

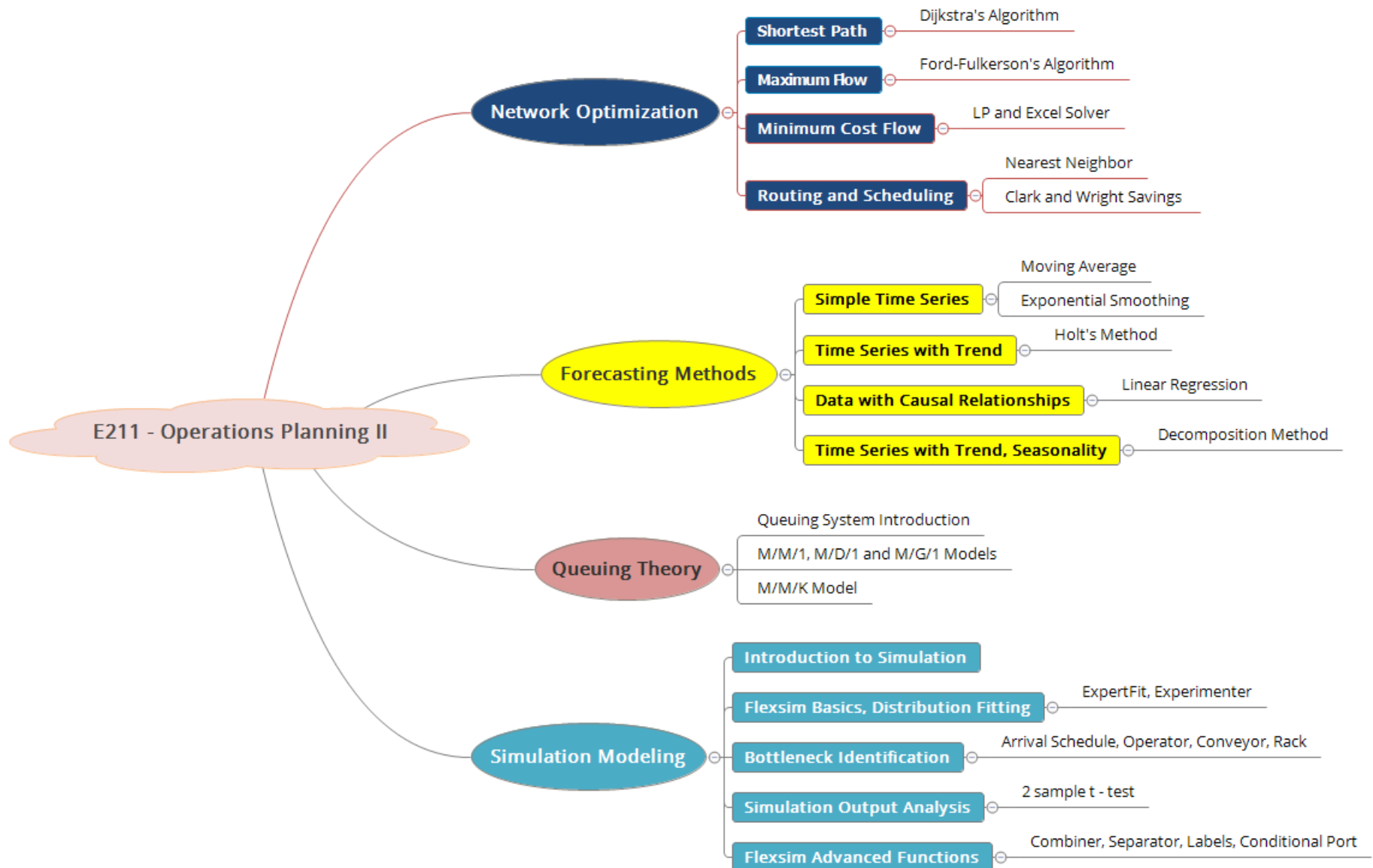
# Problem 12

## Test to Improve

E211 – Operations Planning II

SCHOOL OF  
ENGINEERING

# Module Coverage: E211 Topic Tree



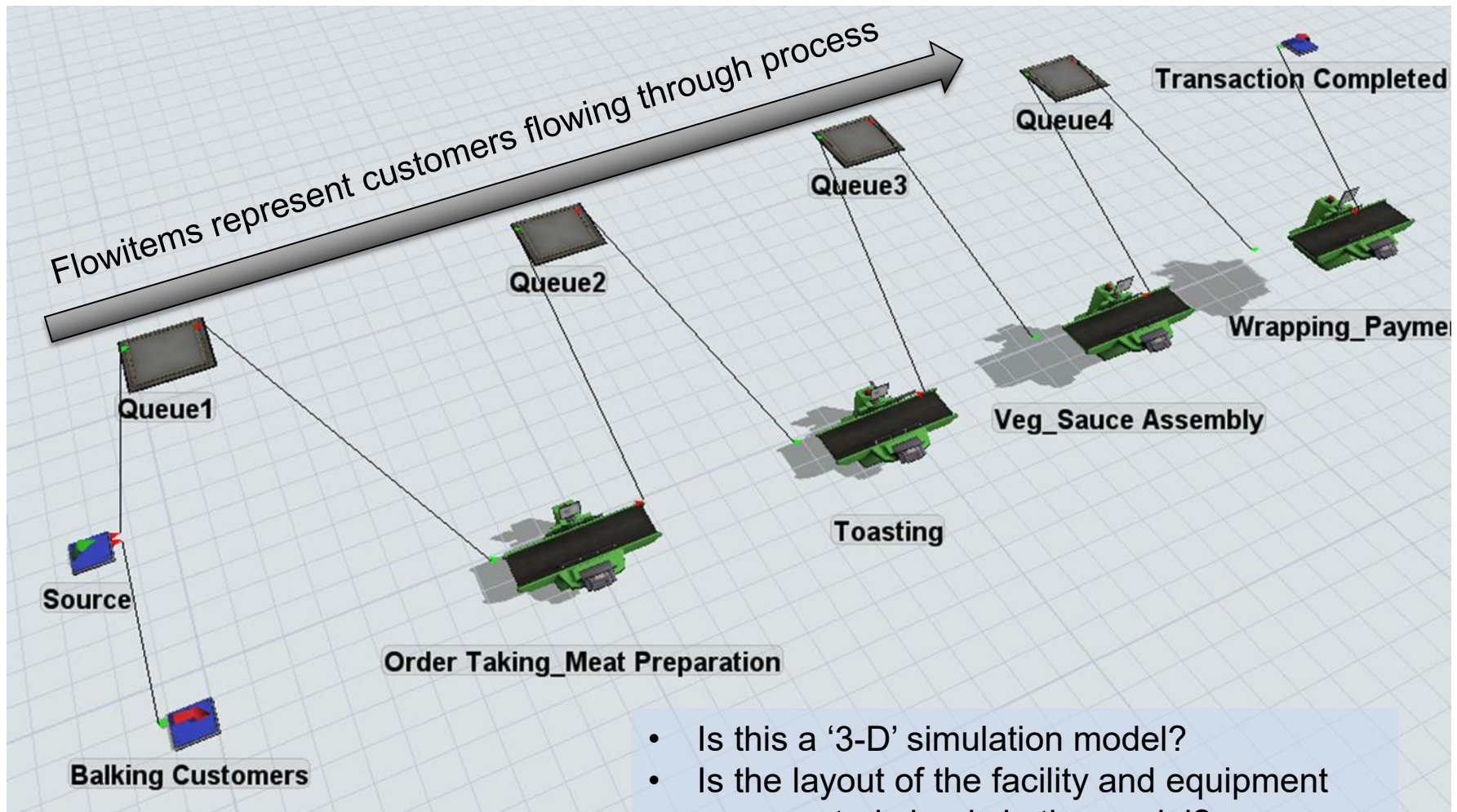
# Learning Objectives

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- 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

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- 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.

