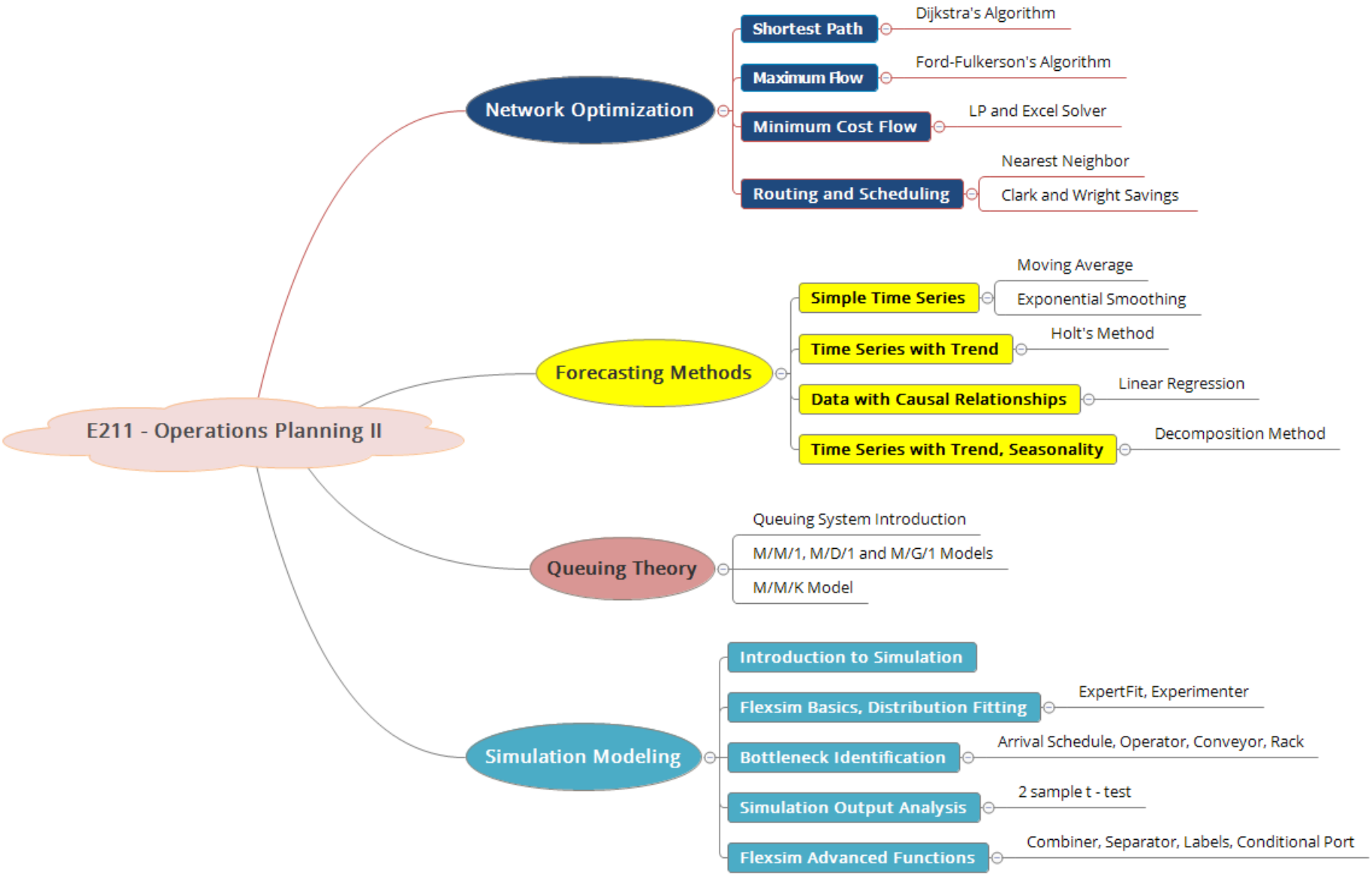
Problem 12

Test to Improve

E211 – Operations Planning II

SCHOOL OF ENGINEERING

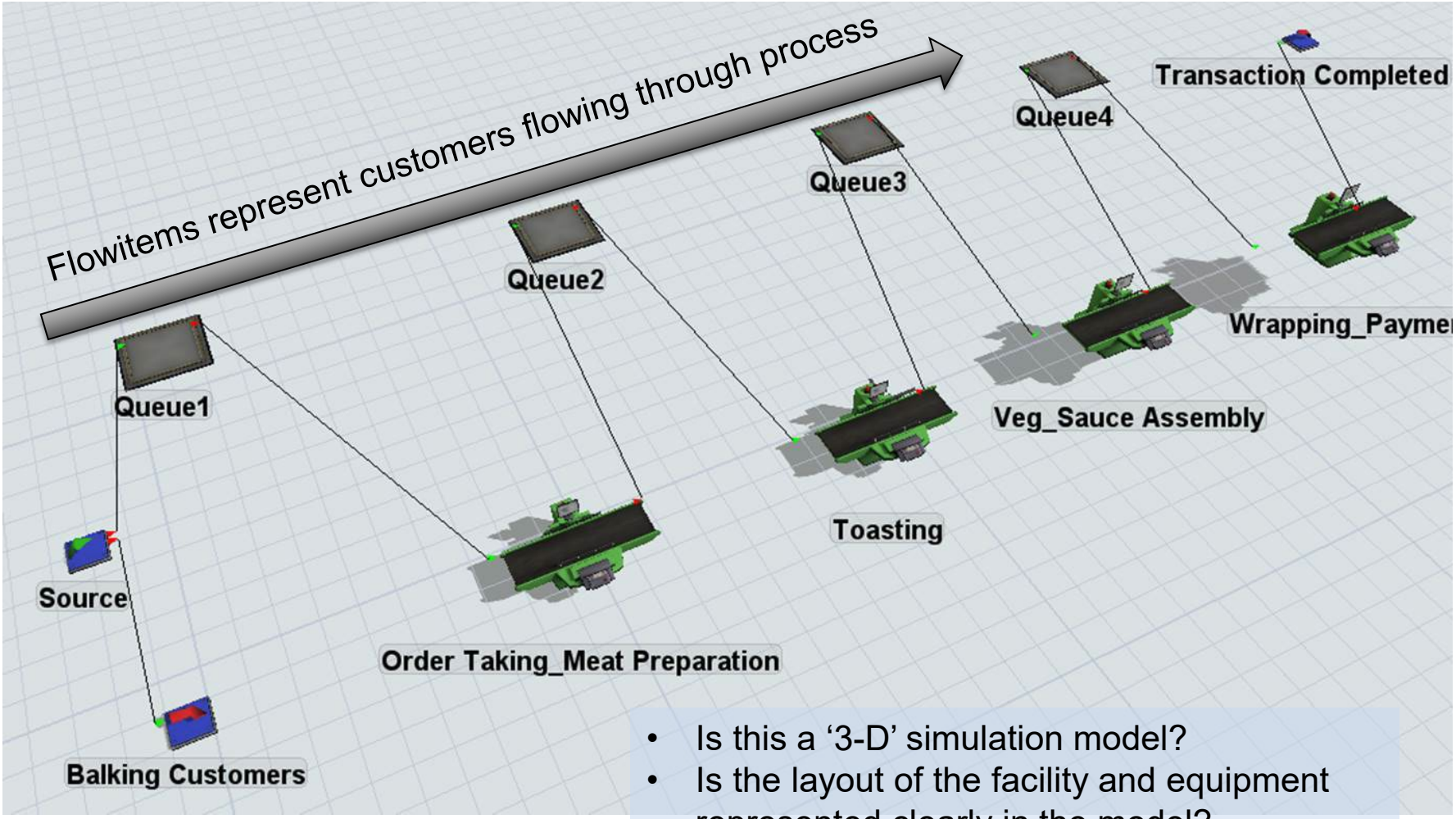
Module Coverage: E211 Topic Tree



Learning Objectives

- Construct a simulation model for a typical warehouse outbound process
- Identify bottleneck operations in the process flow through simulation and analysis
- Recommend ways to alleviate bottleneck operations
- Use statistical test to conclude whether the proposed alternative can effectively alleviate the bottleneck

Recap – P11 Food Ordering Simulation



- Is this a '3-D' simulation model?
- Is the layout of the facility and equipment represented clearly in the model?
- Can we visualize how customers move from station to station?

Next Step: 3-D Model

- To simulate certain processes like warehouse operations, we could build 3-D models to show
  - Layout of facility with actual dimensions
  - Space available
  - Movement speed/path of material handling equipment & operators

Case Scenario

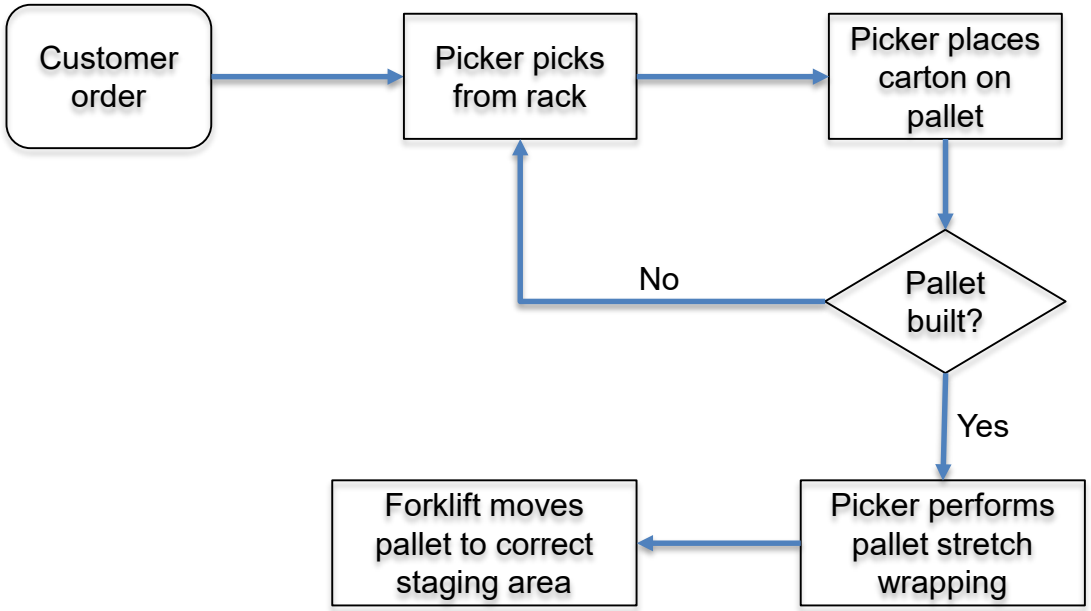
- Nature's Boost is a manufacturer and distributor of organic vegetable and fruit juice blends.
- Due to growing popularity of their products, the company is planning to ramp up production.
- Management is concerned that the current warehouse outbound process for mixed order* fulfillment is too slow.
- The warehouse supervisor proposes to purchase a semi-automated stretch wrap machine to speed up the outbound process.
- Build a simulation model of the process to evaluate the proposed idea and explore other feasible alternatives.

**Mixed order requires carton level picking and consolidation to a pallet*

Understanding the Process

Warehouse outbound process

1. Order arrives
2. Picker picks carton from rack
3. Picker places carton on pallet at stretch wrap machine
4. When pallet build is finished, the pallet is being stretch wrapped
5. Finally the wrapped pallet is moved to the correct staging area



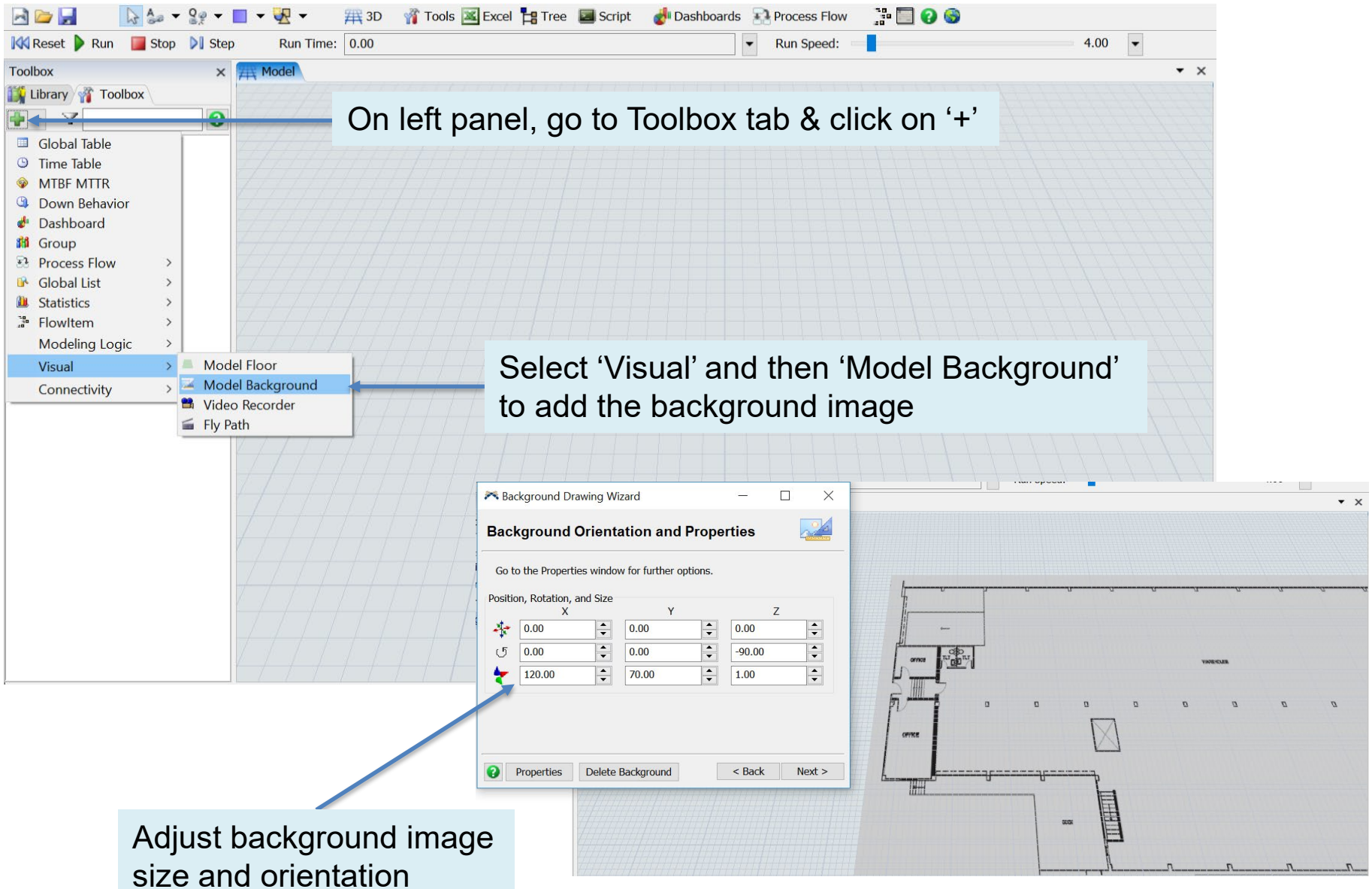
Team Discussion: Model Requirements

Besides process flow, what information do you need to build a simulation model of the outbound process?

