Conveyor Analysis

END4650 – Material Handling Systems

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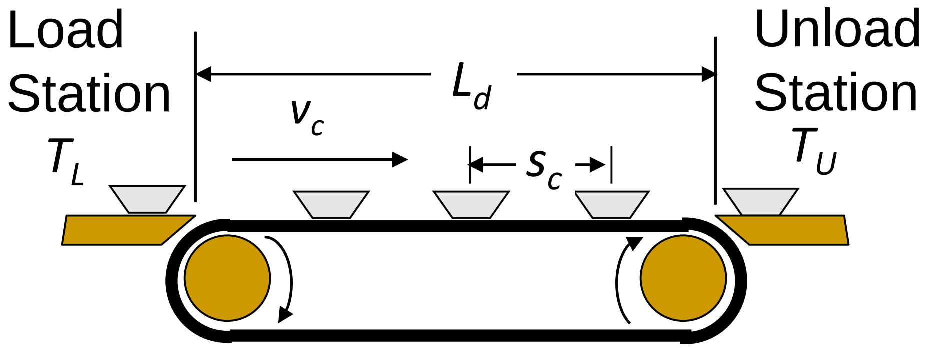
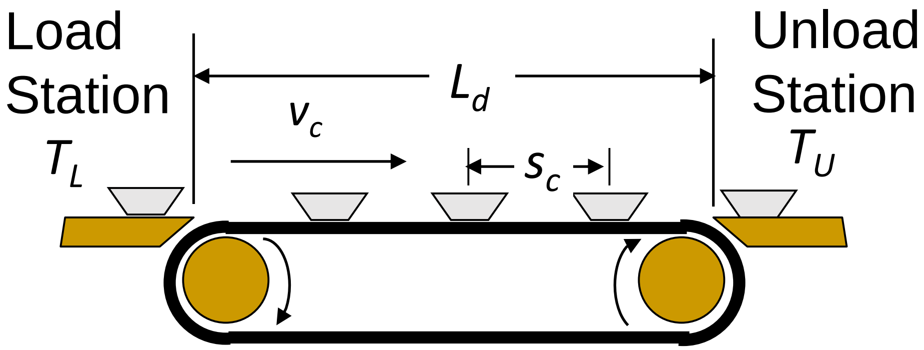
Single Direction

- *Three basic types*
  - ***A. Single direction***
  - *B. Continuous loop*
  - *C. Recirculating*



Single Direction

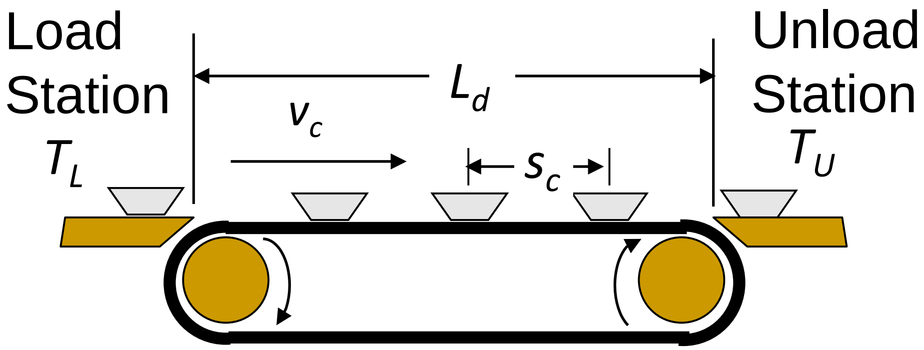


A. Single Direction:

- transport loads one way from origination point to destination point.
- Appropriate when no need
  - to move loads in both directions or
  - to return containers or carriers from the unloading stations back to the loading stations.
- roller, skate wheel, belt, and chain-in-floor types

Single Direction

- *Consider following:*
  - if loading time is 0.25 min/carrier,
  - then max loading rate is
    - 4 carr/min



- T_L: loading time(min/carr)
- **max** available loading rate (R_L) :

$$R_L \leq 1/\ T_L$$

Single Direction

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  - if loading time is 0.25 min/carrier,
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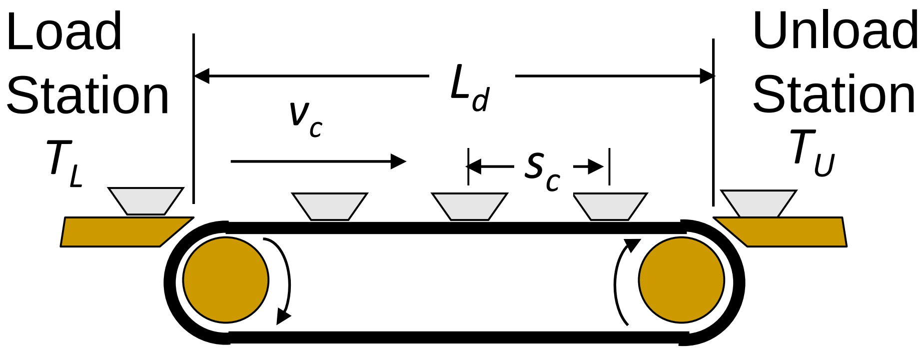


$$T_d = L_d / v_c$$

- T_d *the delivery time i.e.* the time required to move materials from load station to unload station

