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)
  - Walkie-trucks
    - Snowplow 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 5 km/hour
    - Normal walking speed

- Rider trucks
  - A place for worker to sit and drive the vehicle.
  - "Operator"
  - 400 kg - 6,500 kg capacity

- 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 those points are fairly long.
  - Internal combustion vs. electric motors

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

- Relatively low quantity and move distances

- See Figure 10.1

- Multiple Wheels
  - Pellet 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.
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 recharge).
- 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 unloading 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 forklift truck pulling a trailer in a grocery warehouse, followed by commercial ones.

In 1973, Volvo, Swedish carmaker, used AGVs to serve as assembly platforms for moving car bodies. Later, Volvo entered into AGV business and marketed their unit load AGVs to other car maker companies.

Improvements and advancements:
- Vehicle guidance and navigation,
- On-board vehicle intelligence and control,
- Overall system management,
- Safety.

3 Categories:

- Driverless trains
- Pallet trucks
- Unit-load carriers

See Figure 10.3
Vehicle Guidance Technology

- Embedded guide wires
- Paint stripes
- Self-Guided vehicles

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 control
- 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
- pickup electrical power from an electrified rail (No change required)
- Routing variations: switches, turntables
- before 1800 overhead monorail railways were used in slaughterhouses to move carcasses 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
- Roller / Skate Wheel Conveyors
  - Lighter weight
  - As a portable equipment for load and unload truck trailers at shipping/receiving docks.

- Belt conveyors
  - Endless loop
  - Chain-slot - infloor - trolley - overhead - trolley-powered - overhead trolley - cantilevered

- Screw conveyors - vibration based - vertical lift conveyors - chutes, ramps, tubes...

See Figure 10.6

See Figure 10.7

See Figure 10.8

See Figure 10.10
**Conveyor Operations**

- Continuous belt, roller, skate-wheel overhead trolley, slot conveyors.
- Asynchronous (stop and go motion) overhead power-act-free trolley to destination.
- Inflor-tumble cat-antimode conveyors.
- Roller and skate-wheel accumulators.
- Temporary storage.
- Allow for differences in production rates.
- Smooth out production.
- Accommodate different conveyor speeds.

**Conveyors**

- Single chain.
- Recirculating provides storage.
- One-way free circulation.
- Continuous loop further overhead trolley.
- Overhead trolley closed loop.
- Collection of empty cans.
- Roller, skate-wheel, belt, chain-in-floor gravity conveyors.

**Cranes and Hoists**

- Over 100 tons capacity.
- Manual, electric, or pneumatic motor driven.
- Horizontal movement lifts the load horizontally to the desired destination.
- Vertical movement on mechanical device that is used to raise and lower the loads.
- Bridge cranes, gantry cranes, jib cranes.

- See Figure 10.13
- See Figure 10.12
- See Figure 8.2

- Well-mounted 180°
- Column-mounted (floor mounted) 360°
- Parked crane

- Double gantry crane
- Half gantry crane
- Goliath gantry crane
Analysis of vehicle based system:

- load at pickup station
- travel to dropoff station
- unload at dropoff station
- empty travel to pickup station.

Delivery cycle time per vehicle

\[ T_c = T_L + \frac{L_d}{V_c} + T_u + \frac{L_e}{V_c} \]

\( T_c \) ignores losses due to:
- reliability (Availability)
- traffic congestion \( T_f \)
- others

\[ AT = 60 \times A \times T_f \times E \]

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

\[ R_{dv} = \frac{AT}{T_c} \]
Workload \rightarrow \text{specified flow rate of deliveries}

\[ WL = R_f T_c \]

Number of vehicles required

\[
N_c = \frac{WL}{AT} = \frac{R_f T_c}{R_{dv} T_c} = \frac{R_f}{R_{dv}}
\]

**Example 10.1**  

\[
L_d = 110 \text{m} \quad T_L = 0.75 \text{min} \\
L_e = 80 \text{m} \quad T_a = 0.50 \text{min}
\]

\[
T_c = 0.75 + \frac{110}{50} + 0.50 + \frac{80}{50} = 5.05 \text{min}
\]

\[
WL = 40 \times 5.05 = 202 \text{min/hr}
\]

\[
AT = 60 (0.85)(0.80)(1.0) = 51.30 \text{ min/hr vehicle}
\]

\[
N_c = \frac{202}{51.30} = 3.94 \text{ vehicles} \quad \Rightarrow N_c = 4 \text{ vehicles}
\]
Example 10.2: Weighted average

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

\[ L_d = \frac{4360}{42} = 103.8 \text{ m} \]

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

If return back to station 1

\[ L_e = 9(110) + 5(200) + 6(115) + 8(90) + 2(235) + 3(130) + 8(233) \]

\[ = 980 + 1000 + 680 + 720 + 470 + 450 + 1880 \]

\[ = \frac{6200}{42} = 147.62 \text{ m} \]
Conveyor Analysis

Single Direction Conveyors
- single direction
- powered
- ore load station at the upstream end
- ore unload station at the downstream end
- parts, cartons, pallet loads, other unit loads,
- operates at a constant speed \( V_c \)

\[ T_d = \frac{L_d}{V_c} \]