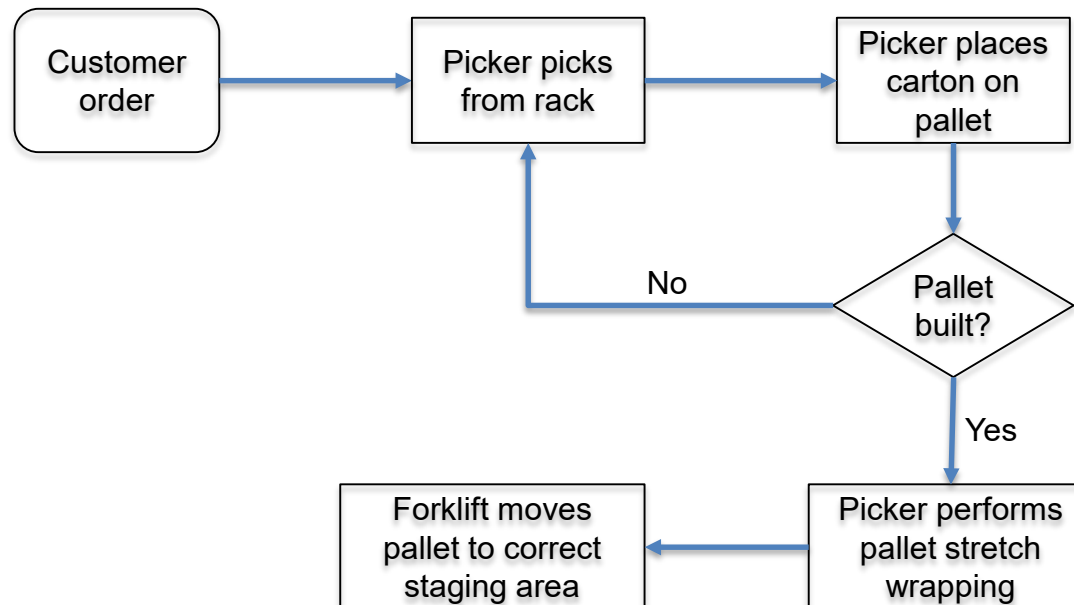
*\*Mixed order requires carton level picking and consolidation to a pallet*

# 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



On left panel, go to Toolbox tab & click on '+'

