

### HOW TO USE THIS GUIDE

This document is a companion to the Product Spec Calc (r4.0). It does not replace the calculator. Open the calc and this guide side by side. For each calculation the calc performs, this guide explains what the formula is doing, why each input matters, what the output is telling you, and what to do when a check fails.

**A student who understands why the formula works will catch a bad input. A student who just uses the calculator without that understanding will not.**

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## SECTION 1 | PACKAGE AND CONVEYOR BASICS

Inputs & Outputs tab — rows 1 through 33

These calculations characterize the product mix and establish the operating parameters every downstream calculation depends on. Complete this section before touching the sorter or transfer tabs.

### Weight per Foot | INPUTS & OUTPUTS — Column G

#### FORMULA

$$WT / (L / 12)$$

Divide carton weight in pounds by carton length in feet. Converts length to feet before dividing.

Variable	What it is	Why it matters
WT	Carton weight (lbs)	Heavier cartons load belts and rollers differently. Used to check roller capacity and incline belt sizing.
L	Carton length (in)	Dividing by 12 converts inches to feet so the result is lbs per running foot of conveyor.

#### RIVERSIDE WORKED EXAMPLE

Max carton: 20 in long, 50 lbs.  $WT/FT = 50 / (20/12) = 50 / 1.667 = 30$  lbs/ft. This value feeds roller capacity checks and incline belt calculations.

**Note** This is a per-carton output. The worst case is the heaviest carton at the shortest length. Check the WT/FT column for that combination, not the average.

### Minimum Curve Between-Frame Width | INPUTS & OUTPUTS — Column H

#### FORMULA

$$SQRT((IR + W)^2 + (L/2)^2) - (IR - 2)$$

Pythagoras applied to the worst-case carton position in a curve. The carton corner must clear the outside rail.

Variable	What it is	Why it matters
IR	Inside curve radius (in)	Set in the global inputs. From the manufacturer catalog. A tighter radius demands a wider between-frame.
W	Carton width (in)	The widest carton in the mix is binding. A wide carton swings further outward in the curve.
L	Carton length (in)	A longer carton pivots further. L/2 is the distance from the carton center to the leading or trailing corner.

#### RIVERSIDE WORKED EXAMPLE

IR = 34.5 in, Max W = 15 in, Max L = 20 in.  $Min\ Curve\ BF = SQRT((34.5+15)^2 + (20/2)^2) - (34.5-2) = SQRT(2450.25 + 100) - 32.5 = 50.5 - 32.5 = 18$  in. Round UP to the next catalog BF. Never round down.

**Note** Run this calculation against every carton in the mix. The largest result sets the required curve BF. One outlier carton can force a significantly wider curve.

### Tumble Angle | INPUTS & OUTPUTS — Column I

#### FORMULA

$$ATAN(L / (3 \times H)) \times 180 / PI$$

The maximum incline angle before the carton tips forward. The carton is modeled as tipping when its center of gravity passes its front bottom edge.

Variable	What it is	Why it matters
L	Carton length (in)	A longer carton tips more easily. Longer relative to height means the center of gravity is farther forward.
H	Carton height (in)	A taller carton tips at a shallower angle. The critical dimension is the L to H ratio.

#### RIVERSIDE WORKED EXAMPLE

Min carton: L=9 in, H=3 in. Tumble Angle =  $\text{ATAN}(9 / (3 \times 3)) \times 180/\text{PI} = \text{ATAN}(1.0) \times 57.3 = 45$  degrees. This is the theoretical limit. Design inclines to the minimum tumble angle in the mix with a safety margin. Riverside uses 30 degrees maximum incline based on the worst case carton.

#### PASS

Your incline angle is below the minimum tumble angle in the mix. All cartons will remain upright.

#### IF IT FAILS

Your incline angle exceeds the minimum tumble angle. The worst case carton will tip. Reduce the incline, reduce the conveyor speed on the incline, or remove the outlier carton from the mix and handle it separately.

**Note** The calc shows MIN tumble angle in cell C26 — this is the worst case carton. Design all inclines against this number, not the average.

