CONVEYOR ANALYSIS:

"closed-loop, irreversible, or re-circulating conveyors with discretely spaced carriers"

- Deterministic model of a towline or trolley conveyor, powered belt and roller conveyors

Kwo @ GENERAL ELECTRIC     Mayers @ WESTERN ELECTRIC
(deterministic)               (probabilistic with multi-loading stations)

.: Deterministic model of materials flow on a conveyor having one loading station and one unloading station.

Issues to be worked on:

- Input and output rates,
- Operating problems (in overhead trolley conveyors),
  - at a loading station, no empty carriers were available when a loading operation was to be performed.
  - at an unloading station, no loaded carriers were available when an unloading operation was to be performed.
- Relationships among the design parameters and operating variables
A conveyor consists of: - the conveyor equipment, - loading & unloading stations, - operating discipline.

System design parameters include:
- equipment parameters,
- working space allowances,
- number, spacing and sequencing of loading and unloading stations.

Conveyors are used not only to transport or deliver materials, but also to provide storage capacity.
- some are basically handling or transport,
- some are storage or accumulation,
- some perform both handling and storage.

The general principles in designing closed-loop, irreversible conveyors:

1. Uniformity: uniformly distributed over the conveyor,
2. Capacity: carrying capacity of the conveyor must be greater than or equal to the system throughput requirements.
3. Speed: speed must be within permissible range, defined by loading and unloading station requirements and the technological capabilities.
There are equally spaced "$k" carriers.
There are "$s" loading and/or unloading stations.

Station 1 is used as a reference point.

Carrier n becomes carrier n+k immediately after passing station 1.

\( \{t_n\} \): Sequence of points in time at which a carrier passes station 1.
\( t_n \) is the time at which carrier n passes station 1.

\( f_i(n) \): the amount of material loaded on carrier n as it passes station i, \( i = 1, \ldots, s \).
Negative values are denoting unloading.

\( h_i(n) \): the amount of material carried by carrier n immediately after passing station i.

Long-time behaviour (steady-state operations):

Total amount of material loaded on the conveyor must be equal to the total amount of material unloaded.
The sequences \( \{f_i(n)\} \) are assumed to be periodic with period "\( p \)".

\[
\{f_i(n)\} = \{f_i(n+p)\}
\]

\[
\sum_{i}^{p} \sum_{i}^{s} f_i(n) = 0 \quad \text{Additionally, } F_i(n) = \sum_{i=1}^{s} f_i(n)
\]

Results of Muth: From his descriptive model,
- \( \frac{k}{p} \) can not be integer for steady-state operation
- let \( r = k \mod p; \frac{r}{p} \) must be a proper fraction for general sequences \( \{F_i(n)\} \) to be accommodated.

- it is desirable for "\( p \)" to be a prime number, as conveyor compatibility results for all admissible values of \( k \).

The material balance equation for carrier \( n \):

\[
H_i(n) = H_i(n-r) + F_i(n)
\]

Solution approach in order to determine the values of \( H_i(n) \):

Let \( H_i^*(n) = 0 \) "in order to solve recursively"

\[
H_i^*(n) = H_i^*(n-r) + F_i(n)
\]
\[ H_{ii}^{*}(n) = H_{ii}^{*}(n) - f_{i}(n) \]

\[ C = \min_{i, n} H_{i}^{*}(n) \]

Then; \[ H_{i}(n) = H_{i}^{*}(n) - C \]

Finally; \[ B = \max_{i, n} H_{i}(n) \] "required capacity per carrier"

Example: "Deterministic Model"
- Single loading and single unloading stations;
- with equally spaced nine carriers;
- loading and unloading sequences have periods of 7 time units.

\[ \{f_{i}(n)\} = \{1, 1, 2, 2, 2, 1, 1\} \]

\[ \{f_{2}(n)\} = \{0, 0, 0, 0, 0, -5, -5\} \]

\[ \{f_{i}(n)\} = \{1, 1, 2, 2, 2, -4, -4\} \]

\[ k/p = 9/7 \text{ is not an integer, } \checkmark \]

\[ r = k \mod p \]

\[ r = 9 \mod 7 = 2 \]

\[ ?p = 2/7 \text{ is a proper fraction. } \checkmark \]

\[ p = 7 \text{ is a prime number. } \checkmark \]