Delivery Time (min)

- length of conveyor between load and unload stations (m)
- conveyor velocity (m/min, ft/min)

Flow rate depends on loading rate of load station.

\[ R_f = R_L = \frac{V_c}{S_c} \leq \frac{1}{T_L} \]

- material flow rate (pots/min)
- loading rate (pots/min)

\[ R_L = \frac{1}{T_L} \]

- However, it is set by \( R_f \)
- is determined by ergonomic factors

\[ T_u \leq T_L \]

- unloading time (min/pot)

- otherwise accumulation of unloaded pots
- or dumped onto the floor?
\[
R_f = R_L = \frac{Y_c}{S_c} \leq \frac{1}{T_L}, \quad Tu \leq T_L
\]

If \( n_p \) parts exist in a carrier rather than a single part, number of parts per carrier

\[
R_f = \frac{N_p \cdot Y_c}{S_c} \leq \frac{1}{T_L} \quad \text{loading time per carrier (min/carrier)}
\]

Flow rate (pots/min)

Example 10.3:

Specify between takt times:

\[
\text{max (10 sec, 25 sec)}
\]

\[
S_c = \frac{(40 \text{ m/min}) \times \frac{60}{25} \text{ min}}{60} = \frac{60 \times 25}{60} \text{ m/parts/takt}
\]

\[
= 16.67 \text{ m}
\]

Flow rate:

\[
R_f = \frac{N_p \cdot Y_c}{S_c} = \frac{20 \text{ parts/25 sec} \cdot 40 \text{ m/min}}{16.67 \text{ m/takt}} = \frac{20 \cdot 40}{16.67} = \frac{60 \text{ pots/min}}{25}
\]

20 parts in every 25 seconds.

\[
\frac{20}{25} = 0.8 \text{ pots/sec} \Rightarrow 60 \cdot 0.8 = 48 \text{ pots/min}
\]
Minimum allowable time to unload:

\[ t_{\text{min}} \]

\[ T_u \leq 25 \text{ seconds.} \]

**Continuous loop Conveyors:**

- Total cycle time (min) \( T_c = \frac{L}{c} \)
- Total length of the conveyor (m, ft)
- Speed of conveyor (m/min, ft/min)
- Number of carriers (integer)

\[ T_d = \frac{L_d}{c} \]

\[ N_c = \frac{L}{c} \]

On delivery loop \( P_d \) pets/corner

On return loop \( 0 \) pets/corner

Total pets in the system = \( \frac{N_c \cdot L_d}{S_c} \) pets

Maximum flow rate = \( R_f = \frac{P_d \cdot N_c \cdot c}{S_c} \) pets/min

- Example: Overhead trolley
  - Carriers are suspended for the track and pulled by the chain
  - Move pets in the carriers between a load end and unloading station

Two section loop:
- Delivery loop "corner-loaded"
- Return loop "corner-travel" empty

LOAD

Delivery Loop

\[ L = L_d + L_e \]

UNLOAD

Return Loop

\[ P_d \text{ pets/corner} \]

\[ P_e \text{ pets/corner} \]
Recirculating Conveyors: Two Analysis.

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

1) Speed Rule:

\[
\frac{N_p \cdot Y_c}{Sc} \geq \text{max} \left\{ \frac{R_u}{R_c}, R_u \right\}
\]

\[
\frac{Y_c}{Sc} \leq \text{Min} \left\{ \frac{1}{T_L}, \frac{1}{T_U} \right\}
\]

Speed must not exceed the technological limits of the recirculating conveyor!!

2) Capacity Constraint:

\[
\frac{N_p \cdot Y_c}{Sc} \geq R_f
\]

3) Uniformity Principle:
Pots (loads) should be uniformly distributed throughout the length of the conveyer, so that there will be no sections of the conveyer in which carrier is full while other sections are virtually empty.
Example 10.4

Total length 300 m,

Speed \( \nu_c = 60 \text{ m/min} \)

Spacing of port covers \( S_c = 12 \text{ m/cov} \)

\( N_p = 2 \text{ pots/cov} \)

\[ T_L = 0.2 \text{ min} \] loading & unloading rate!

\[ T_u = 0.2 \text{ min} \] loading & unloading rate

\( R_u, R_c = 4 \text{ pots/min} \) "flowrate"

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

**Speed Rule:**

\[ \frac{N_p \nu_c}{S_c} \geq \max (R_u, R_c) \]

\[ \frac{(2 \text{ pots/cov}) (60 \text{ m/min})}{12 \text{ m/cov}} = 10 \text{ pots/min} > 4 \text{ pots/min} \]

**Lower limit**

\[ \frac{60 \text{ m/min}}{12 \text{ m/cov}} = 5 \text{ cov/min} \leq \min \left\{ \frac{1}{0.2}, \frac{1}{0.2} \right\} = 5 \]

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