## Gap Produced | INPUTS & OUTPUTS — row 31

#### FORMULA

**SpeedOut x (L / SpeedIn) - L + StartingGap**

The gap between cartons after a speed change. When cartons accelerate, the gap grows. When they decelerate, it shrinks.

Variable	What it is	Why it matters
SpeedIn	Inbound belt speed (FPM)	The speed the carton is traveling before the transition.
SpeedOut	Outbound belt speed (FPM)	The speed the carton is traveling after the transition.
L	Carton length (in)	The formula calculates gap change per carton length. Longer cartons amplify the speed change effect.
StartingGap	Gap before speed change (in)	The gap you enter at the start of the system. The calculation builds on this starting condition.

#### RIVERSIDE WORKED EXAMPLE

SpeedIn=60, SpeedOut=120, L=20 in, StartingGap=24 in. Gap =  $120 \times (20/60) - 20 + 24 = 40 - 20 + 24 = 44$  in. The gap grew from 24 to 44 inches when speed doubled. This output feeds the sorter induction gap input.

**Note** Run this for Min, Max, and Avg carton length. The Min carton produces the smallest gap at SpeedOut and is the binding case for gap checks downstream.

## Theoretical Rate | INPUTS & OUTPUTS — row 32

#### FORMULA

**SpeedIn / ((L + StartingGap) / 12)**

The maximum cartons per minute achievable at a given speed and gap. Dividing by 12 converts the pitch from inches to feet to match the speed in feet per minute.

Variable	What it is	Why it matters
SpeedIn	Belt speed (FPM)	Higher speed at the same pitch produces more CPM.
L	Carton length (in)	Longer cartons take up more of the belt at any given speed, reducing CPM.
StartingGap	Gap between cartons (in)	The pitch is L plus the gap. A larger gap reduces CPM.

### RIVERSIDE WORKED EXAMPLE

SpeedIn=60 FPM, L=20 in (max), StartingGap=24 in. Rate =  $60 / ((20+24)/12) = 60 / 3.667 = 16.4$  CPM. This is the design rate for the system — based on the max carton length. The min carton gives a higher theoretical rate but you design to the worst case.

### PASS

Theoretical rate equals or exceeds required rate. The system can achieve the throughput at the specified speed and gap.

### IF IT FAILS

Theoretical rate is below required rate. You must increase belt speed, reduce carton gap, or confirm whether the required rate is achievable with this product mix.

## Pitch | INPUTS & OUTPUTS — row 33

### FORMULA

**Gap + L**

Center to center distance between cartons. The simplest calculation in the sheet. Everything else derives from this.

Variable	What it is	Why it matters
Gap	Gap between cartons (in)	The space between the trailing edge of one carton and the leading edge of the next.
L	Carton length (in)	The length of the carton itself.

### RIVERSIDE WORKED EXAMPLE

Gap=44 in, L=20 in. Pitch = 64 in. Every 64 inches of belt carries one carton. At 120 FPM that is  $120/64 \times 12 = 22.5$  CPM. Use pitch to sanity check your rate calculations.

**Note** Pitch is used internally in other calculations. If it looks wrong, go back and check Gap Produced first.

## SECTION 2 | SKEW AND LOOKUP UTILITY

Inputs & Outputs tab — rows 35 through 40

### Skew Conveyor Required Length | INPUTS & OUTPUTS — row 36

#### FORMULA

$$((BF - MinW) \times BF / RollerCenters + MaxL) / 12$$

The minimum length of skewed roller conveyor needed to fully align the narrowest carton across the full belt width, while containing the longest carton during the traverse.

Variable	What it is	Why it matters
BF	Between-frame width (in)	The full width the carton must travel across. A wider BF requires a longer skew section.
MinW	Minimum carton width (in)	The narrowest carton takes the longest path across the BF. It is the binding case.
RollerCenters	Roller spacing (in)	Closer roller centers allow sharper skew angle with less length. Standard is 3 inches.
MaxL	Maximum carton length (in)	The longest carton must be fully on the skew section before the narrowest carton completes its traverse.