Start with letting \[ H_{i}^{*}(1) = 0 \]

\[ \Rightarrow H_{i}^{*}(n) = H_{i}^{*}(n-r) + F_{i}(n) \]
\[ H_i^*(3) = H_i^*(1) + F_i(3) = 0 + 2 = 2 \]
\[ H_i^*(5) = H_i^*(3) + F_i(5) = 2 + 2 = 4 \]
\[ H_i^*(7) = H_i^*(5) + F_i(7) = 4 - 4 = 0 \]
\[ H_i^*(9) = H_i^*(2) = H_i^*(7) + F_i(2) = 0 + 1 = 1 \]
\[ H_i^*(4) = H_i^*(2) + F_i(4) = 1 + 2 = 3 \]
\[ H_i^*(6) = H_i^*(4) + F_i(6) = 3 - 4 = -1 \]

Hence, \( \{H_i^*(n)\} = \{0, 1, 2, 3, 4, -1, 0\} \)

Since, \( H_2^*(n) = H_1^*(n) - F_i(n) \)
\[ = \{0, 1, 2, 3, 4, -1, 0\} - \{1, 1, 2, 2, 2, 2, 1, 1\} \]
\[ H_2^*(n) = \{-1, 0, 0, 1, 2, -2, -1\} \]

Finding \( C = \min_{i,n} H_i^*(n) = -2 \)

As a result in order to obtain the final solution, by subtracting \( C = \)
\[ H_1(n) = \{2, 3, 4, 5, 6, 1, 2\} \]
\[ H_2(n) = \{1, 2, 2, 3, 4, 0, 1\} \]

Therefore, each carrier must have sufficient capacity to accommodate 8 units of product.
The required carrier capacity "B" is affected by the value of the number of carriers, "k".

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\( B = 9 \) \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \q
\( k = 8 \)

\( k/p = 8/4 \) not integer \checkmark

\( r = 8 \text{ mod } 7 = 1 \) \checkmark

\( \gamma_p = 1/7 \) a proper fraction \checkmark

\[
\begin{align*}
H_1^*(2) &= H_1^*(1)^2 + F_1(2) = 0 + 1 = 1 \\
H_1^*(3) &= H_1^*(2) + F_1(3) = 1 + 2 = 3 \\
H_1^*(4) &= H_1^*(3) + F_1(4) = 3 + 2 = 5 \\
H_1^*(5) &= H_1^*(4) + F_1(5) = 5 + 2 = 7 \\
H_1^*(6) &= H_1^*(5) + F_1(6) = 7 + (-4) = 3 \\
H_1^*(7) &= H_1^*(6) + F_1(7) = 3 + (-4) = -1
\end{align*}
\]

\( H_1^*(n) = \{0, 1, 3, 5, 7, 3, -1\} \)

\( H_2^*(n) = \{0, 1, 3, 5, 7, 3, -1\} - \{1, 1, 2, 2, 1, 1\} \)

\( H_2^*(n) = \{-1, 0, 1, 3, 5, 2, -2\} \)

\( c = -2 \)

\( \begin{array}{c}
H_1(n) = \{2, 3, 5, 7, 9, 5, 4\} \\
H_2(n) = \{4, 1, 2, 3, 5, 7, 4, 0\}
\end{array} \)

\( \beta = 9 \)
\[ k = 10 \quad \text{not integer} \]
\[ \ell = 10 \mod 7 = 3 \]
\[ \frac{\ell}{p} = \frac{3}{7} \text{ is a proper fraction} \]

\[ H_1^\ast(4) = H_1^\ast(1) + F_1(4) = 0 + 2 = 2 \]
\[ H_1^\ast(7) = H_1^\ast(4) + F_1(7) = 2 + (-4) = -2 \]
\[ H_1^\ast(10) = H_1^\ast(3) = H_1^\ast(4) + F_1(3) = -2 + 2 = 0 \]
\[ H_1^\ast(6) = H_1^\ast(3) + F_1(6) = 0 + (-4) = -4 \]
\[ H_1^\ast(9) = H_1^\ast(2) = H_1^\ast(6) + F_1(2) = -4 + 1 = -3 \]
\[ H_1^\ast(12) = H_1^\ast(5) = H_1^\ast(2) + F_1(5) = -3 + 2 = -1 \]