- T_L: loading time(min/carr)
- **max** available loading rate (R_L) :

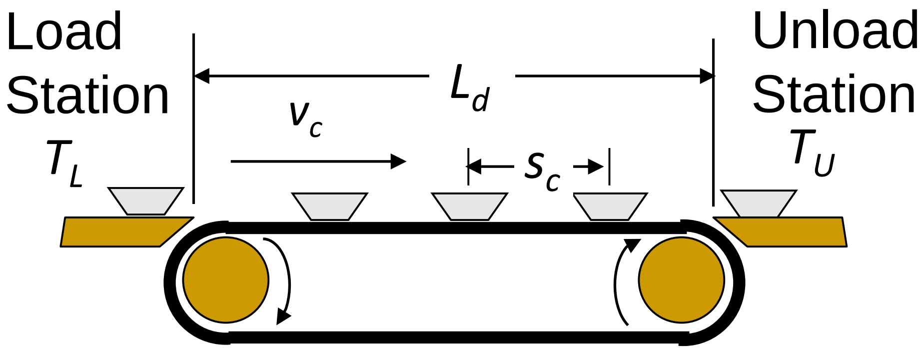
$$R_L \leq 1/\ T_L$$

Single Direction

- The flow (needed) rate[$\boldsymbol{R_f}$] of materials on the conveyor is determined by the loading rate [$\boldsymbol{R_L}$]

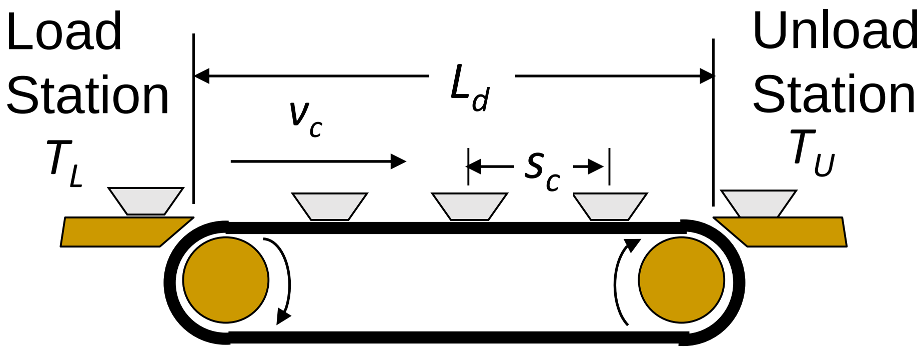
$$(\boldsymbol{R_f} = \boldsymbol{R_L})$$

- Let
  - n_p: number of parts per carrier.
  - s_c: Carriers spacing on conveyor(m/carr)
- How to determine s_c?



- Ex:
  - V_c=50m/min
  - R_L=20 part/min
  - n_p=2part/carr
  - Then
    - $s_C = 2\ x\ (\frac{50}{20})$ = 5 mt/carr
    - $s_C = \frac{n_p V_c}{R_L}$

Single Direction



- One might think that $\boldsymbol{R_L = n_p / T_L}$
- However,
  - R_L is set by the flow rate requirement R_f,
  - T_L is determined by ergonomic factors.
- The worker at loading (T_L) may be faster than the required flow rate (R_f).
- The flow requirement cannot be faster than it is humanly possible to perform the loading task.
- Therefore $\boldsymbol{R_L \leq n_p / T_L}$

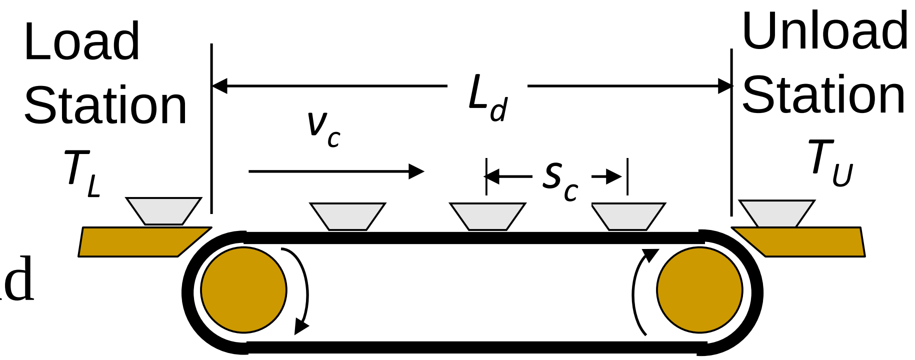
$$\boldsymbol{R_f = R_L = \frac{n_p v_c}{s_c} \leq \frac{n_p}{T_L}}$$