Select 'Visual' and then 'Model Background' to add the background image

Adjust background image size and orientation

**Background Drawing Wizard**

Background Orientation and Properties

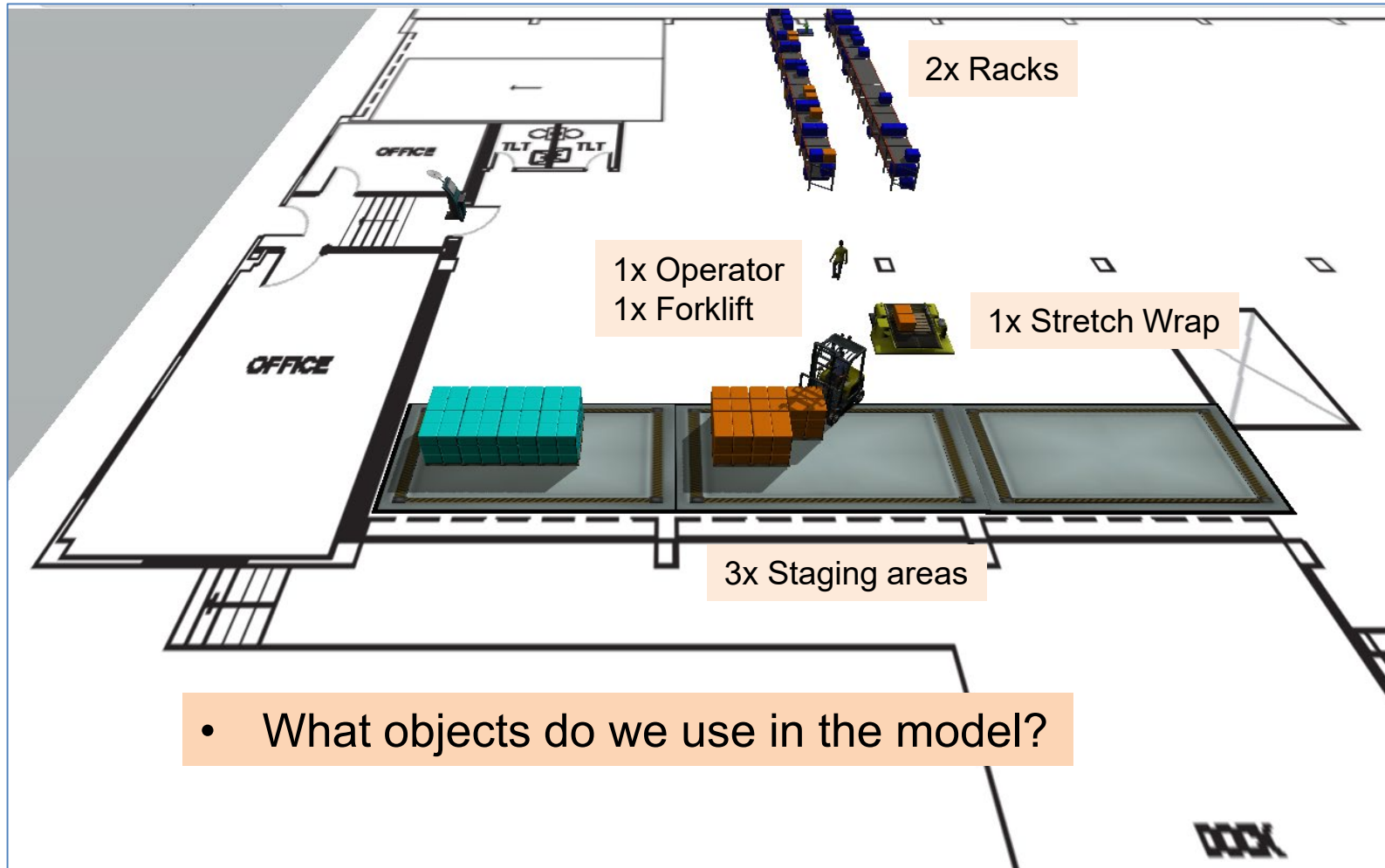
Go to the Properties window for further options.