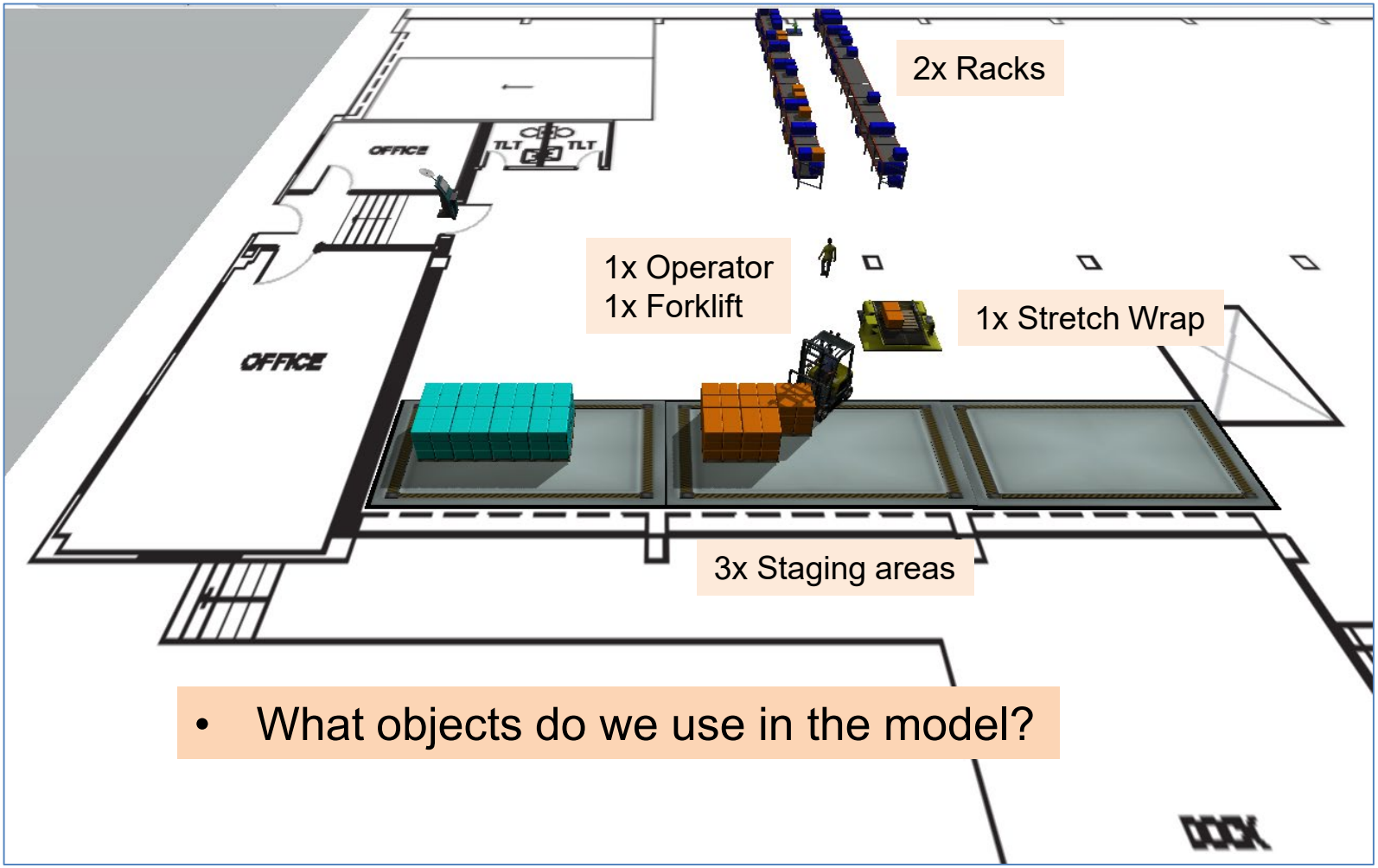
- Facility layout drawing
- Rack specifications
- Operator walking/working speed
- Number of cartons per pallet
- Stretch wrap timing
- Forklift speed
- Customer order pattern
- Object (racks, forklift, stretch wrap machine, carton boxes) dimensions for 3-D modeling

Building the Warehouse Model

Import Model Background



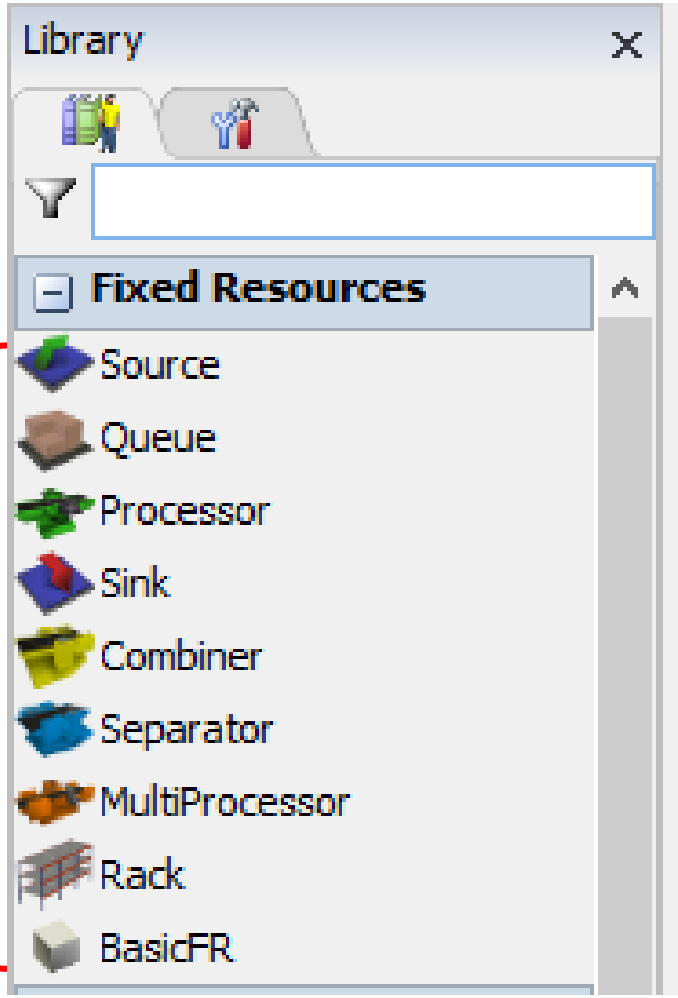
Overview of Model



- What objects do we use in the model?

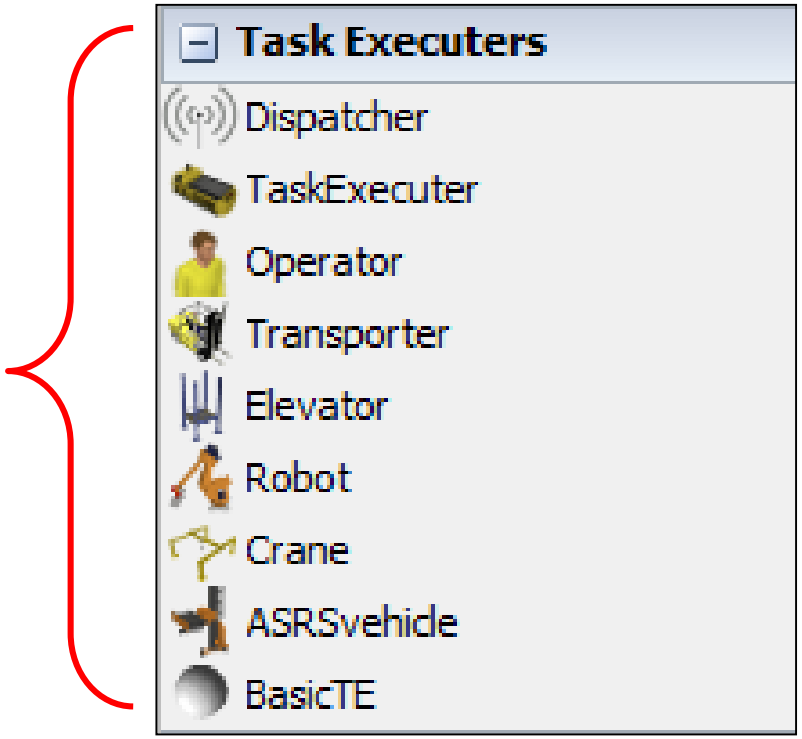
Fixed Resources Objects

- FixedResource class – objects which receive and send flow items, e.g.
  - Processor
  - Queue
  - Rack
- Which object only receives items?
- Which object only sends items?

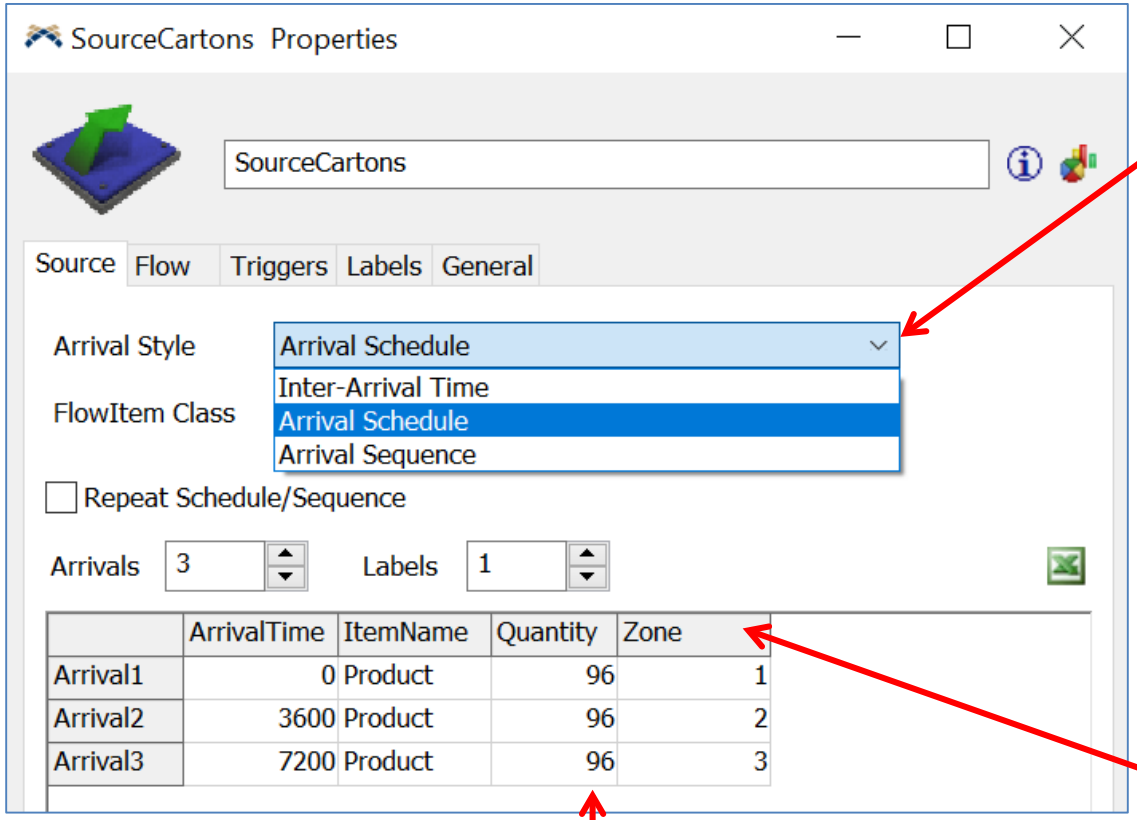


Task Executers Objects

- TaskExecuter class – shared resources and mobile resources that help in moving flow items, e.g.
  - Operator
  - Transporter
- Which object controls the task executers rather than move items?



Define Source: Generation of Cartons



Arrival Style -

- Inter-arrival time: can represent a random pattern between the arrival times of items
- Arrival schedule: specifies the exact arrival times and quantities
- Arrival sequence: only specifies quantity and sequence of arrivals

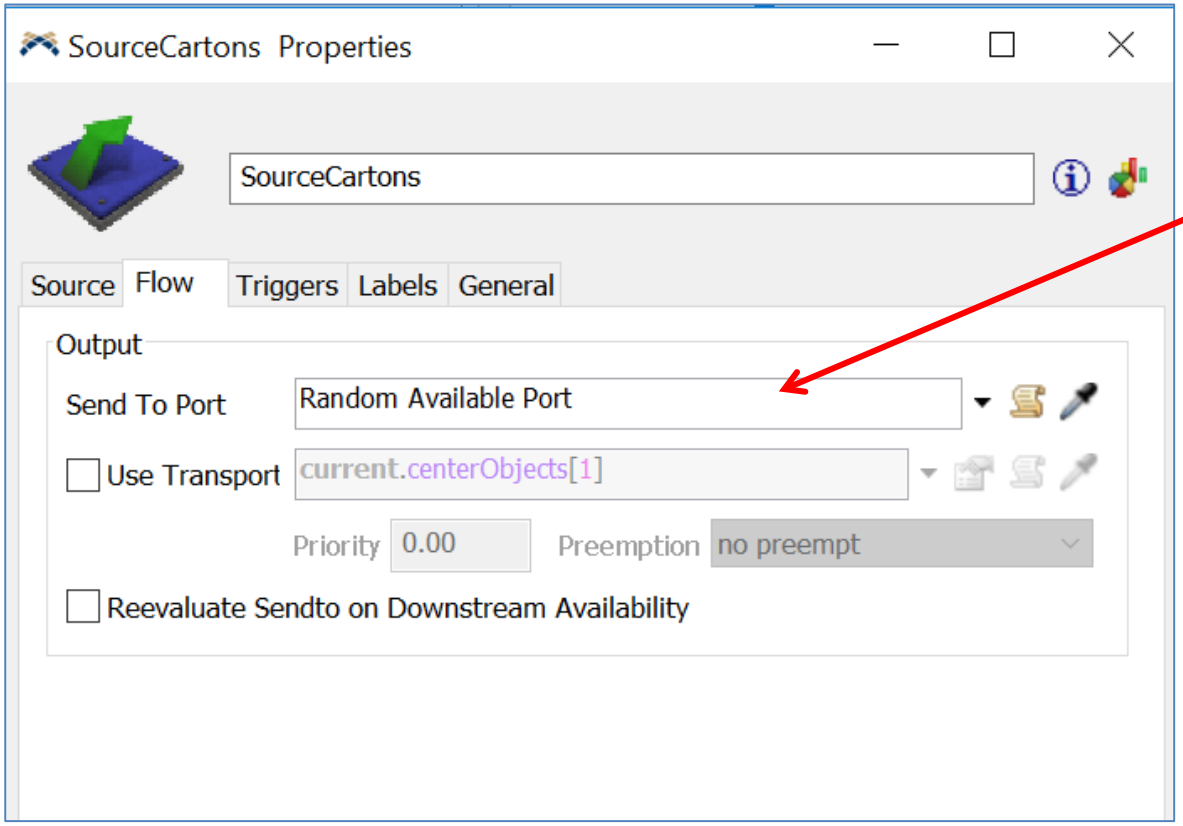
Create Label 'Zone'

- Each zone label value represents a different staging area (e.g. delivery zone)

Generate 3 Arrivals of Carton Boxes

- Create an order release schedule: 96 carton boxes each hour at 3 consecutive hours

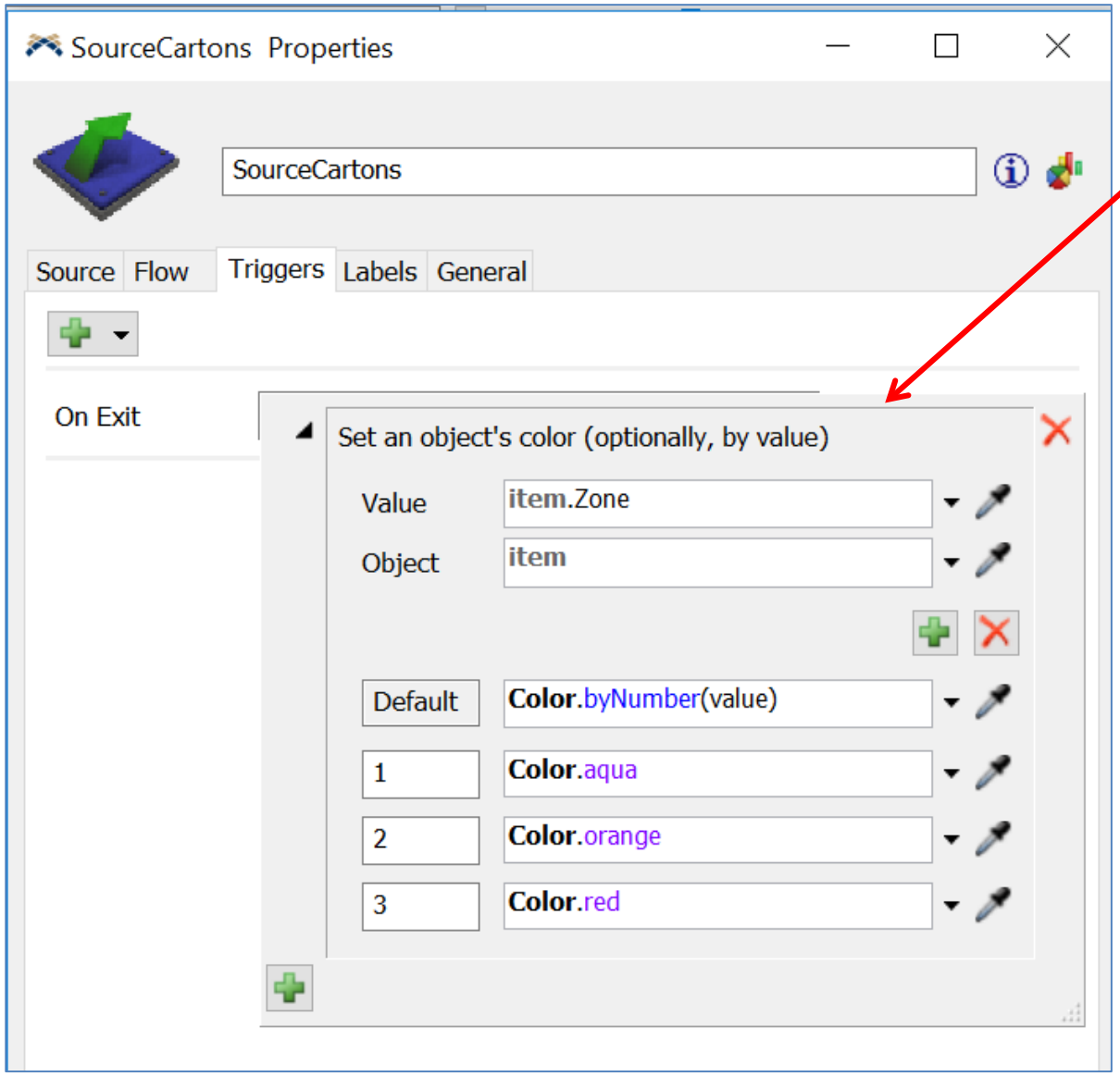
Where do the Cartons Go?