- Additionally we have $\boldsymbol{T_u \leq T_L}$, where T_U is the unloading time (min/carr)

Single Direction: Summary

<u>Assumptions</u>:

1. Belt moves in one direction
2. One load station at the input end
3. One unload station at the output end



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

$$\boxed{R_f = R_L = \frac{n_p v_c}{s_c} \le \frac{n_p}{T_L}}$$

where:

T_d = delivery time (min/carrier)

L_d = conveying distance between load and unload stations (m,ft)

v_c = conveyor speed (m/min, ft/min)

R_f = material flow rate (parts/min)

R_L= loading rate (parts/min)

n_p= number of parts per carrier

s_c = carriers spacing on conveyor (m/carrier, ft/carrier)

T_L= loading time (min/carrier) ➔ Property of the worker

T_U= unloading time (min/carrier) ➔ Property of the worker

$$\boxed{T_U \le T_L}$$

Single Direction Conveyors – An Example

- A roller conveyor follows a pathway 35m long between a parts production dept and an assembly dept.
- Velocity of the conveyor is 40m/min.
- Parts are loaded into large boxes.
- Two operators work the loading station.
  - The first worker loads parts into boxes, which takes 20sec.
    - Each box holds 20 parts.
  - The second worker loads boxes onto the conveyor, which takes only 10sec.
- Parts enter the loading station in such a way that a full box can be loaded to conveyor at 25 seconds.

Single Direction Conveyors

Determine

(a) spacing between boxes along the conveyor,

(b) max possible flow rate in parts/min.

(c) the maximum allowable time required to unload the box in assembly department.

Single Direction Conveyors

(a) Spacing between boxes

- Loading time for boxes is 25. (*Why?*)

  R_L = 60/25 =2.4 box/min

  V_c = 40m/min

- s_c = (40 m/min)/ 2.4(box/min) =16.67 m/box

(b) Flow rate is given by

- $R_f = \frac{n_p v_c}{s_c}$
- $R_f = \frac{(20)(40)}{16.67} = 48$ parts/min

or 2.4 box/min x 20 = 48 parts /min

Single Direction Conveyors

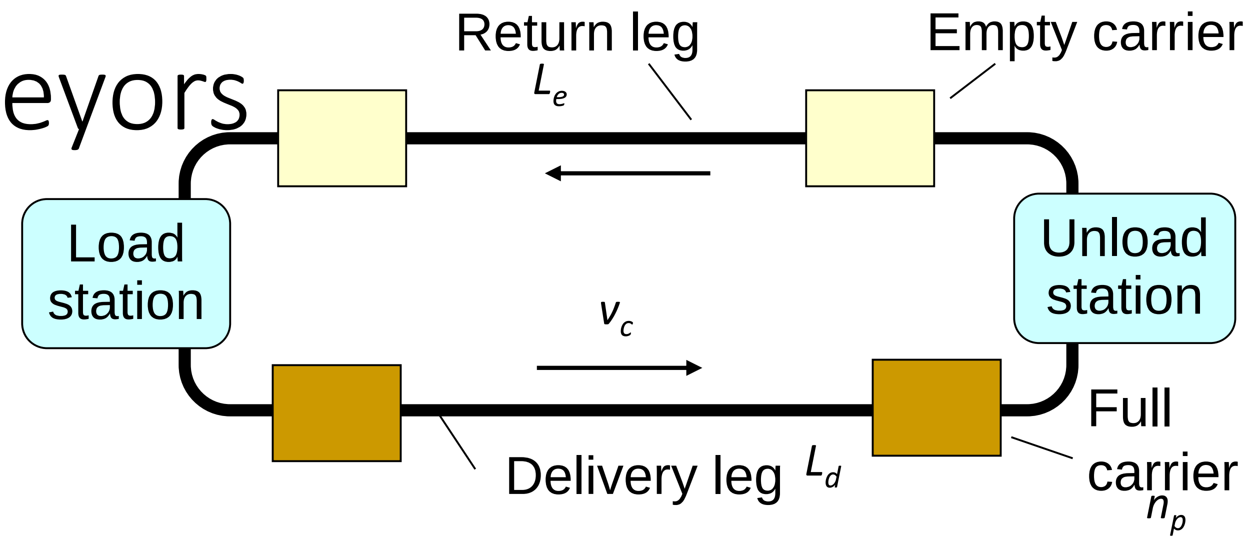
Compare with the loading rate T_L

- Load parts to a box is 20 sec
- Load a box to conveyor 10 sec
- T_L= max(10,20)=20sec=1/3min
- Max loading rate is 1/(1/3)=3 box/min
- *Compare with 2.4 box/min*