\[ H_1^\ast(n) = \{0, -3, 0, 2, -4, -4, -2\} \]
\[ H_2^\ast(n) = \{0, 3, 0, 2, -1, -4, -2\} - \{1, 1, 2, 2, 2, 1, 1\} \]
\[ H_2^\ast(n) = \{-1, -4, -2, 0, -3, -5, -3\} \quad c = -5 \]

\[ H_1(n) = \{5, 2, 5, 7, 4, 1, 3\} \]
\[ H_2(n) = \{4, 4, 3, 5, 2, 0, 2\} \quad B = 7 \]
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$B=7$  $B=6$  $B=8$
When the 15th carrier reaches station 2:
\[ f_2(15) = f_2(8) = f_2(1) = 0, \text{ since } p = 7, \]
nothing happens.
But, at station 4:
\[ f_4(15) = f_4(8) = f_4(1) = 1, \]
1 product is to be added to the carrier, and the total is raised to 2, note that, it is the steady-state value, \( H_i(1) = 2 \).

When the 24th carrier reaches station 2:
\[ f_2(24) = f_2(17) = f_2(10) = f_2(3) = 0, \text{ nothing happens.} \]
But, at station 1, \( f_1(3) = 2 \), the content of the carrier reaches 4.

When the 33rd carrier reaches station 2:
\[ f_2(33) = f_2(26) = f_2(19) = f_2(12) = f_2(5) = 0, \text{ nothing happens.} \]
But, at station 1, \( f_1(5) = 2 \), the carrier content is increased to 6 units.

42nd carrier: \( f_2(42) = f_2(7) = -5 \), the carrier content is reduced to 1 unit.
\( f_i(t) = 1, \) the content of the carrier is increased to 2 units.

- 51st carrier: \( f_2(51) = f_2(2) = 0, \) nothing happens.
  \( f_1(2) = 1, \) the content of the carrier is increased to 3 units.

- 60th carrier: \( f_2(60) = f_2(4) = 0, \) nothing happens,
  \( f_1(4) = 2, \) 2 units will be added, and the content will reach to 5 units.

- 69th carrier: \( f_2(69) = f_2(6) = -5, \) 5 units will be removed from the carrier.

So, the carrier arrives at station 4, as empty. This is the same with carrier 6, so the cycle repeats.

Content of the carrier as it left station i, followed a sequence which is a permutation of \( \{H_i(n)\}. \)

Example: A conveyor with 1 loading and 1 unloading station.

\[ \{f_i(n)\} = \{0, 0, 2, 3, 1\} \]

Assuming 7 carriers on the conveyor, solve for \( \{H_i(n)\}. \)
\[ k/p = 7/5 \text{ not integer} \checkmark \]

\[ r = 7 \mod 5 = 2 \checkmark \]

\[ 2/5 \text{ is a proper fraction} \checkmark \]

\[
\begin{align*}
H_1^*(3) &= \frac{H_1^*(1)}{p} + F_1(3) = 0 + 2 = 2 \\
H_1^*(5) &= H_1^*(3) + F_1(5) = 2 + (-3) = -1 \\
H_1^*(7) &= H_1^*(2) = H_1^*(5) + F_1(2) = -1 + 0 = -1 \\
H_1^*(9) &= H_1^*(4) = H_1^*(2) + F_1(4) = -1 + 1 = 0 \\
H_1^*(n) &= \begin{cases} 0, -1, 2, 0, -1 \\ \end{cases} \\
H_2^*(n) &= \begin{cases} 0, -1, 2, 0, -1 \\ 0, 0, 2, 3, 1 \\ \end{cases} = \begin{cases} 0, -1, 0, -3, -2 \\ \end{cases} \\
c = -3 \\
\begin{align*}
H_1(n) &= \{3, 2, 5, 3, 2\} \\
H_2(n) &= \{3, 2, 3, 0, 1\} \\
\end{align*}
\]

\[ B = 5 \quad \text{carrier capacity should be at least 5 units.} \]

Suppose, the distance from station 2 to station 1 on the conveyor is changed.
\[ \{f_1(n)\} = \{2, 3, 1, 0, 0\} \]
\[ \{f_2(n)\} = \{0, 0, 0, -2, -4\} \]