Send to Port -

- Choose ‘Random Available Port’ so that the cartons will be randomly distributed to one of the two racks

Box Color According to its Zone



On Exit Trigger -

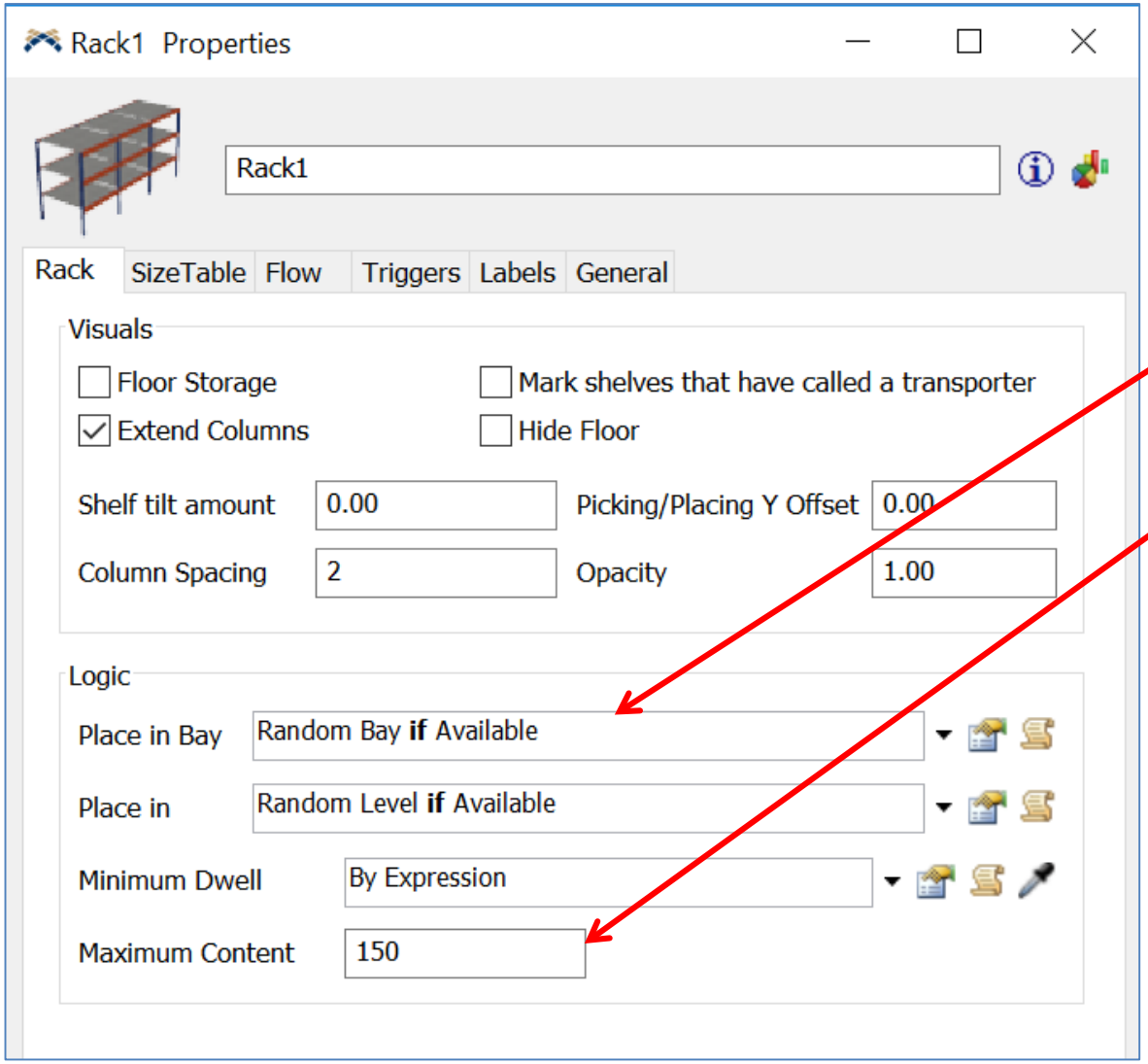
- Choose ‘Set Color by Case’ under ‘Visual’
- Under ‘Value’ input, type in ‘item.Zone’
- Add (+) two cases and set different colours

The colour of the box is set according to the value of the ‘Zone’ label.

Define Rack: Initial Storage Location

- The rack is used to store flowitems as if they were on a warehouse rack.
- The number and size of bays and levels in the rack can be defined by the user.
- The user can specify the bay and level to place entering flowitems.
- If a transporter object is used to deliver or pickup flowitems from a rack, the transporter will drive to the specific cell in the rack where the flowitem is located.
- The rack can also be used as storage on the floor of a warehouse, using the bay number to specify an x position to place a flowitem on the floor, and the level to specify the y position to place the flowitem.

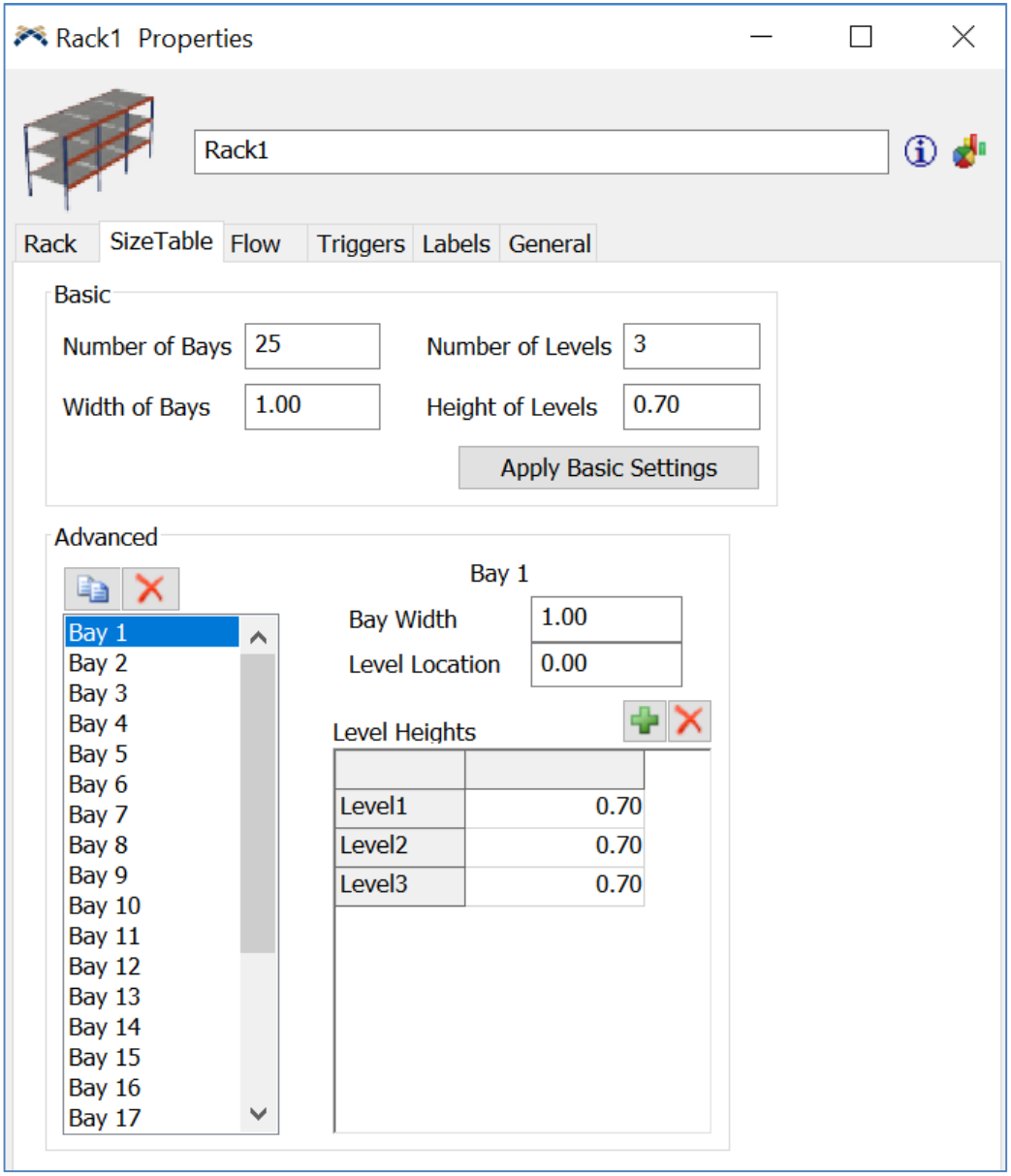
Rack Setup



Logic -

- Determines the starting position of items on rack
- Set random placement of cartons
- Max items per cell = 2
- Maximum number of cartons that this rack can hold

Rack Sizing

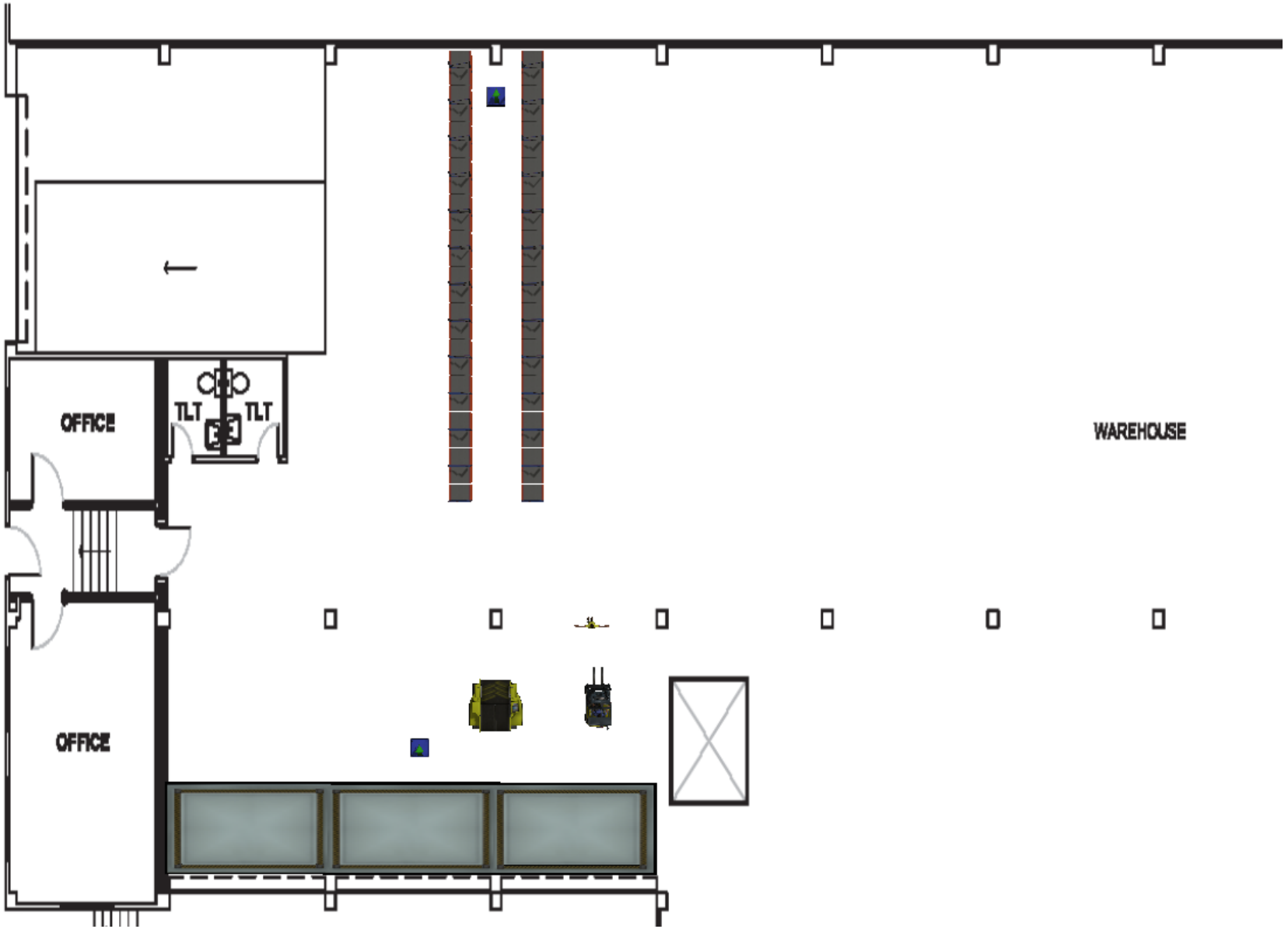


Size Table -

- Specify the dimensions of individual bays to create the correct rack structure

Qn: Why is the rack only 3-tier high?

Object Placement



Buddy Pair-Up 1

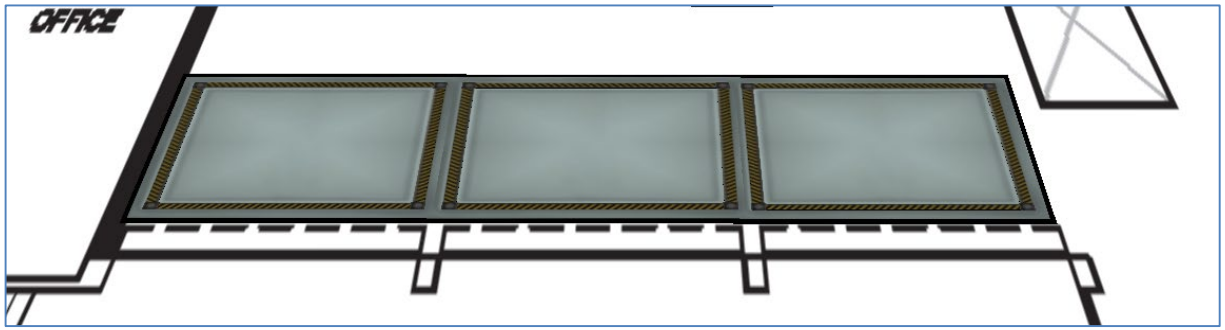
1. Pair up with a buddy and check on each other's model – 1 Source and 2 Racks

2. Connect the Source to the two Racks

3. Run the simulation model

4. Compare your simulation outcomes

Place Queue: Pallet Staging Areas

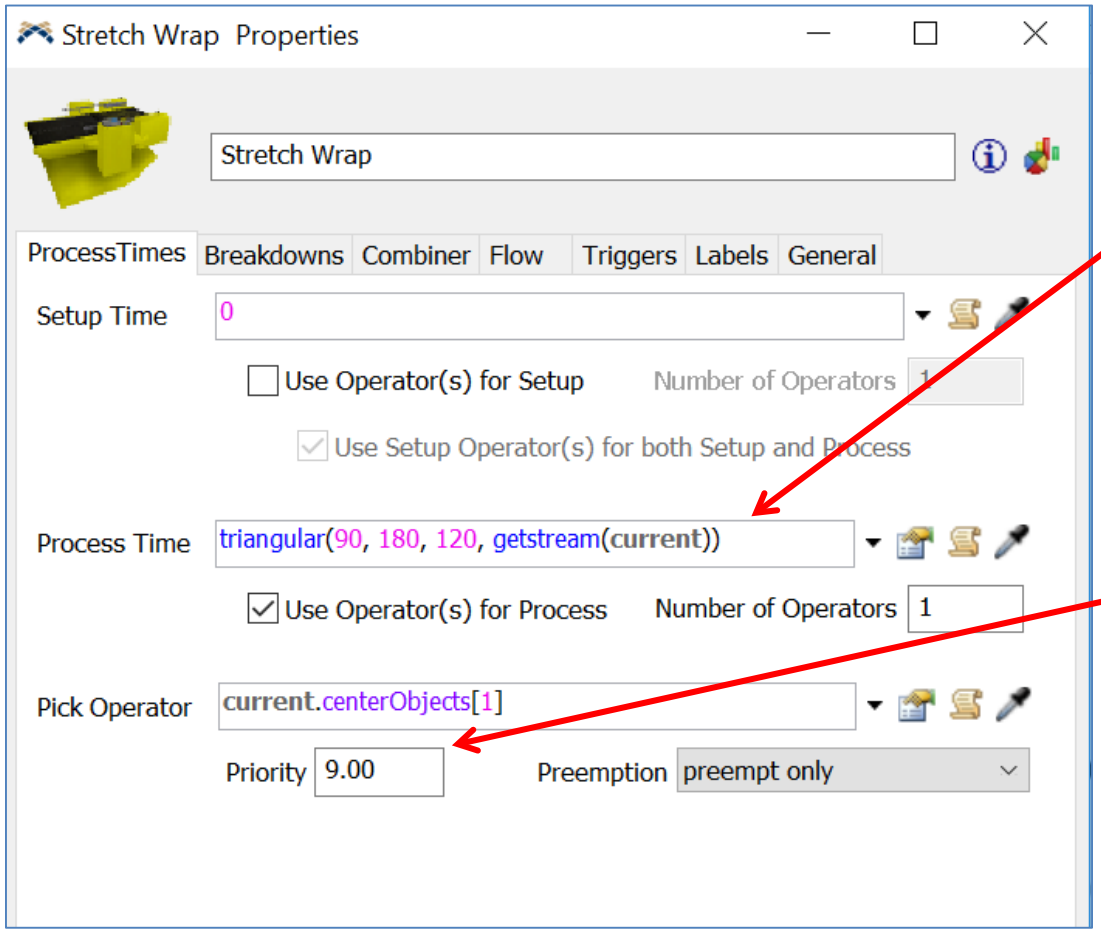


Staging Area -

- Place 3 queue objects at the dock and size them appropriately.