(c) The minimum allowable time to unload a box must be consistent with the flow rate of boxes on the conveyor. Hence:

$$\boldsymbol{T_U \leq 25}$$

Continuous Loop Conveyors



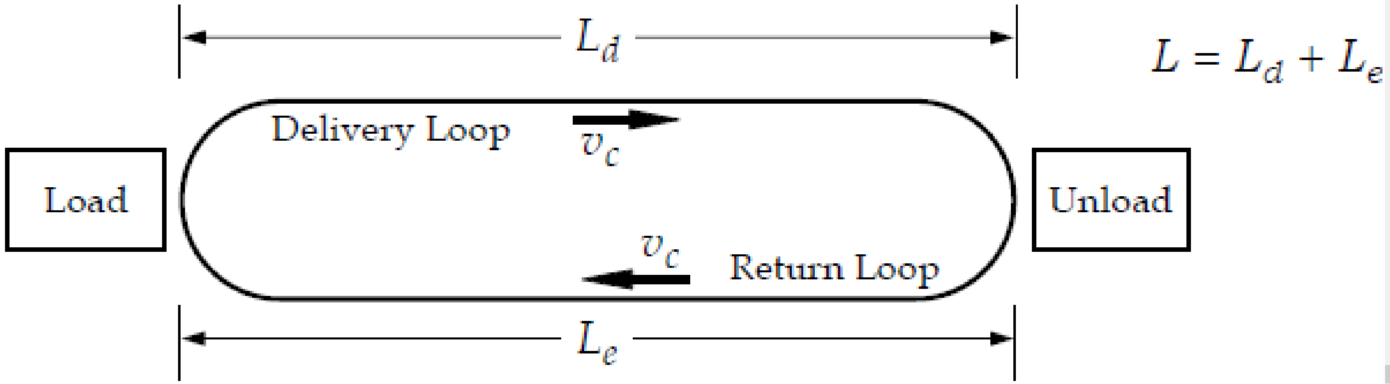
B. Continuous loop conveyors

- Form a complete circuit
- An overhead trolley conveyor is an example of this conveyor type.
- Allows materials to be moved between any two stations
- Used when loads are moved in carriers (e.g., hooks, baskets) between load and unload stations
- All carriers are emptied at the unload station.
- The empty carriers are automatically returned from the unload station back to the load station

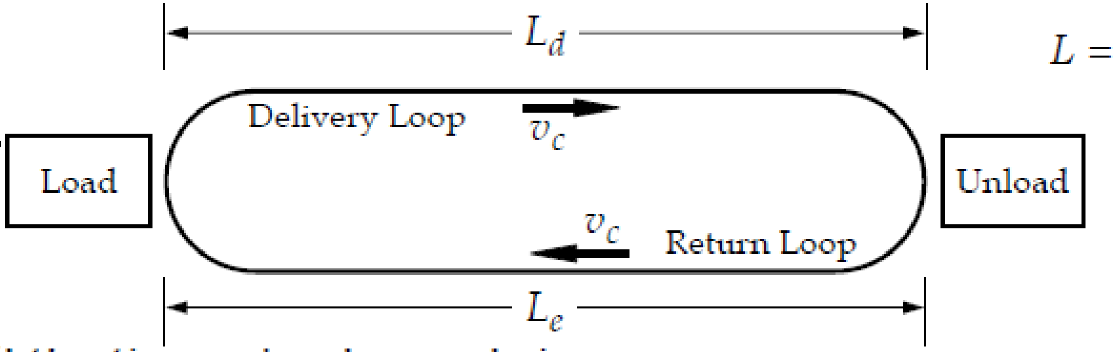
Continuous Loop Conveyors

- L_d: delivery loop length
- L_e: Return loop length
- The total length

$$L = L_d + L_e \,.$$



Continuous Loop Cor



$$L = L_d + L_e$$

The total time required to travel the whole loop and the time a load spends in the forward loop are

$$T_c = \frac{L}{v_c} \qquad T_d = \frac{L_d}{v_c}$$

where T_c = total cycle time (min)

T_d = delivery time on the forward loop (min)

Carriers are equally spaced along the chain at a distance s_c apart. Thus the tota number of carriers in the loop is given by:

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

where n_c = number of carriers

s_c = center-to-center distance between carriers (m/carrier, ft/carrier)

The number of carriers must be an integer, and so L and s_c must be consistent with that requirement.