Assuming again 7 carriers solve for \( \{H_1(n)\} \).
\[ H_1^*(3) = H_1^*(1) + F_1(3) = 0 + 1 = 1 \]

where \( \{F_1(n)\} = \{2, 3, 1, -2, -4\} \)

\[ H_1^*(5) = H_1^*(3) + F_1(5) = 1 + (-4) = -3 \]

\[ H_1^*(7) = H_1^*(2) = H_1^*(5) + F_1(2) = -3 + 3 = 0 \]

\[ H_1^*(9) = H_1^*(4) = H_1^*(2) + F_1(4) = 0 + (-2) = -2 \]

\[ H_1(n) = \{0, 0, 1, -2, -3\} \]

\[ H_2(n) = \{0, 0, 1, -2, -3\} - \{2, 3, 1, 0, 0\} = \{-2, -3, 0, -2, -3\} \]

\[ C = -3 \]

\[ H_1(n) = \{3, 3, 4, 1, 0\} \]

\[ H_2(n) = \{-1, 0, 3, 1, 0\} \]

\[ B = 4 \]

"minimum carrier capacity is decreased by 1 units."

Example: A closed loop, irreversible conveyor with discretely spaced carriers to serve for three workstations.

\[ f_1(n) = (4, 4, 0) \quad k = 16 \]

\[ f_2(n) = (-3, -1, 0) \quad r = 1 \]

\[ f_3(n) = (0, -2, -2) \]

\[ F(n) = (4, 1, 2) \]
\[ H^*_i(2) = H^*_i(1) + F_i(2) = 1 \]
\[ H^*_i(3) = H^*_i(2) + F_i(3) = 1 + (-2) = -1 \]
\[ H^*_i(n) = (0, 1, -1) \]
\[ H^*_2(n) = (0, 1, -1) - (4, 4, 0) = (-4, -3, -1) \]
\[ H^*_3(n) = (-4, -3, -1) - (-3, -1, 0) = (-1, -2, -1) \]
\[ C = -4 \]
\[ H_1(n) = (4, 5, 3) \]
\[ H_2(n) = (0, 1, 3) \]
\[ H_3(n) = (3, 2, 3) \]
\[ \boxed{B = \begin{array}{c}
4 & \end{array} } \]

If workstations will be re-located as:

\[ f_1(n) = (0, -2, -2) \]
\[ f_2(n) = (4, 4, 0) \]
\[ f_3(n) = (-3, -1, 0) \]
\[ F_i(n) = (1, 1, -2) \]

\[ H^*_i(2) = H^*_i(1) + F_i(2) = 1 \]
\[ H^*_i(3) = H^*_i(2) + F_i(3) = 1 + (-2) = -1 \]
\[ H^*_i(n) = (0, 1, -1) \]
\[ H^*_2(n) = (0, 1, -1) - (0, -2, -2) = (0, 3, 1) \]
\[ H^*_3(n) = (0, 3, 1) - (4, 4, 0) = (-4, -1, 1) \]
\[ C = -4 \]
\[ H_1(n) = (4, 5, 3) \]
\[ H_2(n) = (4, 7, 5) \]
\[ H_3(n) = (0, 3, 5) \]
\[ \boxed{B = \begin{array}{c}
7 & \end{array} } \]

The locations of workstations affect the analysis of the closed-loop, recirculating conveyor, by changing \( H_i(n) \).
Alternative locations of workstations,

+ Alternative conveyor lengths, measured by # of carriers,

+ Economic performance and the cost model,

⇒ OPTIMUM CONVEYOR DESIGN!!!

HORSEPOWER CALCULATIONS IN CONVEYOR DESIGN:

The horsepower requirement depends on the conveyor speed, and the weight of the conveyor and the material it transports.

An approximate model for powered belt and roller conveyors. Our purpose is not to be an expert in determining horsepower requirements. But, being aware of which components affect the requirements.

\[
HP = \text{horsepower requirement (hp)}
\]

\[
S = \text{speed of the conveyor (fpm, feet per minute)}
\]

\[
L = \text{load to be carried (lb, pounds)}
\]

\[
TL = \text{total length of the conveyor (feet)}
\]

\[
RC = \text{spacing between centers of rollers (inch)}
\]
\( WBR = \) width between rails (inch)

(it should be at least 2.5" longer than the width of the load being transported.)

\( \alpha = \) angle of incline, \( (^\circ, \text{ degree}) \)

\( LL_1 = \) live load on incline (lb, pounds)

\( BV = \) base value \( \quad BV = \frac{2}{3} \times WBR \)

\( FF = \) friction factor \( \quad FF = 0.05 \) (for roller-supported)

\( = 0.30 \) (for sliderbed supported)

\( LF = \) length factor

(tabulated LF value for belt conveyors, based on given RC & WBR values.)