Qn: Why 3 staging areas?

Define Combiner: Stretch Wrap



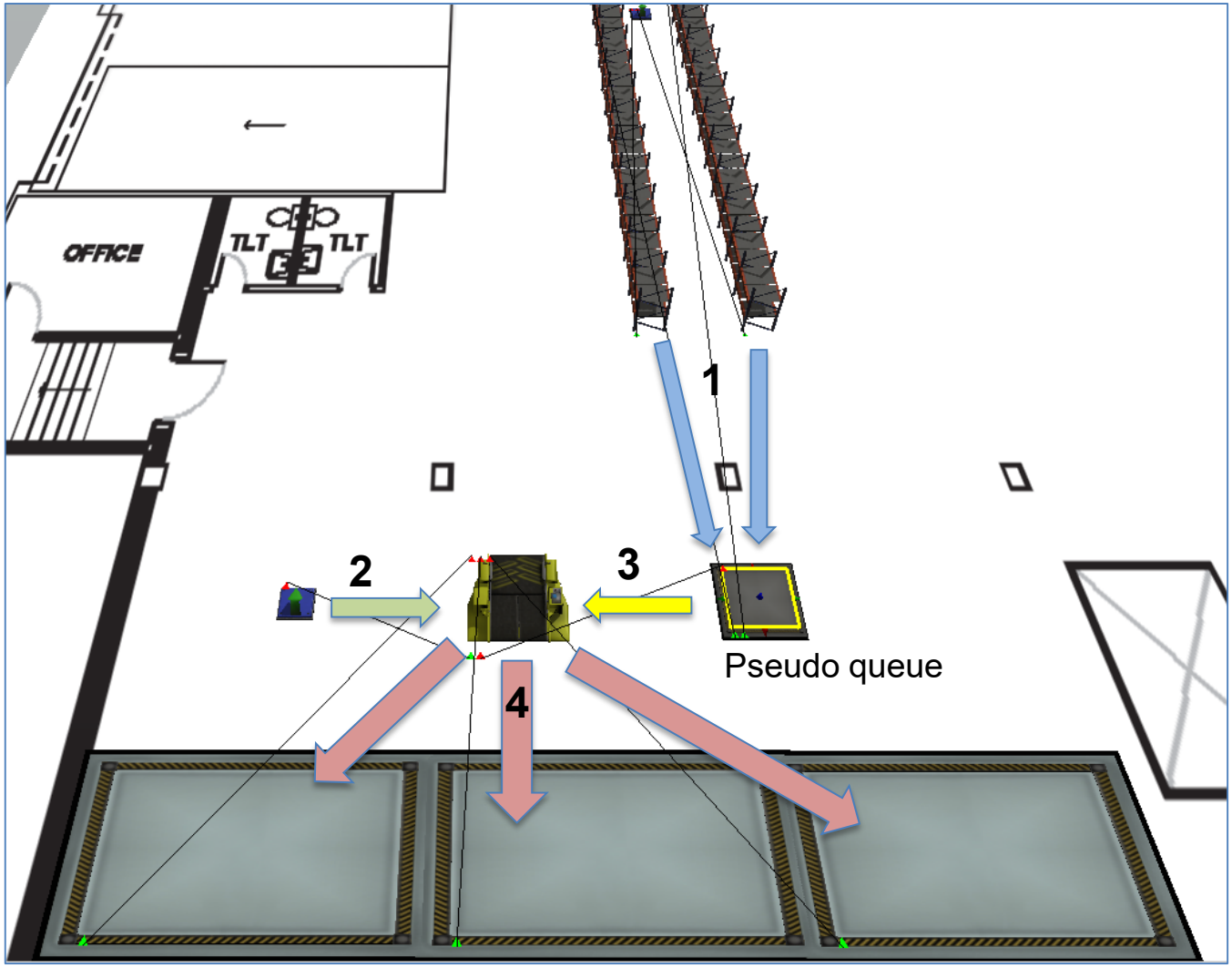
Process Time -

- Use triangular distribution to represent variable manual stretch wrap timings

Pick Operator -

- Specify this process as priority task for operator

Flow from Rack to Staging Area



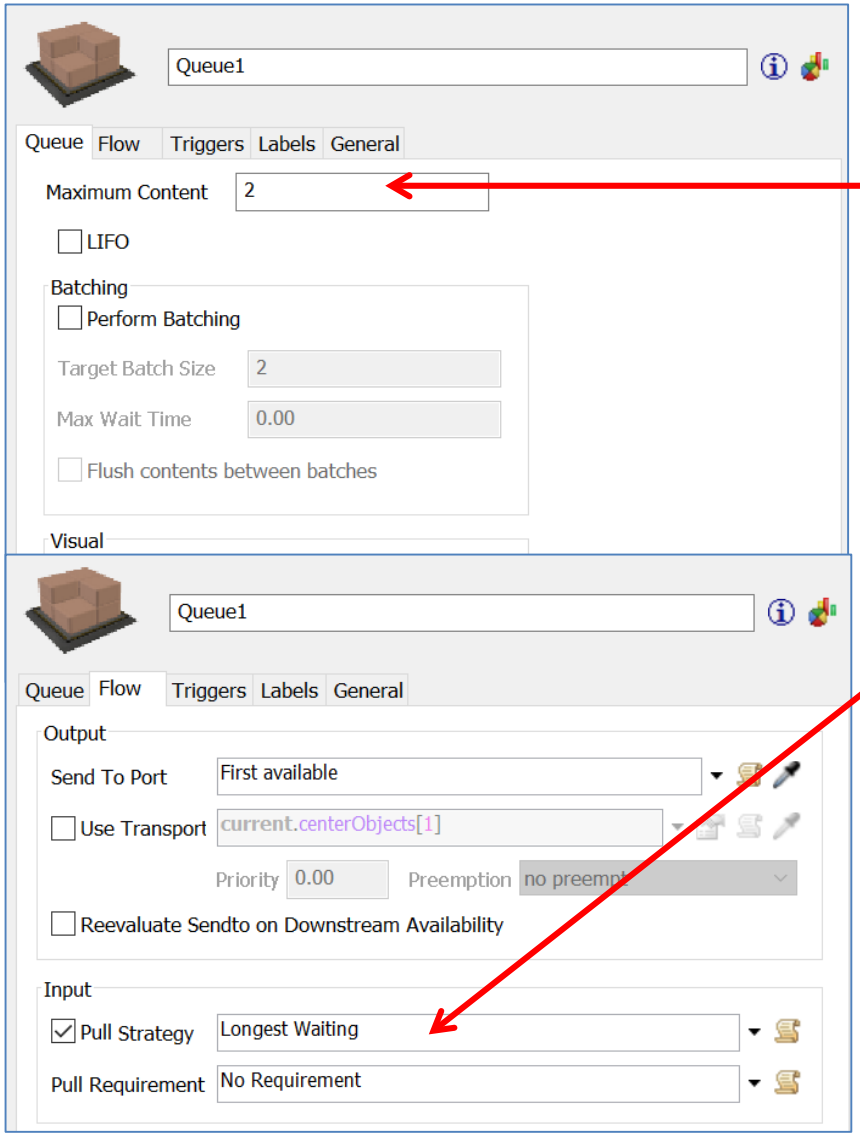
1. Connect racks to pseudo queue

2. Connect pallet source to combiner

3. Connect pseudo queue to combiner

4. Connect combiner to staging queues

Define ‘Psuedo’ Queue



Max Content -

- Simulate the holding space: maximum no. of cartons allowed to be carried in by different operators

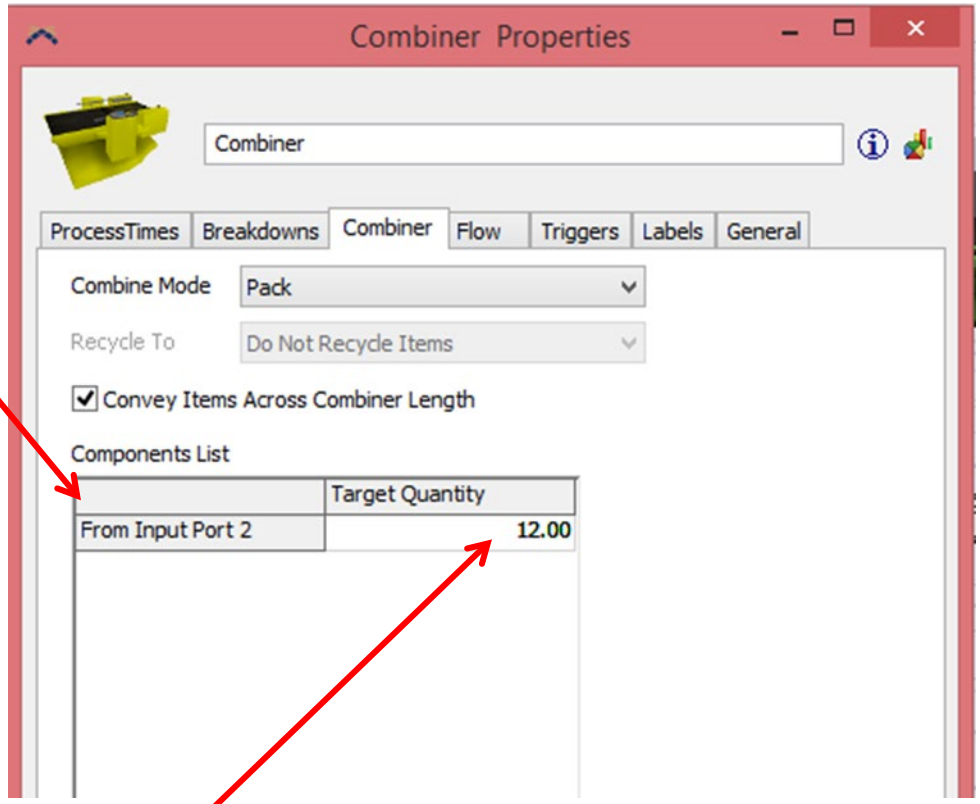
Pull Strategy -

- Pull strategy is required
- Specify ‘Longest Waiting’ so that the earliest arrival batch will be picked first

Combiner: Group Items Together

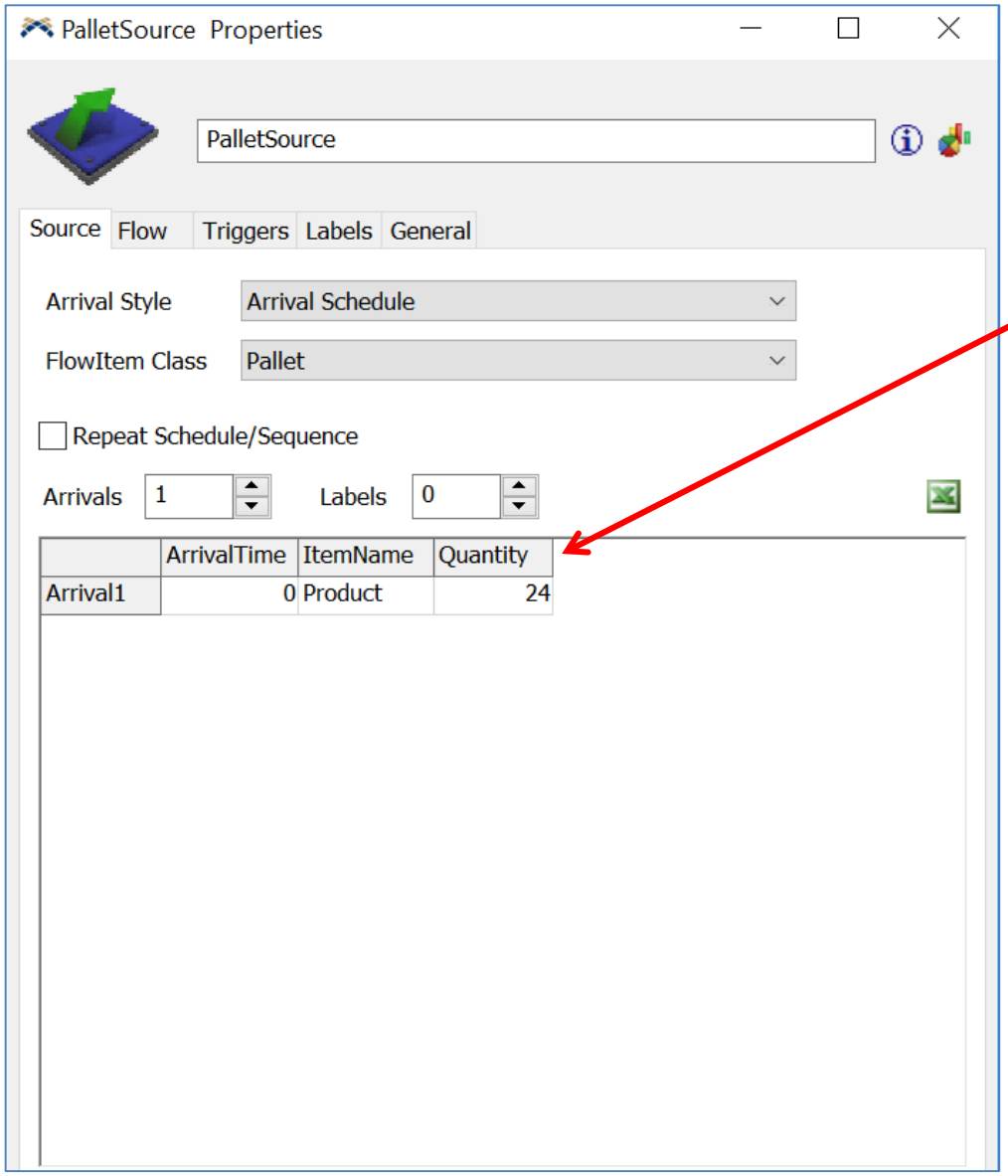
- The combiner is used to group multiple flowitems together as they travel through the model. It can either join the flowitems together permanently, or it can pack them so that they can be separated at a later point in time.

Input Port 1 is always reserved for the container in ‘Pack’ (e.g. pallet) or main item in ‘Join’.