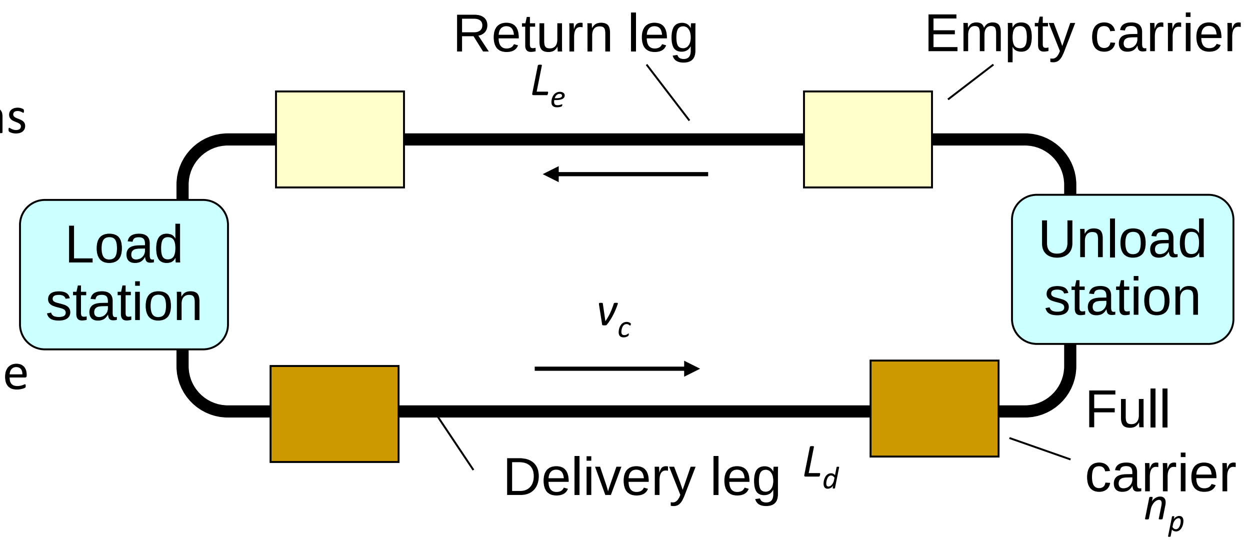
Continuous Loop Conveyors

- Each carrier
  - capable of holding n_p parts on the delivery loop
  - holds no parts on the return trip.
- Only those carriers on the forward loop contains parts,
  - Hence the maximum number of parts in the system at any time :
  - $n_p \left[n_c \left(\frac{L_d}{L} \right) \right]$
- R_f now gives the flow rate (part feed rate) between load and unload stations:

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

Continuous Loop Conveyors – Summary

Consider a continuous closed-loop conveyor, such as an overhead trolley system with one load and one unload station. Assume that all carriers are emptied at the unload station.



$$n_c = \frac{L_d + L_e}{s_c}$$

$$N_p = \frac{n_p L_d}{s_c} = \frac{n_p n_c L_d}{L_d + L_e}$$

$$R_f = \frac{n_p v_c}{s_c} \le \frac{n_p}{T_L}$$

n_c = number of carriers in the system
L_d = length of the delivery leg (ft or m)
L_e = length of the return leg (ft or m)
s_c = carriers spacing (ft or m/carrier)

N_p = total number of parts in the system
n_p = number of parts in each carrier
R_f = part feed rate (parts/min)
v_c = conveyor speed (ft/min or m/min)

Continuous Loop Conveyors – Example

- A closed loop overhead conveyor is to be designed to deliver parts from one load station to one unload station.
- Forward and return loops will be 90 m long each.
- The specified flow rate of parts 10part/min
- The Conveyor speed is 30m/min.
- The loading and unloading time is $T_L = 9+(3)(n_p)$, seconds where n_p is the number of parts per carriers.
- For n_p=2, 3, or 4; determine which of the these values are feasible and specify for each appropriate design parameters for
  - Spacing between carriers
  - Number of carriers that will achieve the flow rate

Continuous Loop Conveyors – Example

- $L_d + L_e$ = 90 + 90
- $R_f = 5 parts/min$
- $T_L = 9+(3)(n_p)$,
- $V_c = 30\ m/min$

- Two things to use:

$$\boxed{R_f = \frac{n_p v_c}{s_c} \le \frac{n_p}{T_L}} \quad \boxed{n_c = \frac{L_d + L_e}{s_c}}$$

- $(1) R_f = \frac{(n_p v_c)}{s_C}$
- $(2) T_L \le \frac{s_c}{v_C}$
- $(3) n_c s_c = L_d + L_e$

Continuous Loop Conveyors – Example

- $s_c = \frac{(n_p v_c)}{R_f} = 6\, meters\ for\ n_p = 2$
- $T_L \le \frac{s_c}{v_C} \Longrightarrow 9 + (3)(2) \le \frac{6}{30}60 \Longrightarrow not\ feasible$
- $\frac{T_L \le s_c}{v_C} = \frac{\frac{(n_p v_c)}{R_f}}{v_c} \Longrightarrow n_p \ge 3$