For belt conveyors:

\[
HP = \left[ BV + LF(TL) + FF(L) + LL_1(Sin\alpha) \right] \cdot S
\]

\[
14,000
\]

Example = 100 ft long roller-supported belt conveyor,

- angle of 10° (for a maximum of 35° incline),
- with a 6 inches spacing,
- WBR of 27 inches,
• Each totebox is 18 inches and weighing 3500 (loaded)
(for stability, at least two rollers be under
the load, a spacing of 12 inches to be
provided between toteboxes.)
• Conveyor speed is to be 90 ft/min,
• Load segment is 30 inches, exactly 40 load
segments will be on the 100 ft-long conveyor,
• Weight of the load will be 40,35 = 1400 lb

\[ S = 90 \text{ fpm} \]
\[ RC = 6'' \]
\[ WBR = 27'' \]
\[ BV = \frac{2}{3} \times 27 = 18'' \]
\[ LF = 0.61 \]
\[ TL = 100' \]
\[ FR = 0.05 \]
\[ L = LL_1 = 1400 \text{ lb} \]
\[ \alpha = 10^\circ \]
\[ HP = \left[ \frac{18 + 0.61(100) + 0.05(1400) + 1400 (0.1737)}{14,000} \right] \times 90 \]
\[ HP = 2.52 \text{ hp} \]
\[ \therefore 2.75 \text{ or } 3.00 \text{ hp should meet the demands placed on the belt conveyor.} \]
What if spacing between toteboxes had been 8 inches, rather than 12 inches.

\[
\frac{100 \times 12}{26} = 46.15 \text{ (46 complete load segments + a partial load segment)}
\]

\[
46 \times 26 = 1196'' \Rightarrow 46 \text{ full toteboxes and a } 4' \text{ of a partial totebox.}
\]

\[
\frac{4}{18} \times 35 = 7.7866
\]

Maximum load \[
46 \times 35 + 7.78 = 1617.78 \text{ lb.}
\]

\[
\text{HP} = \frac{[18 + 0.61(100) + 0.05(1617.78) + 1.617.78 \times (0.1737)] \times 80}{14000}
\]

\[
\text{HP} = 2.83 \text{ hp}
\]

Suppose it is desired to elevate 17.36'.

Alternatives: 10°  20°  30°

Conveyor lengths: 100 ft  51 ft  35 ft

HP requirements: 2.52 hp  ?hp  ?hp

\[
\alpha = 20°, \; TL = 51 \text{ ft}, \; 20 \text{ complete load segments + 12 inches}
\]

Thus: \[
20(\alpha) + \left(\frac{12}{18}\right) \times 35 = 723.33 \text{ lb}
\]
\[
HP = \left[ 18 + 0.61(35) + 0.05(223.33) + 223.33 (\sin 20^\circ) \right] \times 90
\]
\[
14,000
\]
\[
245.35
\]

\[
HP = 2.14 \text{ hp}
\]

\[\Rightarrow \alpha = 30^\circ, \; TL = 35 \text{ ft}, \; 14 \text{ complete load segments}\]

Thus, \[L = LL + 14 \cdot 35 = 480 \text{ lb}\]

\[
HP = \left[ 18 + 0.61(35) + 0.05(430) + 430 (\sin 30^\circ) \right] \times 90
\]
\[
14,000
\]
\[
245.35
\]

\[
= 1.99 \text{ hp}
\]

\[\therefore \text{ The steepest feasible angle of incline would be preferred since it requires a smaller horsepowe motor and a shorter conveyor.}\]

\[\text{Suppose 100 ft horizontal distance, if 2.5 hp motor is available and must be used, what could be the maximum weight per totebox?}\]

\[S = 90 \text{ fpm} \quad TL = 100'\]

\[RC = 6'' \quad FF = 0.04\]

\[WBR = 27'' \quad \alpha = 0^\circ\]

\[BV = \frac{(2)}{3} 27 = 18''\]

\[LF = 0.61 \quad HP = \left[ 18 + 0.61(100) + 0.05 L \right] \times 80
\]
\[
14,000
\]
\[
2.5
\]
\( L = \left[ \frac{2.5 \times 14,000}{80} - 18 - 0.641(100) \right]^\frac{1}{0.05} = \frac{6.197.78 \text{ lb}}{40} = 154.84 \text{ lb} \)

Since there will be 40 toteboxes, the maximum weight per totebox is

For roller conveyors:

\[ FF = 0.10 \quad \text{a flat belt} \]

\[ = 0.085 \quad \text{zero pressure accumulating belt} \]

\[ = 0.075 \quad \text{V-belt} \]

\[ = 0.05 \quad \text{chain driven rollers} \]

\[ BV = 4.60 + 0.445(WBR) \]

Tabulated LF values for various RC and WBR values.