#### RIVERSIDE WORKED EXAMPLE

BF=21 in, MinW=6 in, RollerCenters=3 in, MaxL=20 in. Length =  $((21-6) \times 21/3 + 20) / 12 = (15 \times 7 + 20) / 12 = 125/12 = 10.4$  ft. Round up to next standard conveyor length.

**Note** This is a minimum. Add length for connection to adjacent sections. If your carton mix has extreme variation in width, run the calc for both the narrowest and the widest carton and use the larger result.

### Lookup Time / Time Between Points | INPUTS & OUTPUTS — row 40 | Sorter tab — row 27 | Transfer tab — row 23

#### FORMULA

$$(Distance / 12) / (Speed / 60)$$

How many seconds it takes a carton to travel a given distance at a given speed. Converts distance from inches to feet and speed from FPM to feet per second.

Variable	What it is	Why it matters
Distance	Distance between two points (in)	The physical distance you are calculating travel time for. Measure from the layout.
Speed	Belt speed (FPM)	The speed of the belt carrying the carton between those two points.

#### RIVERSIDE WORKED EXAMPLE

Scan point to sorter divert: Distance=120 in, Speed=120 FPM. Time =  $(120/12) / (120/60) = 10 / 2 = 5.0$  seconds. The WMS has 5 seconds to respond with a sort destination after the scan fires. If confirmed WMS latency is 3 seconds, there is 2 seconds of margin. If latency is 6 seconds, the layout must change.

**Note** This calculation is the physical basis for the scan-to-divert distance check. If you change belt speed anywhere between the scan point and the sorter, you must recalculate. Do not estimate travel time from memory.

## SECTION 3 | SORTER CALCULATIONS

Sorter tab — rows 4 through 27

The sorter section is the most complex in the calculator and the most consequential in a proposal. These calculations run in sequence. Each one feeds the next. A bad input in CFPM produces a wrong Required Sorter Speed, which produces a wrong Gap Produced, which produces a wrong Pass/Fail check. Work through them in order.

### Michael Collins

The sorter calculations exist to answer one question: can this sorter run this product mix at this rate without a gap failure? If the answer is no, you have three levers — rate, speed, or sorter model. Know which one you are pulling before you go back to the customer.

## CFPM — Minimum Conveyor Speed | Sorter tab — row 12

### FORMULA

$$(\text{AvgLength} \times \text{Rate CPM} / 12) \times \text{Safety Factor}$$

The minimum belt speed needed to physically move enough cartons per minute to meet the required rate. Uses average carton length and applies a 1.15 safety factor.

Variable	What it is	Why it matters
AvgLength	Average carton length (in)	CFPM is calculated for min, max, and avg carton. The MAX carton column gives the design speed.
Rate CPM	Required throughput (cartons per minute)	The customer throughput requirement. This drives everything. Confirm it in writing.
Safety Factor	1.15 standard per Hytrol spec	Adds 15% headroom above the theoretical minimum. Accounts for real-world variance in gap and product presentation.

### RIVERSIDE WORKED EXAMPLE

Required Rate = 20 CPM, Max carton L=20 in, Safety Factor=1.15.  $CFPM = (20 \times 20 / 12) \times 1.15 = 33.3 \times 1.15 = 38.3$  FPM. This is the minimum conveyor speed at the sorter induction point to achieve 20 CPM with the largest carton.

**Note** CFPM is the minimum. The required sorter speed will be higher once SGR is applied. Never use CFPM as the sorter run speed.

## SGR — Speed Gap Ratio | Sorter tab — row 13

### FORMULA

$$(\text{L} + \text{GapAtInduct}) / \text{L}$$

The ratio of pitch to carton length. Tells you how much faster the sorter must run relative to the induction belt to maintain the gap that already exists.

Variable	What it is	Why it matters
L	Carton length (in)	The carton length sets the base. SGR is calculated for min, max, and avg.
GapAtInduct	Gap at sorter induction point (in)	The gap produced by the upstream system arriving at the sorter. Defaults from the Gap Produced calculation. The MIN carton produces the smallest gap and the highest SGR — that is the binding case.