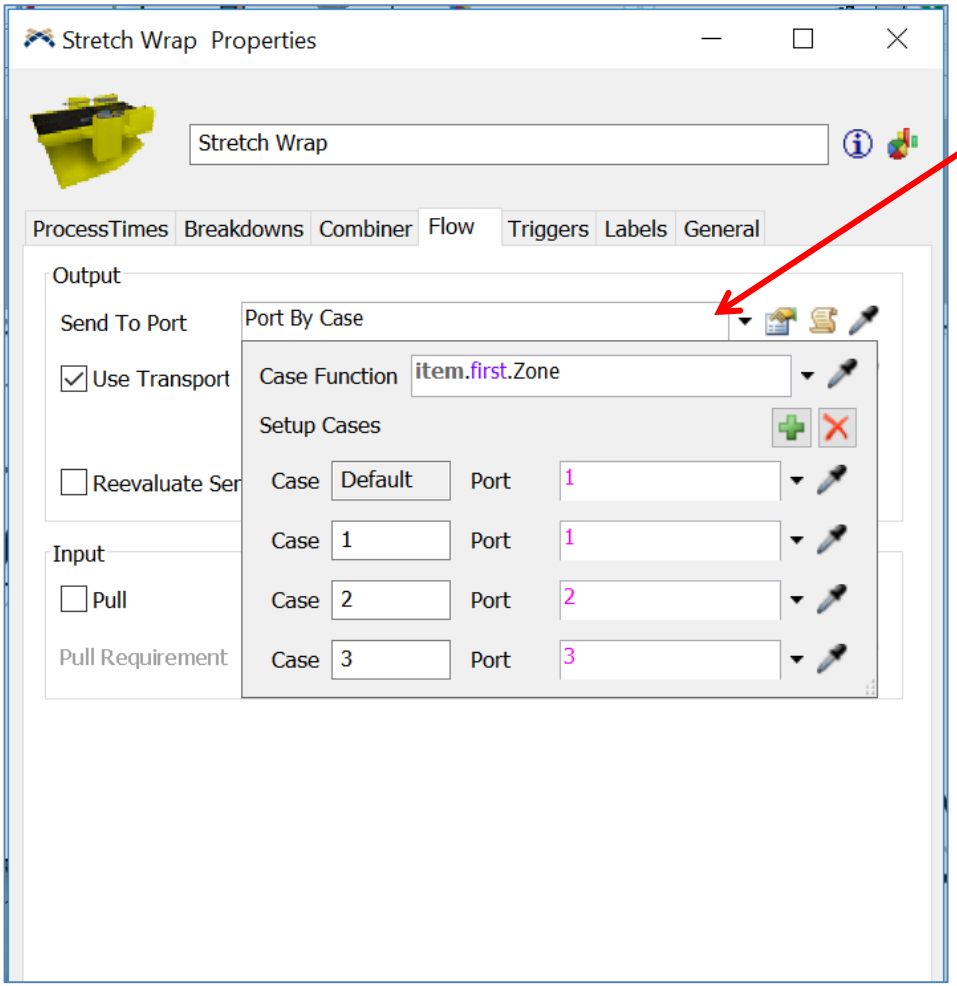
Specify number of items to pack coming from Port 2.

Pallet Source for Combiner



- Select Arrival Schedule to create the required number of pallets

Flow from Stretch Wrap to Staging Areas



Send to Port -

- Select Port by Case to tag output port to item label
- Input ‘item.first.Zone’ under Case Function
- Input 3 Cases, each with own unique output port

Buddy Pair-Up 2

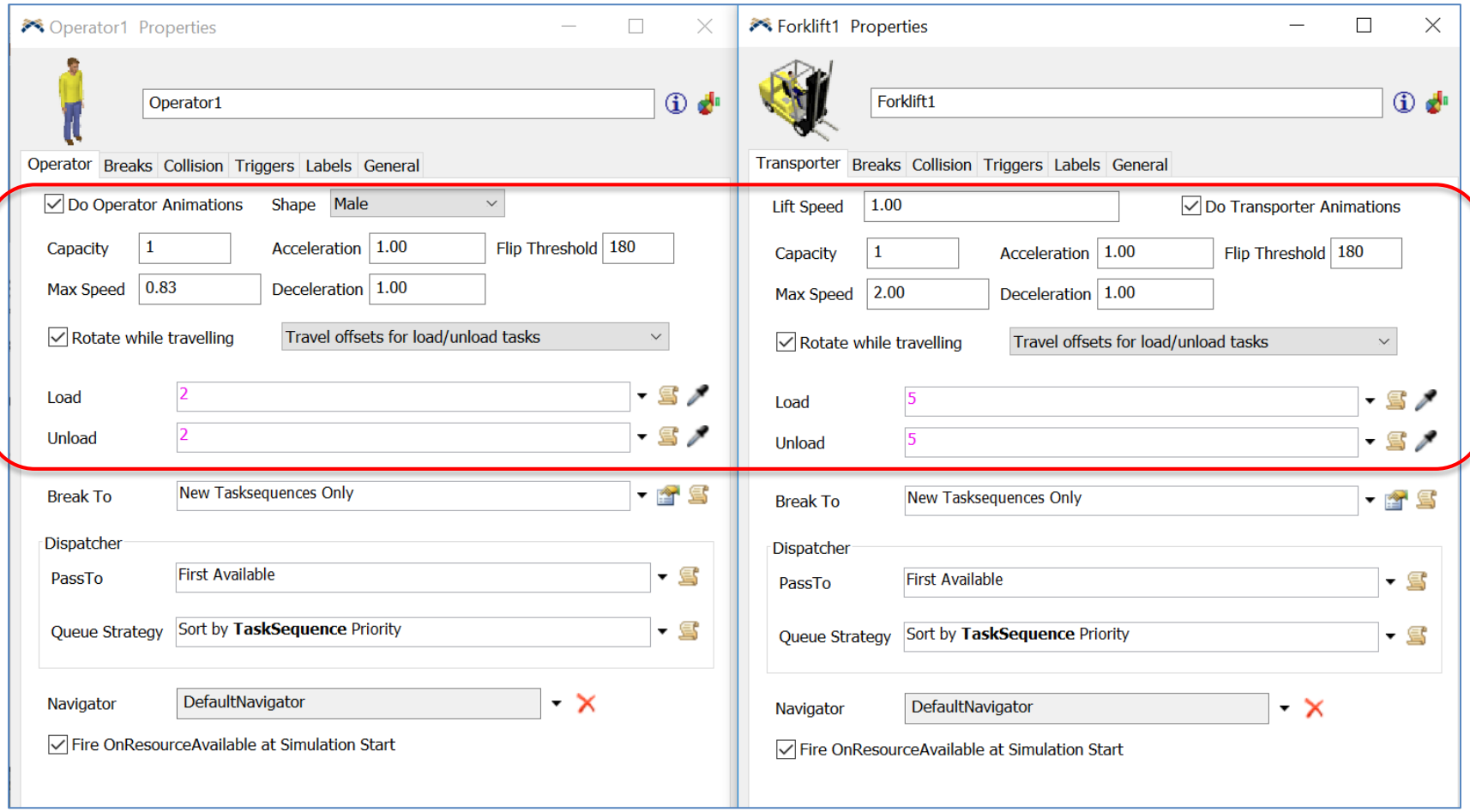
1. Check your buddy's model: Staging area queues, pseudo queue and combiner and the connections (refer to slide 20 for placement position)

2. Uncheck 'Use Transport' and 'Use Operator' in Combiner first before running the simulation model

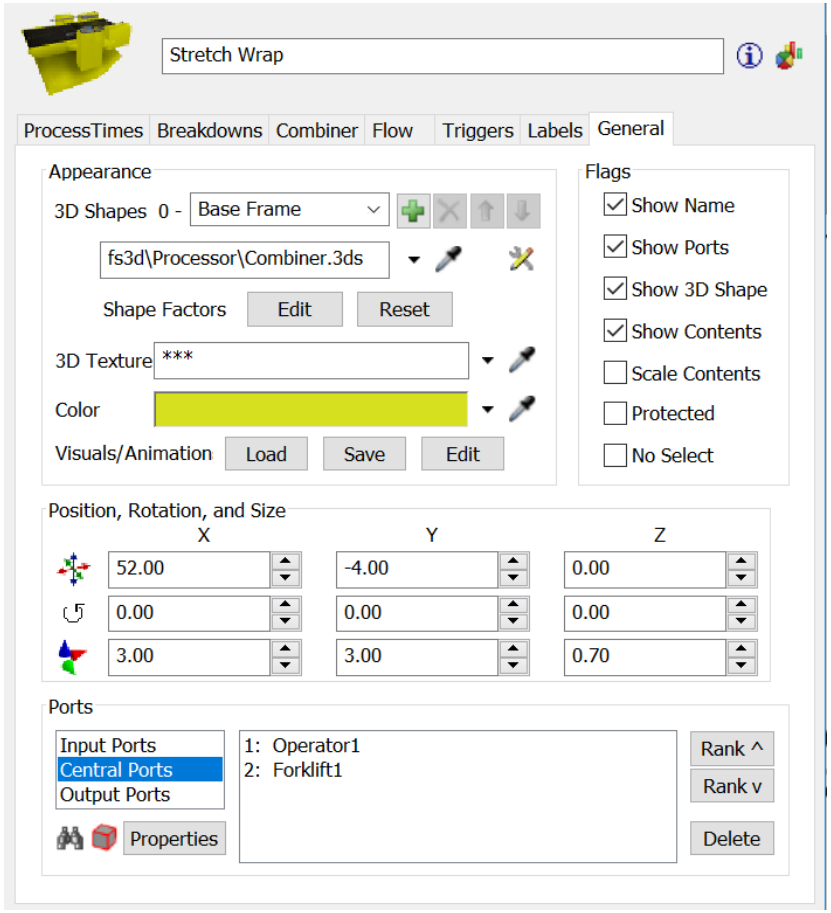
3. Compare your simulation results

Define Task Executers

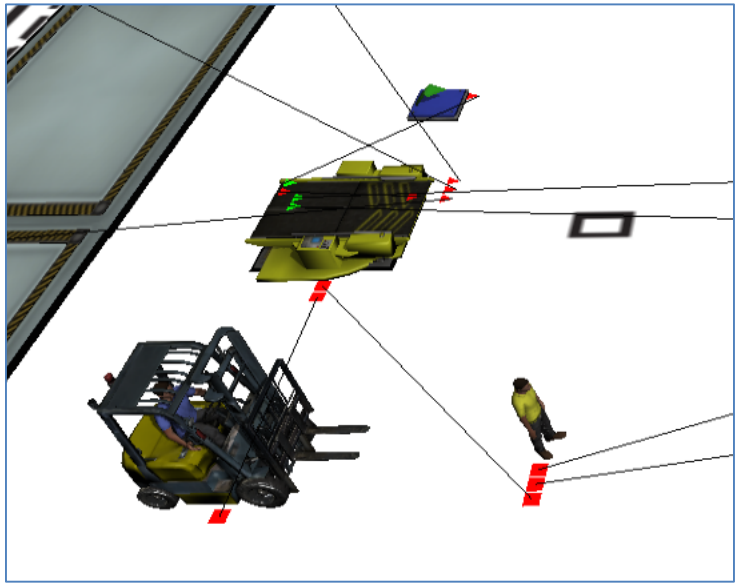
When process involves task executers, it is essential to set the capacity, speed, distance, load/unload time correctly.



Connecting Task Executers: Center Port



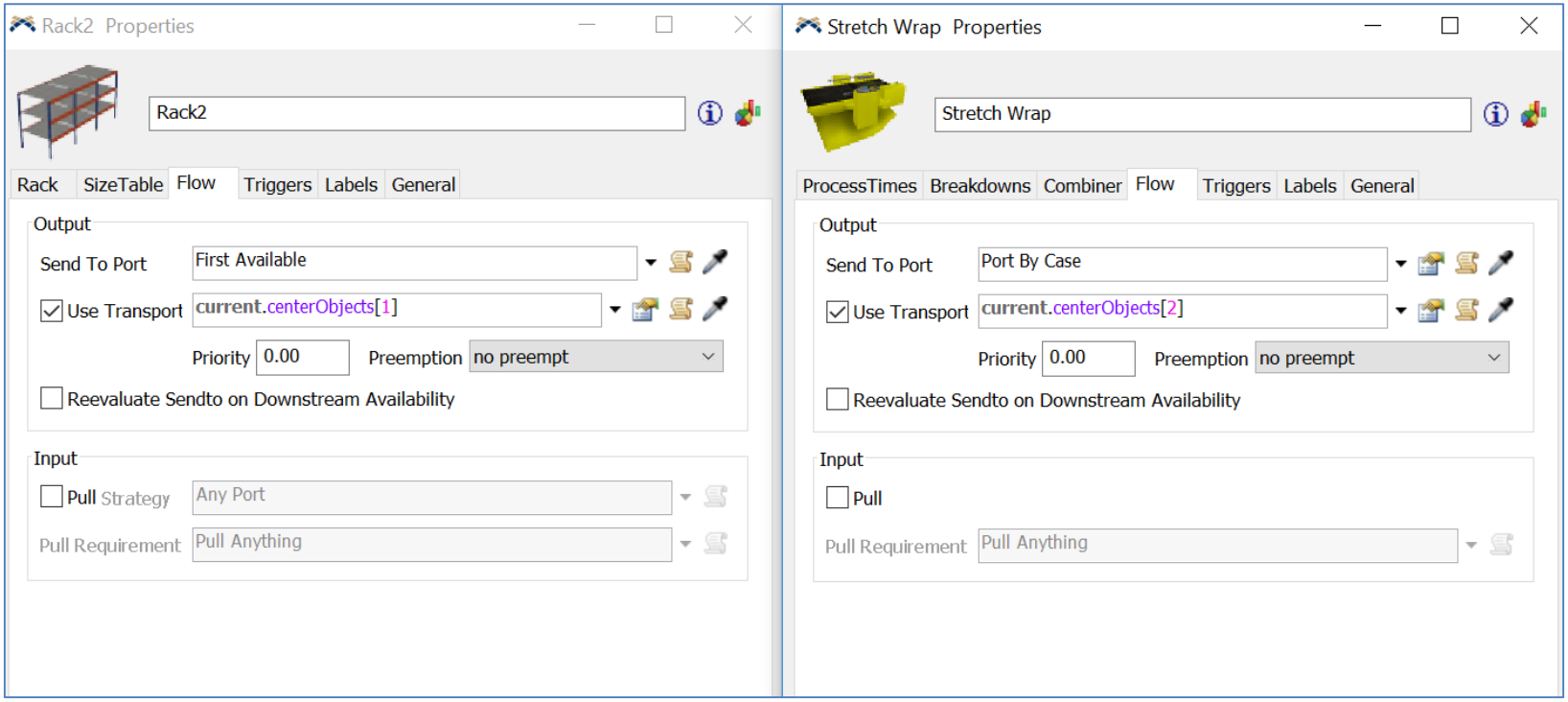
- Center Port connections are made (removed) by holding ‘S’ (‘W’) key while click-and-dragging from one object to another. Direction of connection does not matter.