For an 18 inches long load, the largest roller spacing is 6 inches.

Example: \( S = 90 \text{fpm}, \; RC = 6 \text{ inches}, \; WBR = 27 \text{ inches} \)

\[ BV = 4.60 + 0.445(27) = 16.62", \; LF = 1.0 \]

\[ TL = 100 \text{ft}, \; FF = 0.10, \; L = 1400 \text{ lb}. \]

(Note that, \( L = 0 \text{ lb}, \; \text{since } \alpha = 0^\circ \))

\[ HP = \frac{[16.62 + 1.0(100) + 0.1(1400)]^\frac{1}{0.05}}{14,000} = \frac{1,645.7 \text{ hp}}{14,000} \]

\( \therefore 1.75 \text{ or } 2.00 \text{ hp is an appropriate motor selection.} \)
If the motor is 2.5 hp, then what should be the maximum weight of the totebox?

\[ HP = \left[ \frac{16.62 + 1.0 \times 100 + 0.10 \times L}{90} \right] \times 90 = 2.5 \text{ hp} \]

\[ L = \left[ \frac{2.5 \times 14000}{90} - 16.62 - 100 \right] \times \frac{1}{0.10} = 2722.69 \text{ lb} \]

Maximum weight per totebox = \[ \frac{2722.69}{40} = 68.07 \text{ lb} \]

Example:

First Conveyor

Second Conveyor

18 inches toteboxes move with 90 fpm with a clearance of 12 inches.

\[ 90 \text{ fpm} \times \left( \frac{12 \text{ in}}{1 \text{ ft}} \right) \div \left( 30 \text{ in/totebox} \right) = 36 \text{ toteboxes/min} \]

This is the rate entering to the second conveyor.

Spacing in the second conveyor = \[ \left( 150 \text{ ft/min} \right) \left( \frac{12 \text{ in}}{1 \text{ ft}} \right) \div \left( 36 \text{ toteboxes/min} \right) \]

= 50 inches/totebox

Since, toteboxes are 18 inches, the clearance will be 32 inches in the second conveyor.

Increase in speed is not linear with the increase in spacing.

\[ \frac{100 \times 12}{50} = 24 \text{ complete load segments will be in the second conveyor} \]
\[
S = 150 \text{ fpm}, \quad RC = 6 \text{ inches}, \quad WBR = 27 \text{ inches}
\]
\[
BV = 16.62 \text{ inches}, \quad LF = 1.0, \quad TL = 100 \text{ ft}, \quad FF = 0.10
\]
\[
L = 24 \times 35 = 840 \text{ lb}
\]
\[
HP = \left[ \frac{16.62 + 1.0(100) + 0.10(840)}{14.000} \right] \times 150 = 2.1485 \text{ hp}
\]
\[
\star \quad \begin{array}{cc}
\frac{90 \text{ fpm}}{100 \text{ ft}} & \frac{150 \text{ fpm}}{100 \text{ ft}} \\
1.65 \text{ hp} & 2.15 \text{ hp} \\
\end{array}
\]
\[
\frac{120 \text{ fpm}}{200 \text{ ft}} = \frac{? \text{ hp}}{36 \text{ loadboxes/\text{min}}}
\]

Length of one load segment is 40 inches, 60 complete load segments.

\[
S = 120 \text{ fpm}, \quad RC = 6 \text{ inches}, \quad WBR = 27 \text{ inches}
\]
\[
BV = 16.62 \text{ inches}, \quad LF = 1.0, \quad TL = 200 \text{ ft}, \quad FF = 0.10
\]
\[
L = 60 \times 35 = 2100 \text{ lb}
\]
\[
HP = \left[ \frac{16.62 + 1.0(200) + 0.10(2100)}{14.000} \right] \times 120 = 3.66 \text{ hp}
\]

\[\therefore\text{ Alternatives could be compared and cost optimization could be possible.}\]