### RIVERSIDE WORKED EXAMPLE

Gap at induct = 44 in, Min L = 9 in.  $SGR = (9+44)/9 = 5.89$ . The sorter must run nearly 6x faster than the induction belt for the min carton. This is why min carton gap is the binding constraint, not max carton.

**Note** Check SGR for the MIN carton column. A small carton with a large gap produces a very high SGR and a very high required sorter speed. If that speed is unrealistic, the gap at induction needs to be reduced.

## Required Sorter Speed | Sorter tab — row 14

### FORMULA

$SGR \times CFPM$

The actual operating speed the sorter must run. Multiplies the minimum conveyor speed by the speed gap ratio. Use the MAX column as your design speed.

Variable	What it is	Why it matters
SGR	Speed gap ratio	Accounts for the gap that must be maintained through the sorter.
CFPM	Minimum conveyor speed (FPM)	The base speed before gap adjustment.

### RIVERSIDE WORKED EXAMPLE

$SGR (\text{max pkg}) = 3.2$ ,  $CFPM (\text{max pkg}) = 38.3 \text{ FPM}$ . Required Speed =  $3.2 \times 38.3 = 122.6 \text{ FPM}$ . Round up to the next practical belt speed. This is your sorter run speed.

**Note** Use the MAX carton column for sorter run speed. The MAX carton produces the highest CFPM. The MIN carton produces the highest SGR. The combination that produces the highest Required Speed governs — check all three columns.

## Gap Produced at Sorter Speed | Sorter tab — row 15

### FORMULA

$(\text{SorterSpeed} \times 12 / \text{Rate}) - L$

The actual gap between cartons at the confirmed sorter operating speed. This is the gap available for the sorter to physically divert each carton.

Variable	What it is	Why it matters
SorterSpeed	Required sorter speed (FPM)	From row 14. Higher sorter speed produces a larger gap.
Rate	Required throughput (CPM)	Higher rate reduces the gap at any given speed.
L	Carton length (in)	Subtracted because the gap is the space between cartons, not the pitch.

### RIVERSIDE WORKED EXAMPLE

$\text{SorterSpeed} = 125 \text{ FPM}$ ,  $\text{Rate} = 20 \text{ CPM}$ ,  $\text{MaxL} = 20 \text{ in}$ . Gap =  $(125 \times 12 / 20) - 20 = 75 - 20 = 55 \text{ in}$ . This 55 inch gap must be compared against both the model minimum gap and the geometric gap requirement.

## Sorter Model Minimum Gap | Sorter tab — row 16

### FORMULA

Width-based per Hytrol spec card

The minimum physical gap the selected sorter model requires to complete a divert without the trailing carton entering the divert zone before the leading carton has cleared it. Driven by max carton width.

Variable	What it is	Why it matters
Model	Sorter model selected (dropdown)	Different models have different physical divert mechanisms with different gap requirements.

<b>MaxW</b>	Maximum carton width (in)	Wider cartons require more gap. The model minimum gap is a step function of width per the Hytrol spec card.
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**RIVERSIDE WORKED EXAMPLE**

ProSort 121, MaxW=15 in. Model Min Gap = 9 in (per Hytrol spec: width 8-15 in requires 9 in minimum). The gap produced at sorter speed must equal or exceed this number.

**PASS**

Gap produced at sorter speed is equal to or greater than the model minimum gap. The sorter can complete the divert before the next carton arrives.

**IF IT FAILS**

Gap produced is less than model minimum. Options: increase sorter speed, reduce required rate, select a model with a lower gap requirement, or increase gap at induction by adjusting upstream belt speeds.

**Gap Required by Geometry | Sorter tab — row 17**

**FORMULA**

$$(\text{MaxWidth} \times \text{SIN}(\text{divert angle})) + 2$$

The minimum gap the carton geometry requires for the widest carton to clear the divert without hitting the next carton. Two inches of safety margin is added.

Variable	What it is	Why it matters
<b>MaxWidth</b>	Widest carton in the mix (in)	The widest carton swings the furthest into the gap as it diverts. It is always the binding case.
<b>divert angle</b>	Sorter divert angle (degrees)	A steeper angle requires less gap. A shallower angle requires more. 30 degrees is standard.