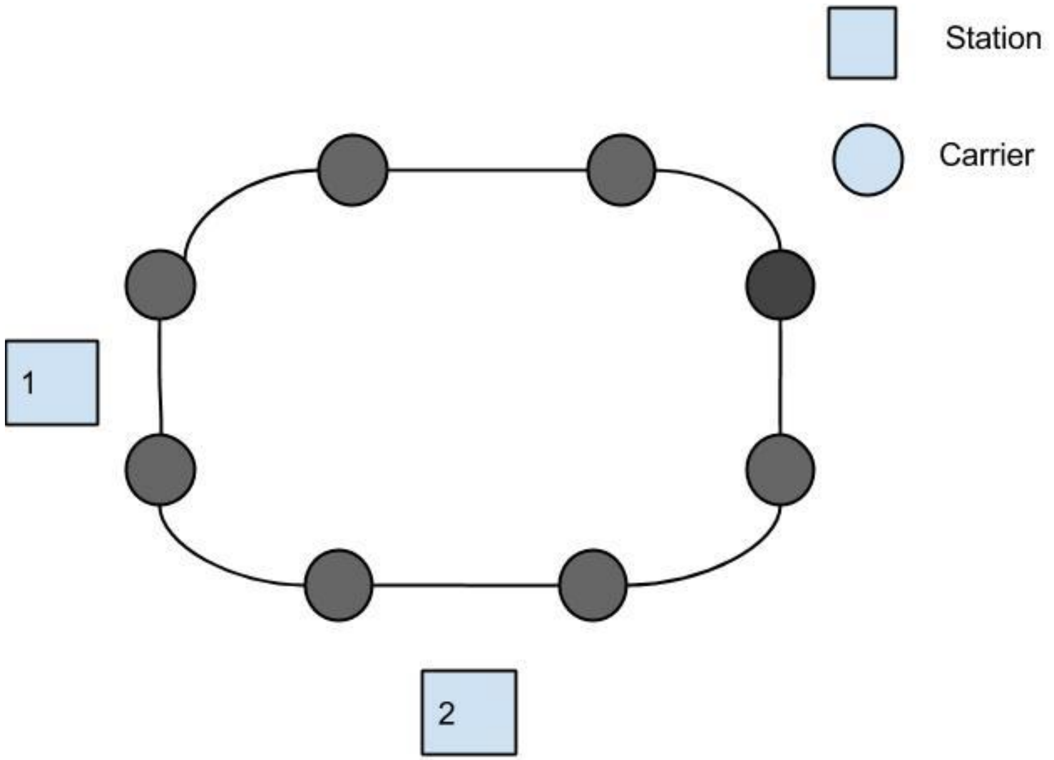
Recirculating Conveyors

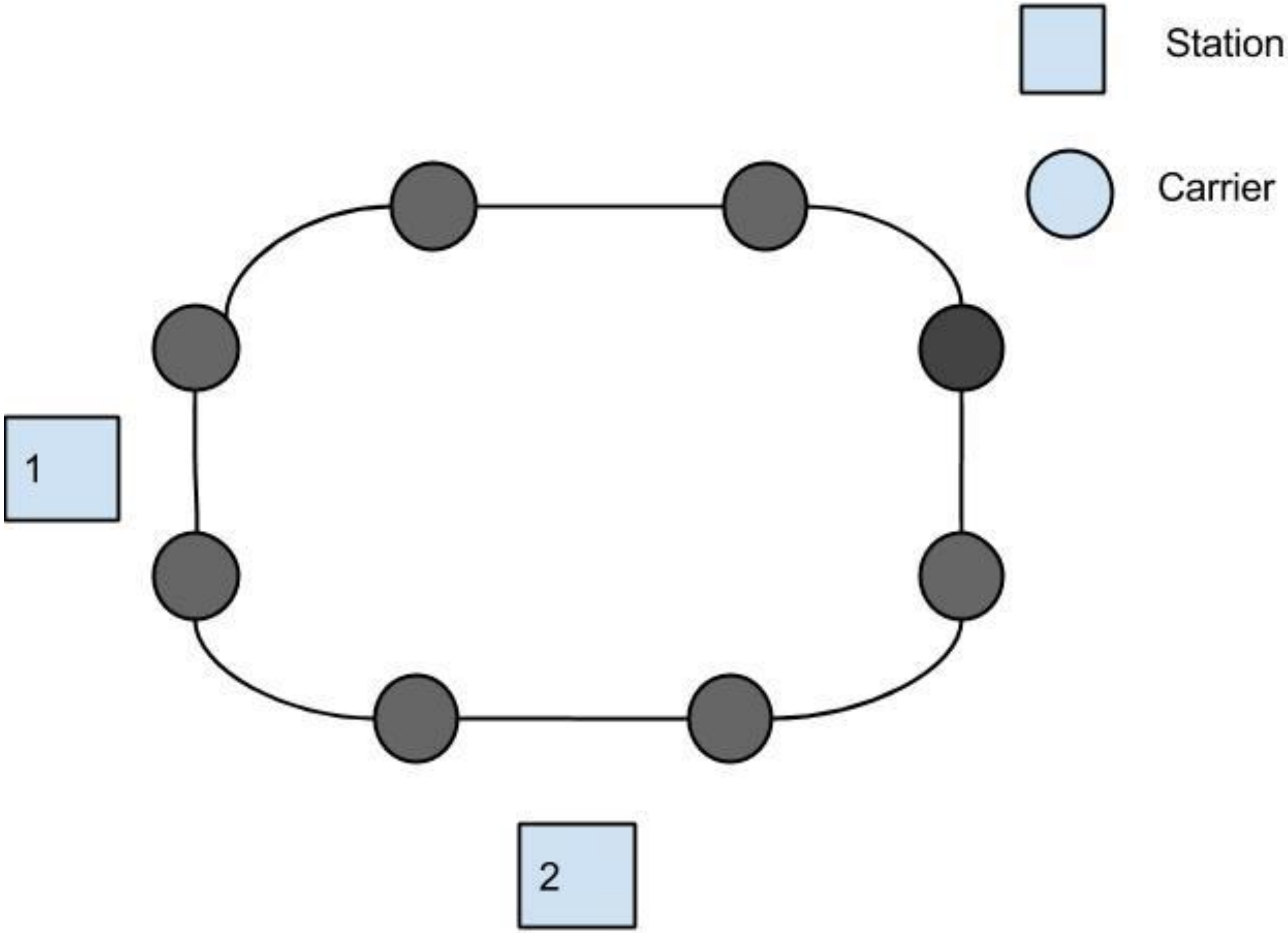
C. Recirculating Conveyors

- Continuous loop conveyors overlooks an important opportunity
  - to <u>store</u> as well as deliver parts.
- Conveyor systems that allow parts to remain on the return loop for one or more revolutions are called **recirculating conveyors**.
- In providing a storage function, the conveyor system can be used to accumulate parts