier (min/carrier)

Example 10.3:



Spacing between totepans:

$\max(10\text{ sec}, 25\text{ sec})$

$$\Rightarrow s_c = \frac{40\text{ m/min}}{\frac{60}{25}\ \text{totepans/min}} = \frac{40 \cdot 25}{60}\ \text{m/totepan} = 16.67\text{ m}$$

Flow rate:

$$R_f = \frac{n_p \cdot \gamma_c}{s_c} = \frac{20\ \text{parts/totepan} \cdot 40\text{ m/min}}{16.67\text{ m/totepan}} = \frac{20 \cdot 40}{16.67} = 48\text{ parts/min}$$

20 parts every 25 seconds.

$$\frac{20}{25} = 0.8\text{ parts/sec} \Rightarrow 60 \cdot 0.8 = 48\text{ parts/min}$$

Minimum allowable time to unload: every 25 seconds.

$T_u \leq 25$ seconds.

Continuous loop Conveyors:

ex: overhead trolley by an endless chain moving in a track loop

- carriers are suspended from the track and pulled by the chain
- move parts in the carriers between a load and an unload station.
- Two section loop:
  - Delivery loop "carriers are loaded"
  - Return loop "carrier travel" empty

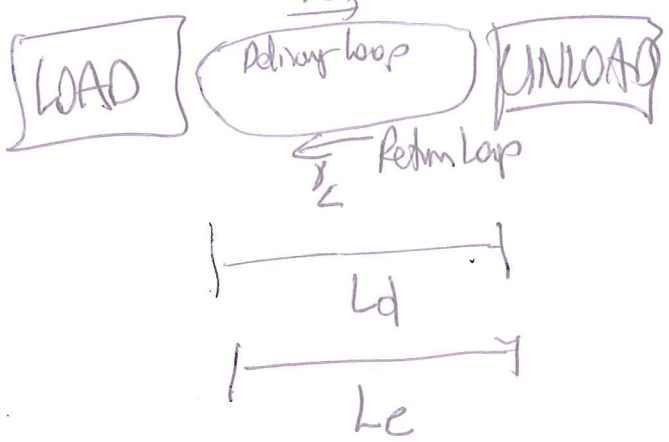
$$T_c = \frac{L}{v_c}$$

T_c: Total cycle time/min; L: Total length of the conveyor (m, ft); v_c: Speed of conveyor (m/min, ft/min)

$$T_d = \frac{L_d}{v_c}$$

$$n_c = \frac{L}{S_c}$$

n_c: number of carriers (integer); S_c: center-to-center distance between carriers (m/carrier, ft/carrier)



$$L = L_d + L_e$$

On delivery loop n_p parts/carrier

On return loop 0 parts/carrier

$$\text{Total parts in the system} = \frac{n_p n_c \cdot L_d}{L} = \text{parts}$$

(n_p: number of parts/carrier; n_c: number of carriers; L_d: m; L: m)

$$\text{Maximum flow rate} = R_f = \frac{n_p v_c}{S_c}$$

(n_p: number of parts per carrier; v_c: m/min; S_c: m/carrier; R_f: parts/min)

parts/min should be consistent with load/unload times.

Recirculating Conveyors: Two Analysis.

Complication:
- possibility of no empty carriers ready at loading station when needed
- possibility of no loaded carriers be ready at the unloading station when needed.

1) Speed Rule:

$$\frac{n_p \cdot v_c}{s_c} \geq \max\{R_L, R_U\}$$

R_L: required loading rate (pcs/min)

R_U: unloading rate (pcs/min)

$$\frac{v_c}{s_c} \leq \min\left\{\frac{1}{T_L}, \frac{1}{T_U}\right\}$$

v_c: m/min

s_c: m/carrier

$\frac{1}{T_L}$: time required to load a carrier, min/carrier

$\frac{1}{T_U}$: time required to unload a carrier, min/carrier

"Speed must not exceed the technological limits" of the mechanical conveyor!!!

2) Capacity constraint:

$$\frac{n_p v_c}{s_c} \geq R_f$$

R_f — flow rate capacity of the system

3) Uniformity principle:

Pcs(loads) should be uniformly distributed throughout the length of the conveyor, so that there will be no sections of the conveyor in which carrier is full while other sections are virtually empty.

Example 10.4

Total length 300m.

Speed $v_c = 60 m/min$

Spacing of part carriers $S_c = 12 m/carrier$

$n_p = 2$ parts/carriers

$T_L = 0.2 min$ } loading & unloading parts from the carrier!

$T_u = 0.2 min$ } loading & unloading rates

$R_u, R_\ell = 4$ parts/min "flowrate"

Evaluate the conveyor system design with respect to KWO's three principles.

Speed Rule:

$$\frac{n_p v_c}{S_c} \geq \max\{R_L, R_u\}$$

$$\frac{(2 \text{ parts/carrier})(60 m/min)}{12 m/carrier} = 10 \text{ parts/min} > 4 \text{ parts/min}$$

Lower limit $\frac{60 m/min}{12 m/carrier} = 5$ carrier/min $\leq \min\left\{\frac{1}{0.2}, \frac{1}{0.2}\right\} = 5$

Capacity Constraint: flow rate capacity 10 parts/min, substantially greater than the required delivery rate 4 parts/min

Uniformity Principle: It is assumed to be uniformly loaded throughout its length, since the loading and unloading rates are equal, and the flow rate capacity is substantially greater than the load/unload rate.