**RIVERSIDE WORKED EXAMPLE**

MaxW=15 in, divert angle=30 degrees. Gap = (15 x SIN(30)) + 2 = (15 x 0.5) + 2 = 7.5 + 2 = 9.5 in. The gap produced must also meet or exceed this number.

**PASS**

Gap produced meets the geometric requirement. No carton-to-carton interference at the divert point.

**IF IT FAILS**

Geometric gap requirement not met. The widest carton will collide with the next carton during divert. Increase gap, reduce divert angle, or limit max carton width entering the sorter.

**Takeaway Spur Speed | Sorter tab — row 18**

**FORMULA**

$$\text{SorterSpeed} / \text{COS}(\text{divert angle})$$

The required belt speed of the takeaway spur conveyor. Because the carton exits the sorter at an angle, the spur must run faster than the sorter to maintain the carton's velocity component in the direction of travel.

Variable	What it is	Why it matters
<b>SorterSpeed</b>	Sorter operating speed (FPM)	The speed the carton is traveling when it enters the spur.
<b>divert angle</b>	Sorter divert angle (degrees)	A shallower angle (30 degrees) requires the spur to run significantly faster than the sorter. A steeper angle requires less speed increase.

**RIVERSIDE WORKED EXAMPLE**

SorterSpeed=125 FPM, divert angle=30 degrees. Spur Speed = 125 / COS(30) = 125 / 0.866 = 144.3 FPM. Round up to the next practical belt speed. This is the takeaway spur specification — not the sorter speed.

**Note** A common mistake is specifying the takeaway spur at sorter speed. That is always wrong. The spur must run faster. At 30 degrees the spur runs approximately 15% faster than the sorter. At 22 degrees it runs approximately 8% faster.



## SECTION 4 | 90 DEGREE TRANSFER CALCULATIONS

Transfer tab — rows 4 through 19

The 90 degree transfer calculations are new content not yet covered in the training modules. A transfer lifts a carton off the trunk line, moves it laterally to an adjacent conveyor, and lowers it. During this cycle the trunk line is still running. The calculation confirms whether the gap on the trunk line is large enough to complete the full cycle before the next carton arrives.

### Michael Collins

Every 90 degree transfer in a system is a potential collision point. The calculation tells you the minimum gap required. If the gap on the trunk line does not meet that minimum, you have a carton collision on every transfer cycle. I have seen this missed in proposals more than once. Run this calculation for every transfer in the system.

## Lateral Travel Distance | Transfer tab — row 14

### FORMULA

$$BF + ((OAW - BF) / 2)$$

The distance the transfer mechanism must move the carton sideways. Assumes worst-case carton position on the side opposite the divert direction.

Variable	What it is	Why it matters
BF	Between-frame width (in)	The conveyor width. The carton must clear the full BF before it is on the receiving conveyor.
OAW	Overall width of conveyor (in)	Includes the side frames. The difference between OAW and BF is the frame width. Half of that is added as worst-case carton offset.

### RIVERSIDE WORKED EXAMPLE

BF=21 in, OAW=24 in. Lateral Distance =  $21 + ((24-21)/2) = 21 + 1.5 = 22.5$  in. The transfer must move the carton 22.5 inches before the cycle is complete.

## Transfer Cycle Time | Transfer tab — row 15

### FORMULA

$$LiftTime + (LateralDist / 12) / (TransferSpeed / 60) + LowerTime$$

Total time the transfer mechanism is busy from the moment it lifts until it is back in the ready position. The trunk line cannot safely deliver the next carton during this window.

Variable	What it is	Why it matters
LiftTime	Time to raise transfer (sec)	Default 0.5 sec. Adjust for the specific transfer model from the manufacturer spec sheet.
LateralDist	Lateral travel distance (in)	From row 14. Converted to feet for the speed calculation.
TransferSpeed	Transfer lateral speed (FPM)	The speed of the transfer mechanism moving the carton sideways. From the manufacturer spec.
LowerTime	Time to lower transfer (sec)	Default 0.5 sec. Adjust for the specific transfer model.