to smooth out effects of loading and unloading variations at stations in the conveyor.

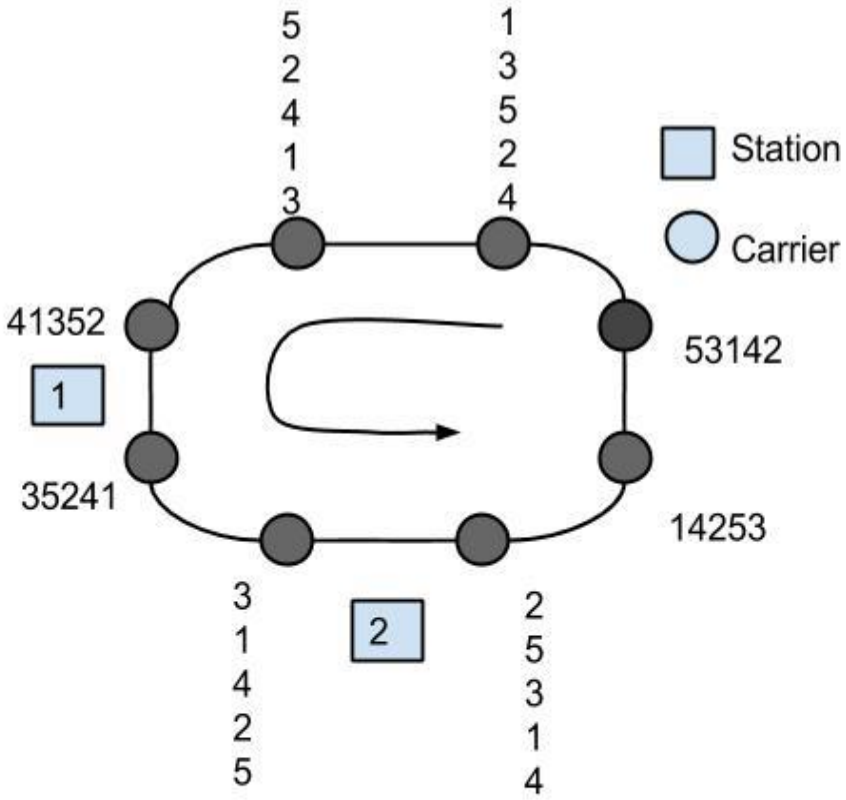
Recirculating Conveyors

- Assume closed-loop recirculating conveyors with equally spaced carriers.
- **Example:**
- Consider the conveyor system
- The load and unload **cycle length** has period 5
- The load and unload sequences for the two stations:,
- F_1 = { 2,0,2, 0, 3}
- F_2 = {-2,0,0,-1,-4}
- Determine the conveyor capacity