- Connect Operator to the 2 racks and the combiner.
- Connect Forklift to the combiner
- Verify the connections in object properties page

Check ‘Use Transport’ in Object Properties

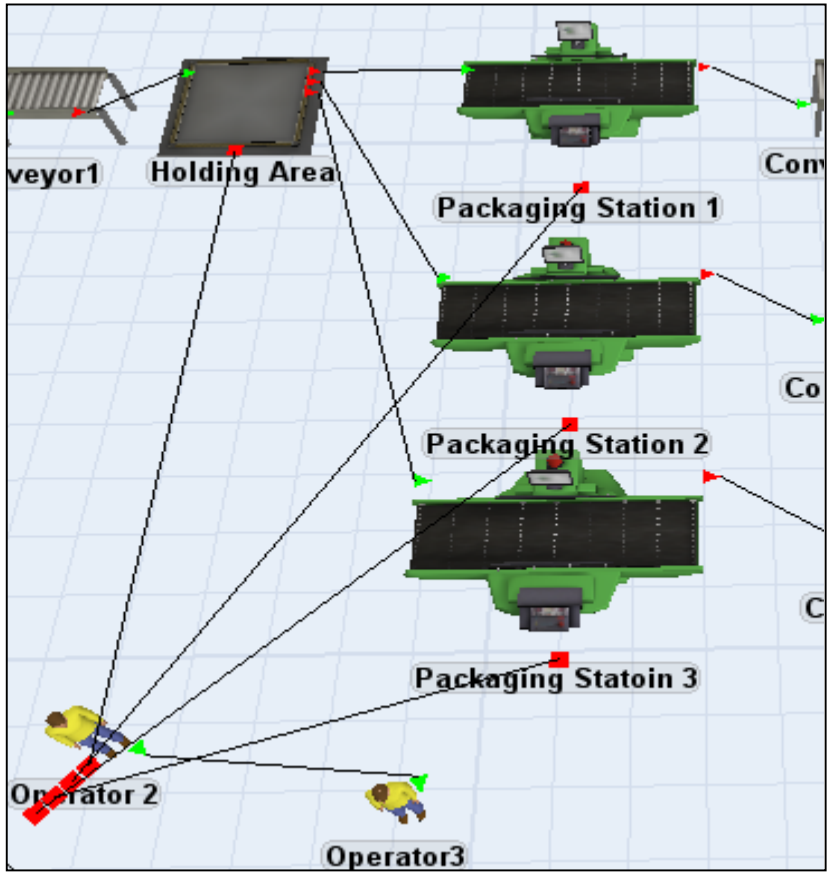
- Specify which object requires a material handler to move items downstream.
  - Operator (to pick from rack) and
  - Forklift (to move pallets from stretch wrap)

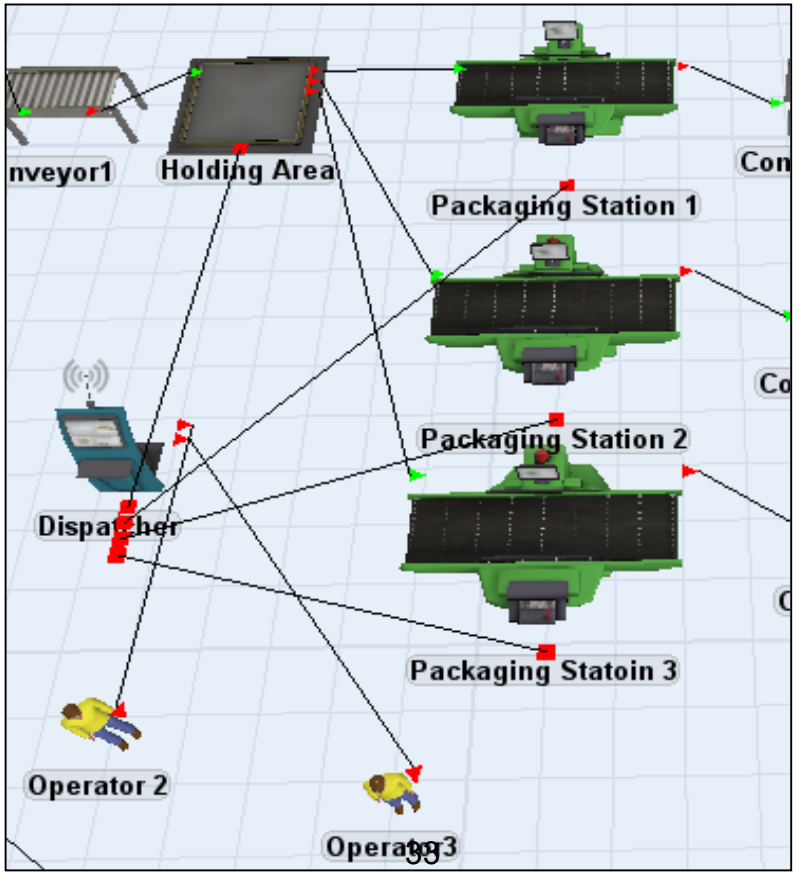


+ check ‘Use operator’ for Stretch Wrap process

Simulation Techniques - More Than 1 Operator (Transporter)

- When using more than 1 operator (transporter) for one route, use
  - either the ‘direct’ Technique(using the <A> key to link the first ‘operator’ with the second one), or
  - use a dispatcher (connect the ‘dispatcher’ with the ‘queue’ using <S> key; link the two ‘operators’ with the ‘dispatcher’ using <A> key)





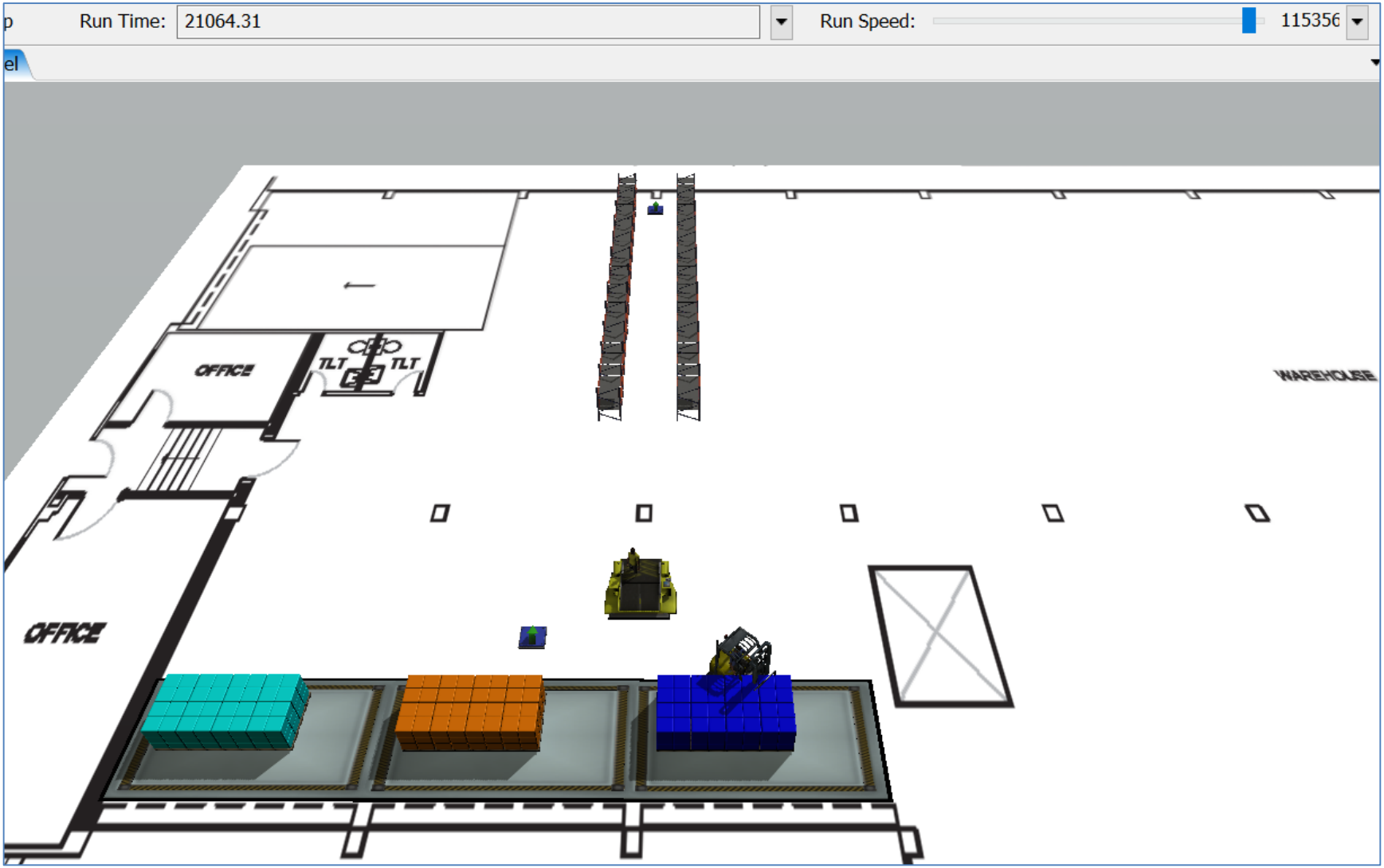
Buddy Pair-Up 3

1. Pair up with a buddy and check each other's model – Operator, Forklift, check 'Use Transport' and the connections

2. Run the simulation model

3. Compare your simulation result – what is the end time (completion time)?

Simulation End State – Now What?



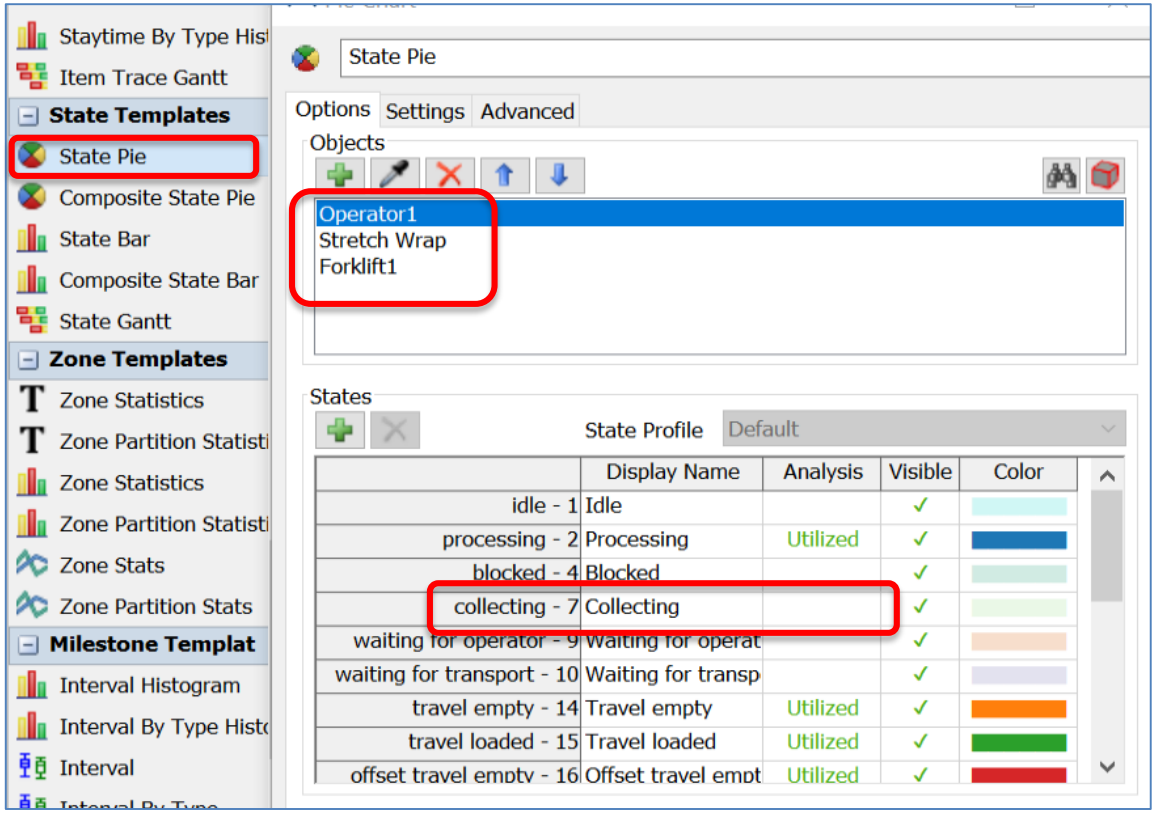
Team Discussion: Simulation Results

- Identify a few key performance indicators (KPI) to generate from the warehouse process simulation

1. Completion time to pick, pack and stage all outbound orders
2. Operator utilization
3. Stretch wrap utilization
4. Fork lift utilization

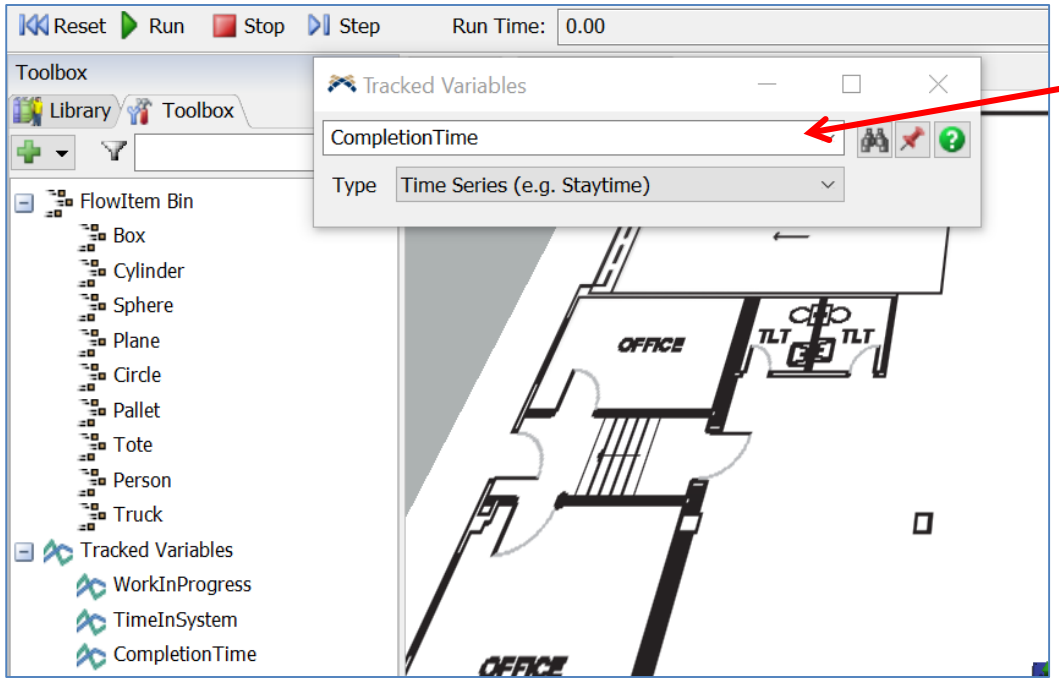
} Obtain from state pie

Track Resource Utilization



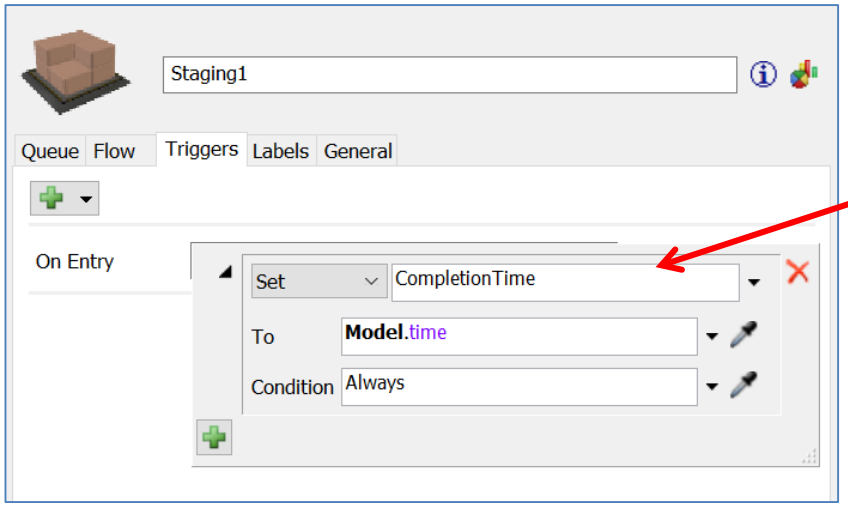
- Add '**State Pie**' from Dashboard library
- Add Operator, Stretch Wrap and Forklift objects to track
- Click on 'collecting – 7' cell under Analysis until the cell is blank. This is to ensure that collecting state is not considered as part of utilization.

Track Completion Time



Add Tracked Variable -

- Add a new variable as 'CompletionTime'
- Pin this variable onto Dashboard



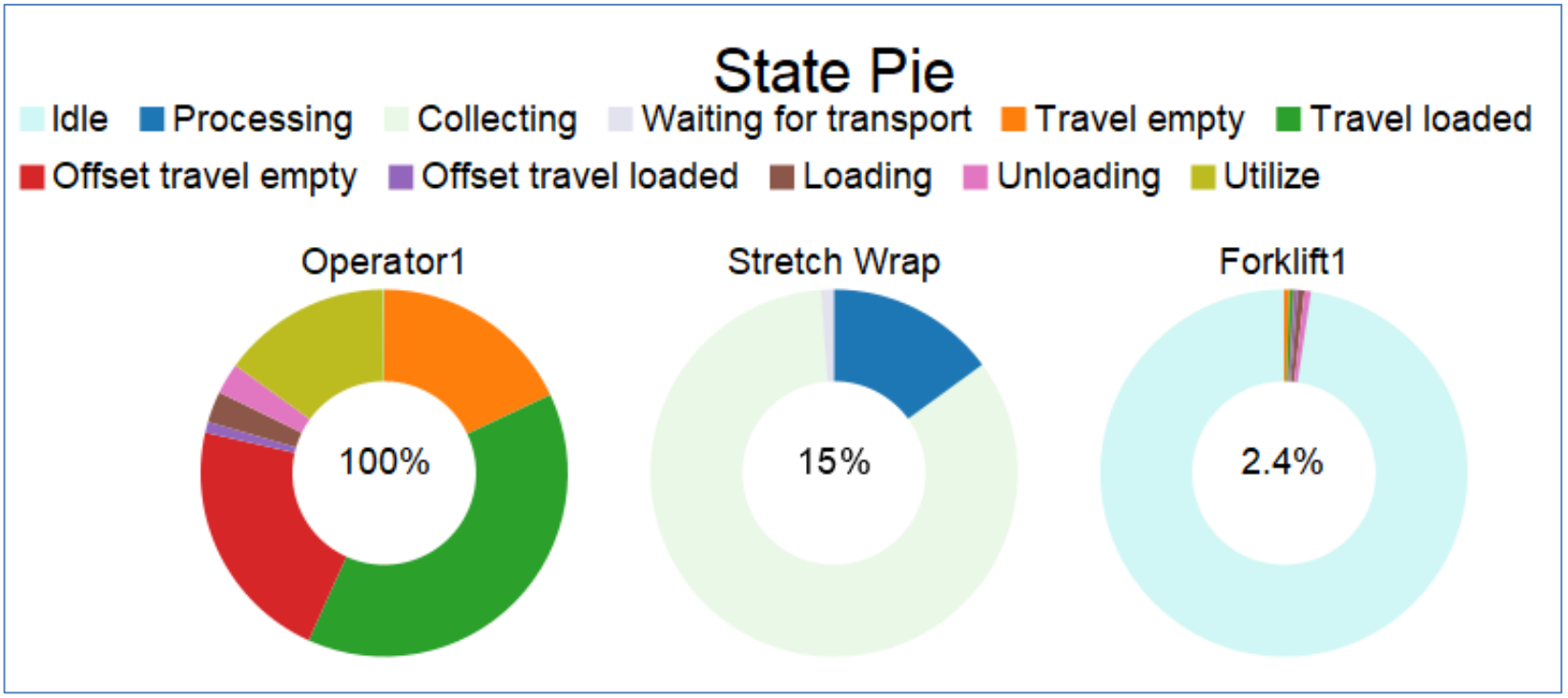
On Entry Trigger -

- In every Staging object, set CompletionTime variable to current model time

Team Discussion

- Obtain the outbound process KPIs from the simulation
- From the results, how do you identify the bottleneck in the process?
- What do you propose to study next?
- Recall the use of Experimenter in Flexsim – how do you make use of it here?