### RIVERSIDE WORKED EXAMPLE

LiftTime=0.5 sec, LateralDist=22.5 in, TransferSpeed=30 FPM, LowerTime=0.5 sec. Cycle =  $0.5 + (22.5/12)/(30/60) + 0.5 = 0.5 + 1.875/0.5 + 0.5 = 0.5 + 3.75 + 0.5 = 4.75$  sec. The trunk line must have enough gap to keep the next carton away for 4.75 seconds.

## Minimum Gap Required on Trunk Line | Transfer tab — row 16

### FORMULA

$$(\text{CycleTime} \times \text{TrunkSpeed} / 5) + 4$$

The minimum gap needed between cartons on the trunk line for the transfer to complete a full cycle before the next carton arrives. Four inches of safety margin is added.

Variable	What it is	Why it matters
CycleTime	Transfer cycle time (sec)	From row 15. A longer cycle requires a larger gap.
TrunkSpeed	Trunk line speed (FPM)	A faster trunk line closes the gap faster. Higher speed demands a larger minimum gap.

### RIVERSIDE WORKED EXAMPLE

CycleTime=4.75 sec, TrunkSpeed=120 FPM.  $\text{MinGap} = (4.75 \times 120 / 5) + 4 = 114 + 4 = 118$  in. The gap between cartons on the trunk line must be at least 118 inches for this transfer to operate without collision.

### PASS

Gap available on trunk line is equal to or greater than minimum gap required. The transfer can complete each cycle before the next carton arrives.

### IF IT FAILS

Gap available is less than minimum required. A carton collision will occur on every transfer cycle. Reduce trunk line speed, increase carton gap upstream, or specify a faster transfer mechanism to reduce cycle time.

**Note** The 4 inch safety margin in this formula is a minimum. On critical transfer points Michael Collins recommends 8 to 10 inches of additional margin to account for variation in product presentation and belt slippage.

## SECTION 5 | SEQUENCE AND DEPENDENCY REFERENCE

Use this as a checklist when working through the calculator

Every calculation in the spec calc has dependencies. Running them out of sequence produces wrong answers that pass their checks but are wrong for the wrong reasons. Use this sequence every time.

Step	Calculation	Feeds into
1	Carton specs entered (L, W, H, WT)	All downstream calculations. This is the foundation.
2	Global conveyor inputs set (SpeedIn, SpeedOut, Gap, IR, BF, OAW)	Gap Produced, Curve BF, Theoretical Rate
3	Weight per Foot calculated	Roller capacity and incline belt checks (outside the calc)
4	Minimum Curve BF calculated	Curve conveyor specification in the proposal
5	Tumble Angle calculated	Maximum allowable incline angle. Sets a hard limit on layout.
6	Gap Produced calculated	Theoretical Rate, Pitch, Sorter induction gap input, Transfer gap check
7	Theoretical Rate confirmed	Confirms the system can achieve required CPM at set speed. If not, SpeedIn must increase.
8	Sorter: Required Rate entered	CFPM — must be confirmed with customer in writing before this step
9	Sorter: CFPM calculated	Required Sorter Speed via SGR
10	Sorter: SGR calculated	Required Sorter Speed
11	Sorter: Required Sorter Speed confirmed	Gap Produced at sorter, Takeaway Spur Speed
12	Sorter: Gap checks run (model min + geometry)	Go / No-go on sorter selection at this rate and product mix
13	Sorter: Takeaway Spur Speed calculated	Takeaway spur conveyor specification in the proposal
14	Transfer: Lateral Distance calculated	Transfer Cycle Time
15	Transfer: Cycle Time calculated	Minimum Gap Required on Trunk Line
16	Transfer: Gap check run	Go / No-go on trunk line speed and gap at this transfer point

### Michael Collins

The most common mistake I see is running the sorter tab before confirming the required rate with the customer. CFPM is driven entirely by rate. If the rate changes after the calc is done, every sorter number is wrong. Get the rate in writing. Then run the calc.