Station
Carrier
1
2

Recirculating Conveyors



		Loads		Cum. Loads		Adjusted Cum.L	
Round Num.	Position	St. 1	St.2	St1	St2	St1	St2
1	1	2	-2	2	0	4	2
2	4	0	-1	0	-1	2	1
3	2	0	0	-1	-1	1	1
4	5	3	-4	2	-2	4	0
5	3	2	0	0	0	2	2

F1 = { 2,0,2, 0, 3}
F2 = {-2,0,0,-1,-4}

Recirculating Conveyors

- General Model
  - **m** stations
  - **n** carriers
  - $\mathbf{f_{ij}}$ = denote the amount of material loaded onto the jth carrier as it passes station i.
  - If material is unloaded then fij<0
  - **p**: load and unload cycle period
  - $\mathbf{F_i}$ ={f_{i1}, f_{i2},…f_{ip}}
  - No need for p=n
  - Recall
    - F1 = { 2,0,2, 0, 3}
    - F2 = {-2,0,0,-1,-4}

- Material Balance Equation:
  - $\sum_{i=1}^{m}\left(f_{i1} + f_{i2} + \ \dots + f_{ip}\right) = 0$
- One round is completed when all n carriers have gone around the conveyor once.
- $\mathbf{P_{ijk}}$= denote the load and on load sequence position of a carrier j, with respect to station i in round k.
- Given $\mathbf{P_{ij1}}$one can determine P_{ijk}
- $P_{ijk} = \left[P_{ijk-1} + n \ \ mod \ \ p\right] modp$

Recirculating Conveyors – Kwo Analysis [read at home]

- There are two problems complicating analysis of the operation of a recirculating conveyor system:
  - (1) the possibility that no empty carriers are immediately available at the loading station when needed
  - (2) the possibility that no loaded carriers are immediately available at the unloading station when needed.
- According to Kwo analysis, there are three basic principles that must be obeyed in designing a conveyor system with one load station and one unload station:

Recirculating Conveyors – Kwo Analysis

Speed Rule:

Speed of the conveyor (vc) must be within a certain range.

- 1. Carrying rate capacity must be greater than loading and unloading rates

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

- 2. The speed of the conveyor must be lower than that is allowed by the loading and unloading times.

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

- T_L and T_U are the loading and unloading rates for the **carrier**

Recirculating Conveyors – Kwo Analysis

Capacity Rule

- flow rate capacity of the conveyor must be at least equal to the flow rate requirement to accommodate reserve stock and allow for the time elapsed between loading and unloading due to delivery distance.

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

- R_f must be interpreted as a system specification required for the recirculating conveyor.
- Flow rate capacity > Flow rate requirement

Recirculating Conveyors – Kwo Analysis

***Uniformity Rule*:**

- The parts should be uniformly distributed throughout the length of the conveyor so that
  - there will be no sections of the conveyor in which every carrier is full
  - while other sections are virtually empty.
- Or, empty and full carriers should be uniformly distributed along the line to avoid excessive waiting for carriers
- We should check whether
  - flow rate capacity is substantially greater than the required loading and unloading rate.
  - Loading rate = unloading rate

Recirculating Conveyors – Kwo Analysis Ex.

- **Example:** A recirculating conveyor has a length of 300m. Its speed is 60m/min, and the spacing of part carriers along its length is 12m.
- Each carrier can hold two parts.
- The task time required to load two parts into each carrier is 0.20min and the unload time is the same.
- The required loading and unloading rates are both defined by the specified flow rate, which is 4parts/min.
- Evaluate the conveyor system design with respect to Kwo's three principles.

Recirculating Conveyors – Kwo Analysis Ex.

- ***Speed Rule:***
- The *lower limit* on speed is set by the required loading and unloading
- rates, which is 4 parts/min.
- $\frac{n_p v_c}{s_c} \geq \max(R_L, R_U)$
- => $\frac{(2)(60)}{12} \geq 4 \Rightarrow 10 \geq 4$
- The *Upper limit* is set by the loading rate of the carriers.
- $\frac{v_c}{s_c} \leq \min\left(\frac{1}{T_L}, \frac{1}{T_U}\right)$
- $\frac{60}{12} \leq \min\left(\frac{1}{0.2}, \frac{1}{0.2}\right)$
- $5 \leq 5$. Hence the speed rule is satisfied.

Recirculating Conveyors – Kwo Analysis Ex.

- ***Capacity Constraint:***
- The conveyor flow rate capacity 10 parts/min.
- This is greater than the required delivery rate of 4 part/min
- Hence, the capacity constraint is satisfied.
- ***Uniformity Principle***:
- The loading and unloading rates are equal
- The flow rate capacity (10parts/min) is substantially greater than the load/unload rate (4parts/min)
- Hence uniformity rate is satisfied.