Simulation Result - Utilization



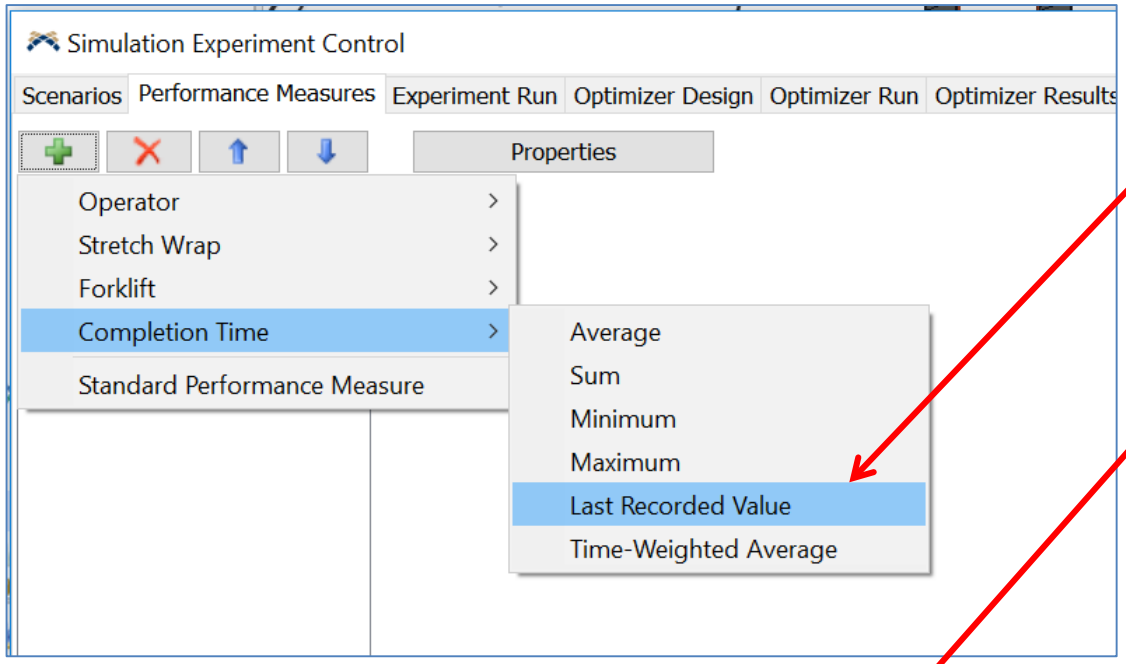
Qns:
Can you identify the bottleneck in the process?
What does the operator do most of the time?
What does the Stretch Wrap machine do most of the time?

Bottleneck & What-if Scenario

- From the results, how do you identify the bottleneck in the process?
  - Compare resource utilization – operator has the highest utilization (>99%)
  - Observe the simulation – stretch wrap is busy due to ‘collecting cartons’ which is operator’s job
  - Therefore operator is the real bottleneck

- What do you propose to study next?
  - We can first evaluate management’s idea of purchasing semi-automated wrapping machine
  - Use 2-sample t-Test

Setting up Experimenter

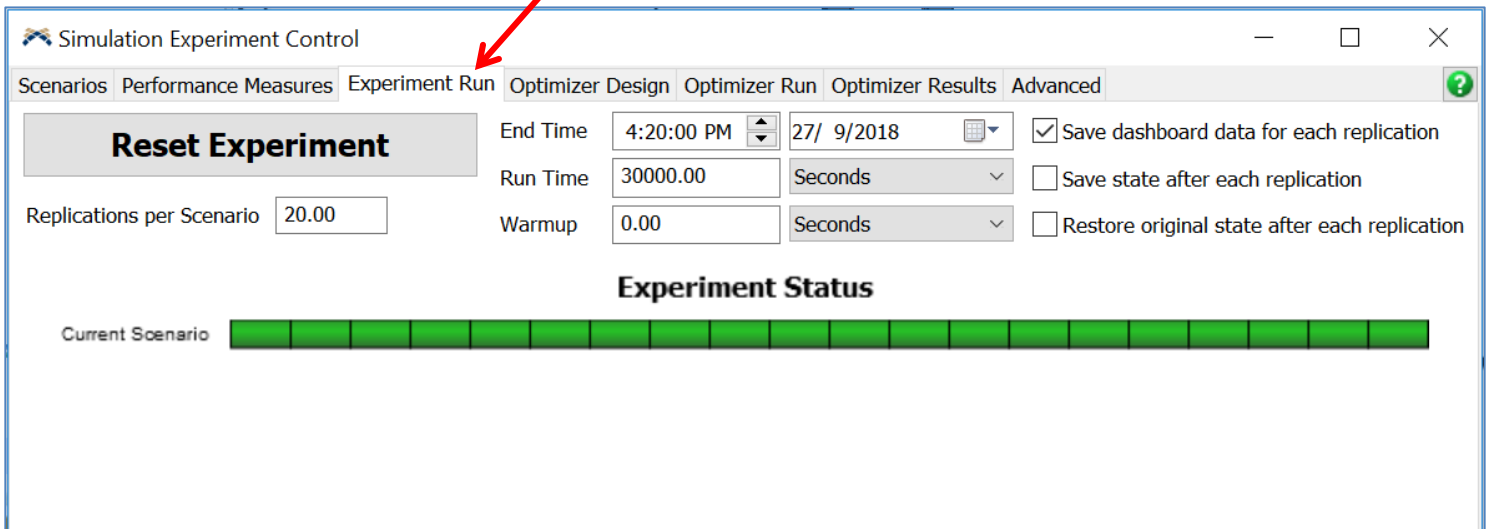


Performance Measures -

- Add Completion Time ‘Last Recorded Value’

Experiment Run -

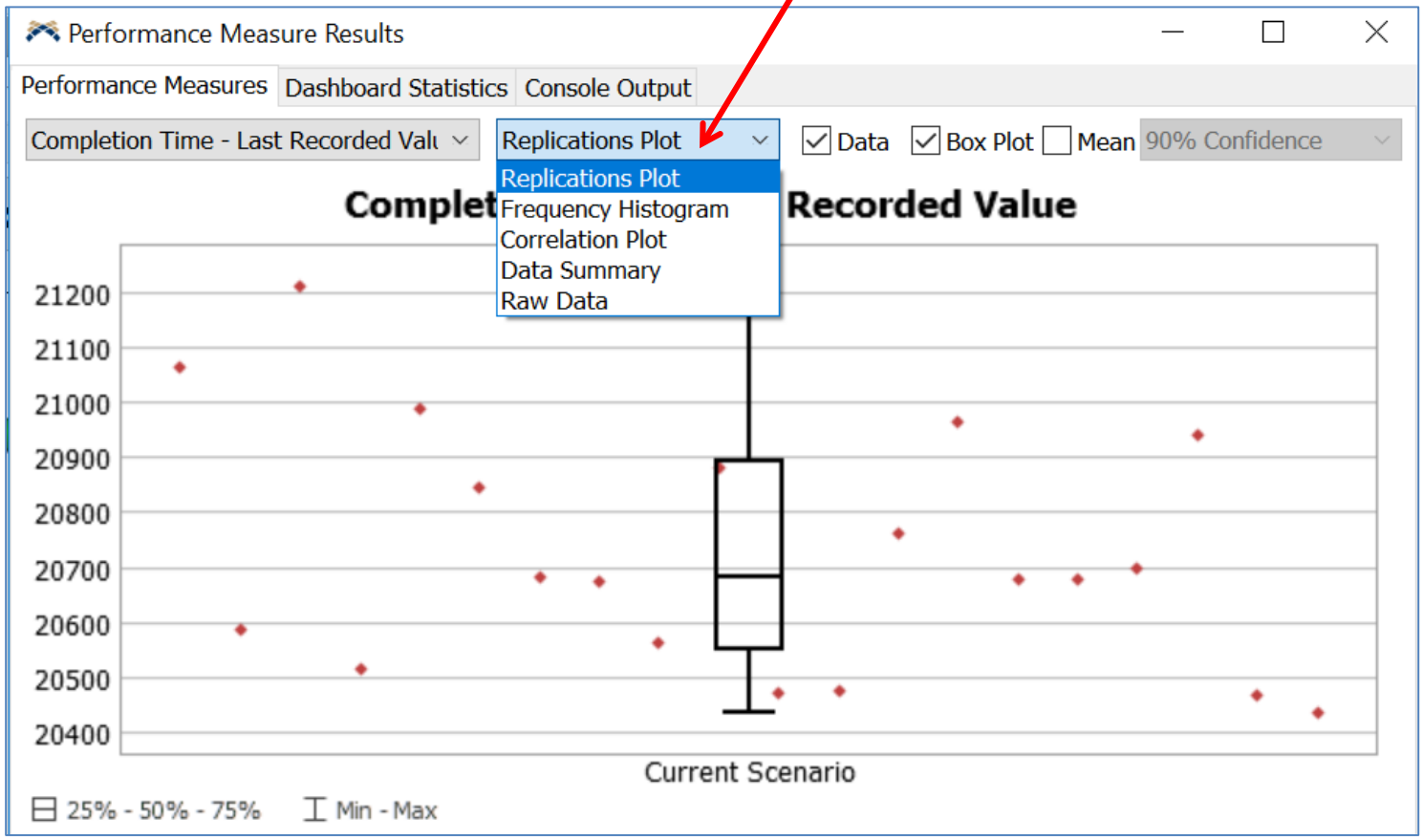
- Set number of replications
- Set run time value to be greater than completion time



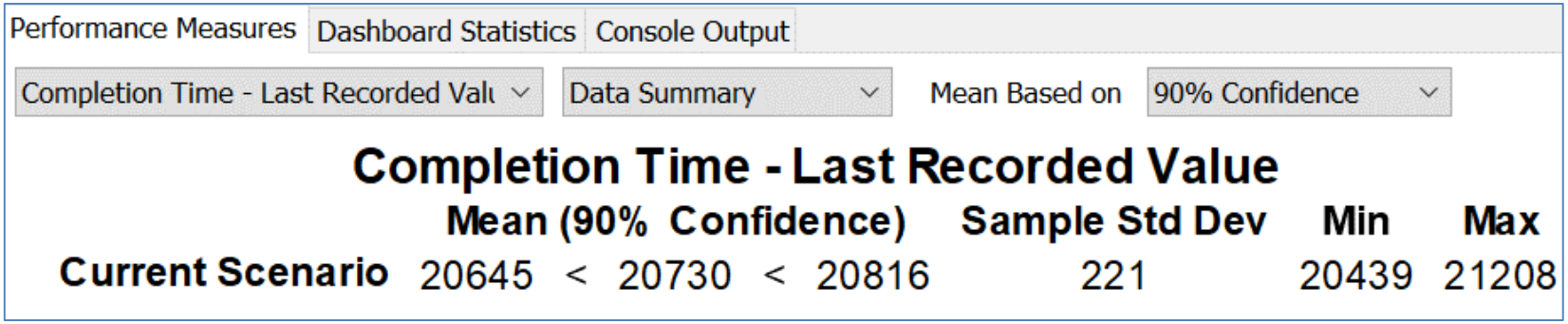
Performance Measure Results

Results -

- Which one have you seen in P11?



Simulation Result – Completion Time



Mean completion time of 20 runs = 20730 seconds or 345.5 minutes

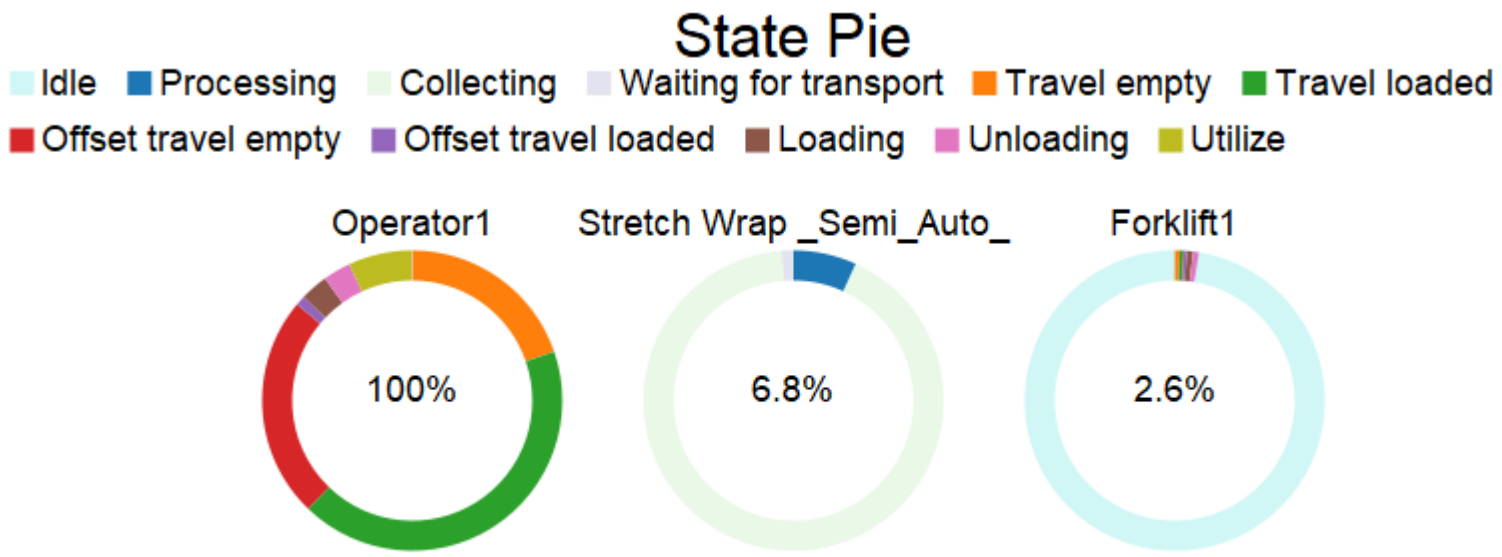
Scenario: Semi-auto Stretch Wrap

- Management's question : Can a semi-auto stretch wrap machine reduce the warehouse outbound time by 30 minutes or more?

- Assume that a shortlisted machine has a process time approximated by normal distribution of mean 55 secs and standard deviation 5 secs.

- Modify your baseline model to simulate this option (save as separate file).

Simulation Results



Completion Time - Last Recorded Value

	Mean (90% Confidence)				Sample Std Dev	Min	Max
Current Scenario	18847	<	18925	<	19003	202	18656	19307

2 Sample t-Test

- We want to statistically prove that the semi-auto stretch wrap machine can improve outbound time by more than 1800 seconds
- Use 2-Sample t-Test under the following assumptions:
  - Collected data are independent of one another;
  - Each of the two samples (current and improved) is drawn from normally distributed population;
  - The two populations have equal variances
- Statistical hypotheses
  - **Null hypothesis (H_0)**: The difference in completion time between the current and new process is equal to 1800 seconds;
  - **Alternative hypothesis (H_1)**: The difference in completion time between the current and new process is more than 1800 seconds.

Data for 2-Sample t-Test

Get 20 sets of results from Experimenter

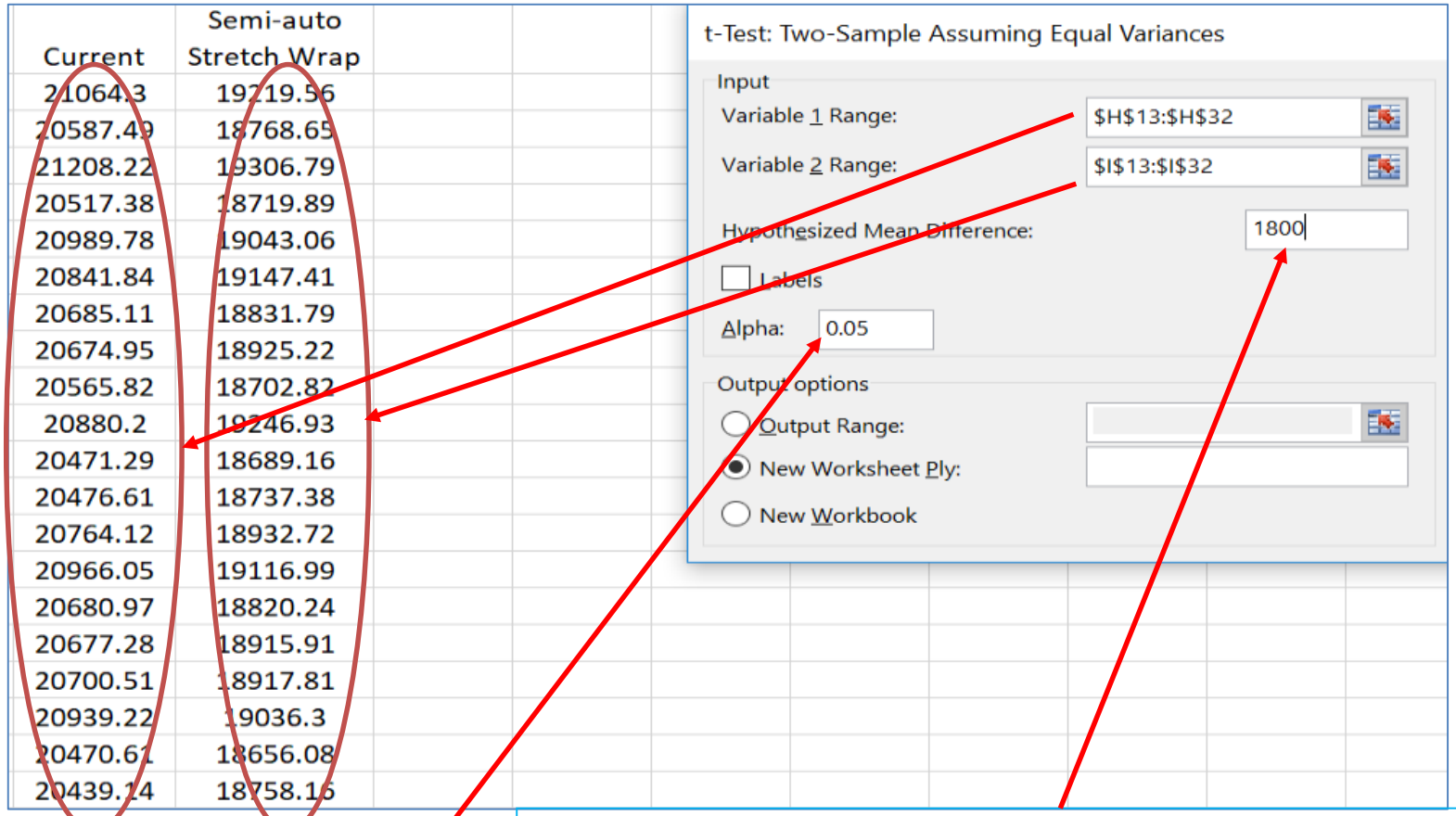
Data for 2-Sample t-Test

	Completion Time (Seconds)			
	Manual stretch wrap (current)		Semi-auto stretch wrap (new)	
	21064.3	20471.29	19219.56	18689.16
	20587.49	20476.61	18768.65	18737.38
	21208.22	20764.12	19306.79	18932.72
	20517.38	20966.05	18719.89	19116.99
	20989.78	20680.97	19043.06	18820.24
	20841.84	20677.28	19147.41	18915.91
	20685.11	20700.51	18831.79	18917.81
	20674.95	20939.22	18925.22	19036.3
	20565.82	20470.61	18702.82	18656.08
	20880.2	20439.14	19246.93	18758.16
Average	20730s or 345.5mins		18925s or 315.4mins	

Average Difference >1800s

Statistical Comparison: 2-Sample t-Test

Excel>Data>Data Analysis>t-Test: Two-Sample Assuming Equal Variances.



Current	Semi-auto Stretch Wrap
21064.3	19719.56
20587.49	18768.65
21208.22	19306.79
20517.38	18719.89
20989.78	19043.06
20841.84	19147.41
20685.11	18831.79
20674.95	18925.22
20565.82	18702.82
20880.2	19246.93
20471.29	18689.16
20476.61	18737.38
20764.12	18932.72
20966.05	19116.99
20680.97	18820.24
20677.28	18915.91
20700.51	18917.81
20939.22	19036.3
20470.61	18656.08
20439.14	18758.16

Level of significance

The improvement in time (between the current and proposed alternative) you want to statistically prove

2-Sample t-test Results Using Excel Data Analysis

t-Test: Two-Sample Assuming Equal Variances		
	Variable 1	*Variable 2*
Mean	20730.0445	18924.6435
Variance	48960.61036	40817.32865
Observations	20	20
Pooled Variance	44888.9695	
Hypothesized Mean Difference	1800	
df	38	
t Stat	0.080612866	
P(T<=t) one-tail	0.468086455	
t Critical one-tail	1.68595446	
P(T<=t) two-tail	0.936172911	
t Critical two-tail	2.024394164	

- Compare t-statistic with critical value (one-tail):

  t-statistic < critical value

- Or compare P-value with level of significance (one-tail):

  P-value > 0.05

- Conclusion: Do not reject H_0 and conclude that there is no strong evidence to suggest that the difference in completion time between current and new process is more than 1800 seconds.

Experimentation & Solutioning

P12 Submission Exercise

- Suggest 1 other alternative that company can adopt to improve the outbound process *[team brainstorm]*
- Modify the existing model and simulate the alternative *[individual work]*
- Perform 2 sample t-Test to prove whether the alternative will statistically improve the outbound time **by more than 150 minutes** *[individual work]*
- Upload your Flexsim models and Excel t-Test file. Make sure the hypothesis and test conclusion are stated clearly in the Excel.

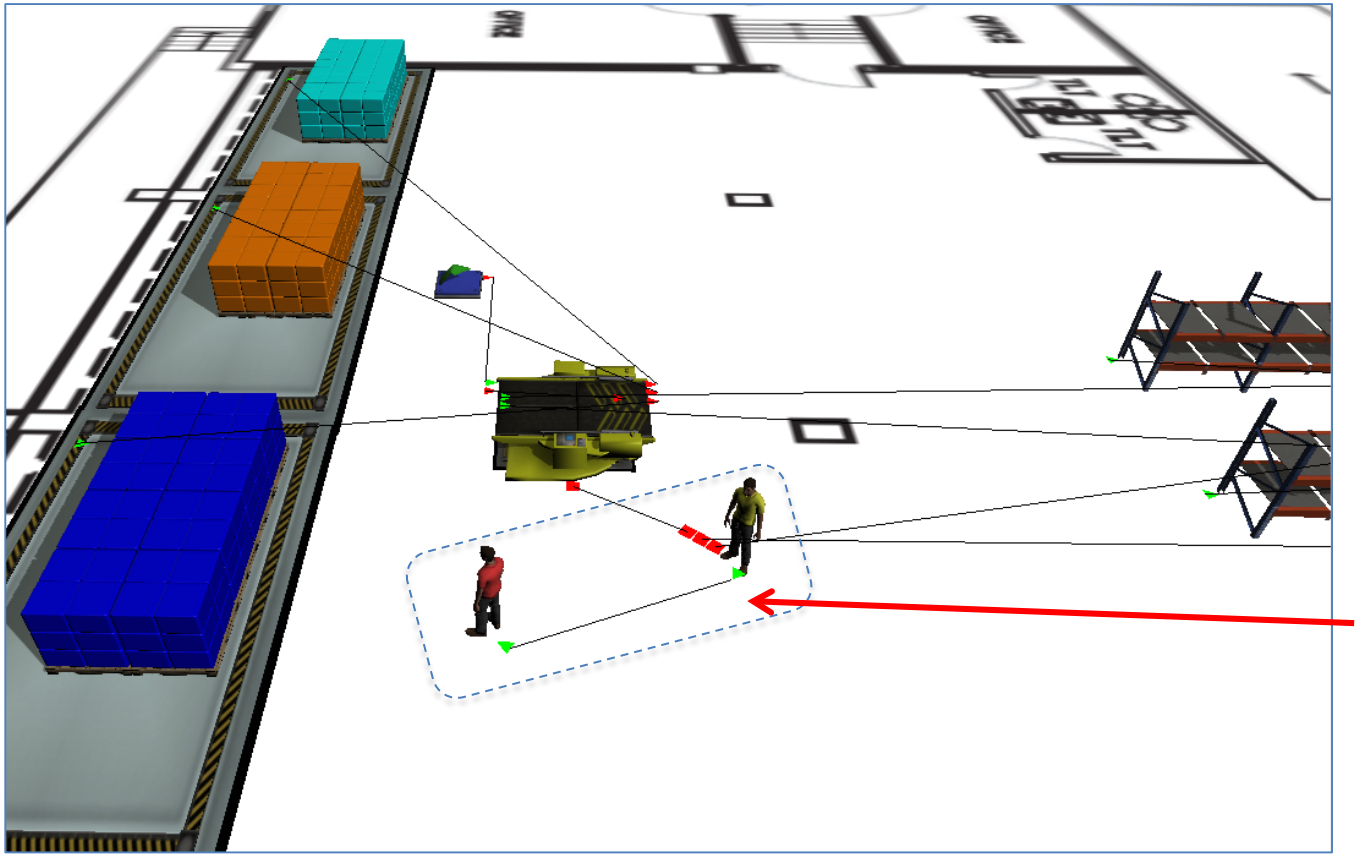
Proposed Alternative

- Based on existing model results, we determine that the bottleneck is at the picking operations.

- Instead of hiring 1 more operator, we can reassign the forklift driver to picking operations. The pallets will then be moved to the staging areas by the operators using a pallet jack.

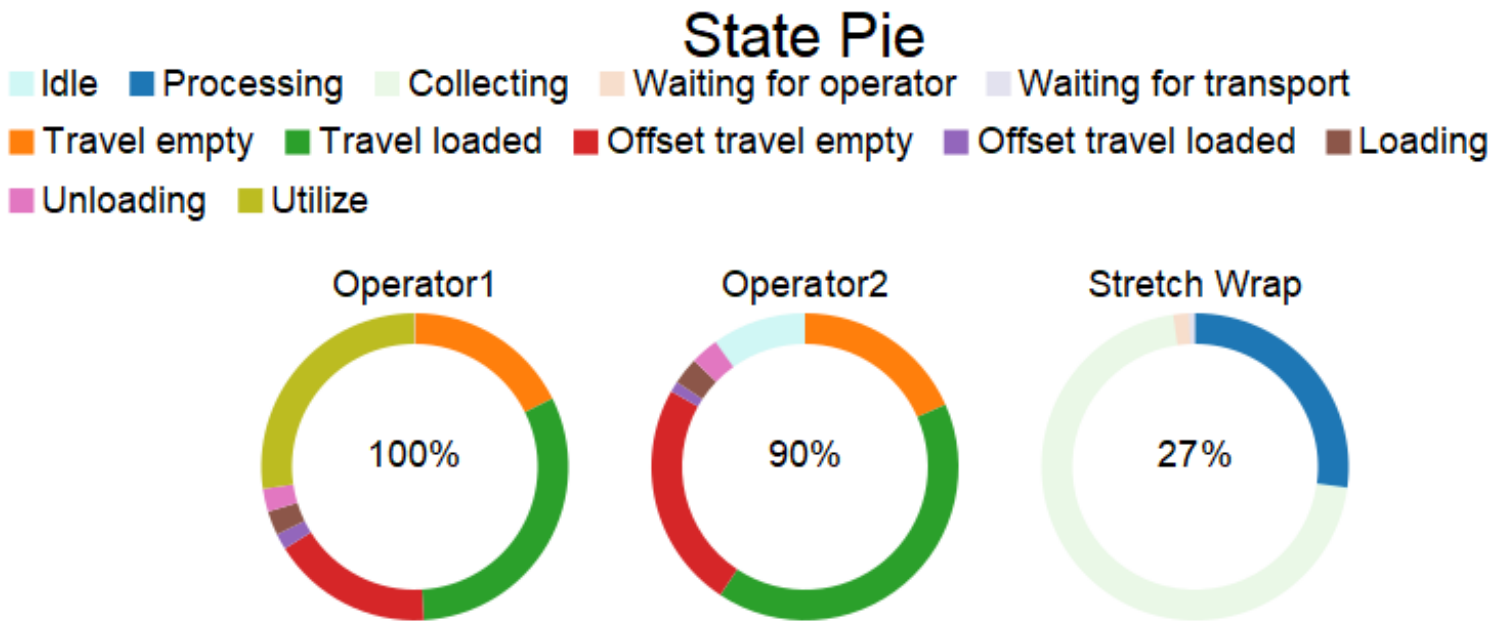
- We will test the claim that the improvement in outbound time will be more than 150 minutes (a lot greater than the purchase-new-machine alternative).

Proposed: Two Operators and no Forklift



Daisy chain connection:
'A' key connection from Operator 1 (who is connected to Objects) to Operator 2

Simulation Results



Completion Time - Last Recorded Value

	Mean (90% Confidence)			Sample Std Dev	Min	Max
Current Scenario	11356	< 11412	< 11468	145	11176	11738

Statistical Comparison: 2-Sample t-Test

Completion Time (Seconds)			
Current		Proposed alternative of 2 Operators, no Forklift	
21064.3	20471.29	11586.14	11175.62
20587.49	20476.61	11366.55	11325.98
21208.22	20764.12	11738.34	11343.53
20517.38	20966.05	11260.37	11453.84
20989.78	20680.97	11644.6	11626.71
20841.84	20677.28	11470.34	11415.54
20685.11	20700.51	11433.42	11253.59
20674.95	20939.22	11341.83	11470.32
20565.82	20470.61	11298.64	11312.98
20880.2	20439.14	11336.37	11389.15
20730s or 345.5mins		11412s or 190.2mins	

Average

- Statistical hypotheses
  - **Null hypothesis (H_0)**: The difference in completion time between the current and proposed alternative is equal to 9000 seconds;
  - **Alternative hypothesis (H_1)**: The difference in completion time between the current and proposed alternative is more than 9000 seconds.

Statistical Comparison: 2-Sample t-Test

t-Test: Two-Sample Assuming Equal Variances		
	Variable 1	*Variable 2*
Mean	20730.0445	11412.193
Variance	48960.61036	20946.69039
Observations	20	20
Pooled Variance	34953.65038	
Hypothesized Mean Difference	9000	
df	38	
t Stat	5.376231936	
P(T<=t) one-tail	2.03902E-06	
t Critical one-tail	1.68595446	
P(T<=t) two-tail	4.07803E-06	
t Critical two-tail	2.024394164	

- Compare t-statistic with critical value (one-tail):

  t-statistic > critical value

- Or compare P-value with level of significance (one-tail):

  P-value < 0.05

- Conclusion: Reject H_0 and conclude that the difference in completion time between current and proposed alternative is more than 9000 seconds.

Conclusion

Configuration	Average Completion Time (based on 20 replications)	Hypothesized improvement	2-sample t-Test conclusion
Current	20730 seconds	-	-
New semi-auto stretch wrap machine	18925 seconds	1800 seconds	Do not reject H_0
Add 1 operator to picking (no forklift)	11412 seconds	9000 seconds	Reject H_0

- By observing the simulation and examining the resource utilization results, we identified picking as the bottleneck in the warehouse outbound process.
- To improve the process completion time, we compared 2 alternatives. Simulation results showed that assigning 1 more operator to picking is more effective in reducing the completion time.
- Based on 2-sample t-Test, we made the appropriate conclusion of whether the proposed alternative will significantly improve the completion time by the hypothesized amount.

Learning Objectives

- Construct a simulation model for a typical warehouse outbound process
- Identify bottleneck operations in the process flow through simulation and analysis
- Recommend ways to alleviate bottleneck operations
- Use statistical test to conclude whether the proposed alternative can effectively alleviate the bottleneck

Overview of E211 Operations Planning II Module