Position, Rotation, and Size

	X	Y	Z
Position	0.00	0.00	0.00
Rotation	0.00	0.00	-90.00
Size	120.00	70.00	1.00

Properties Delete Background < Back Next >

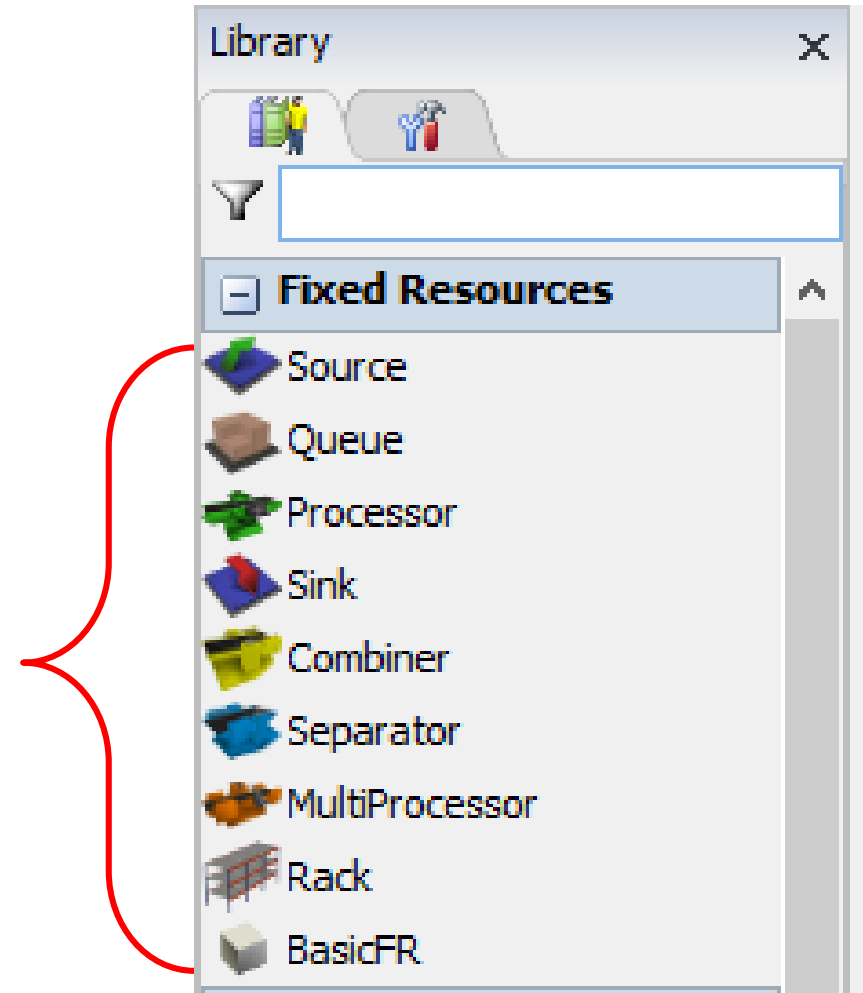
# Overview of Model



# Fixed Resources Objects



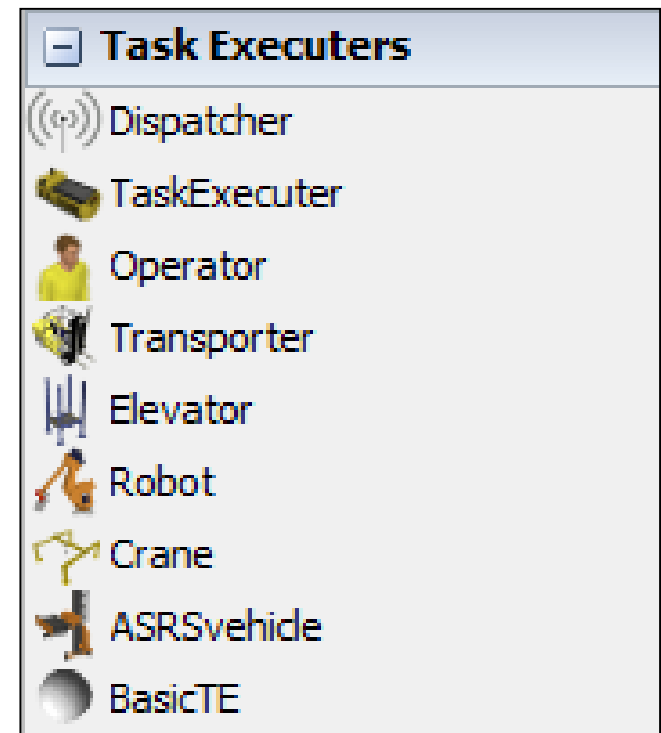
- **FixedResource class** – objects which receive and send flow items, e.g.
  - Processor
  - Queue
  - Rack
- Which object only receives items?
- Which object only sends items?



# Task Executors Objects



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



# Define Source: Generation of Cartons



SourceCartons Properties

SourceCartons

Source | Flow | Triggers | Labels | General

Arrival Style: **Arrival Schedule**

FlowItem Class: **Arrival Schedule**

☐ Repeat Schedule/Sequence

Arrivals: 3 Labels: 1

	ArrivalTime	ItemName	Quantity	Zone
Arrival1	0	Product	96	1
Arrival2	3600	Product	96	2
Arrival3	7200	Product	96	3

## 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

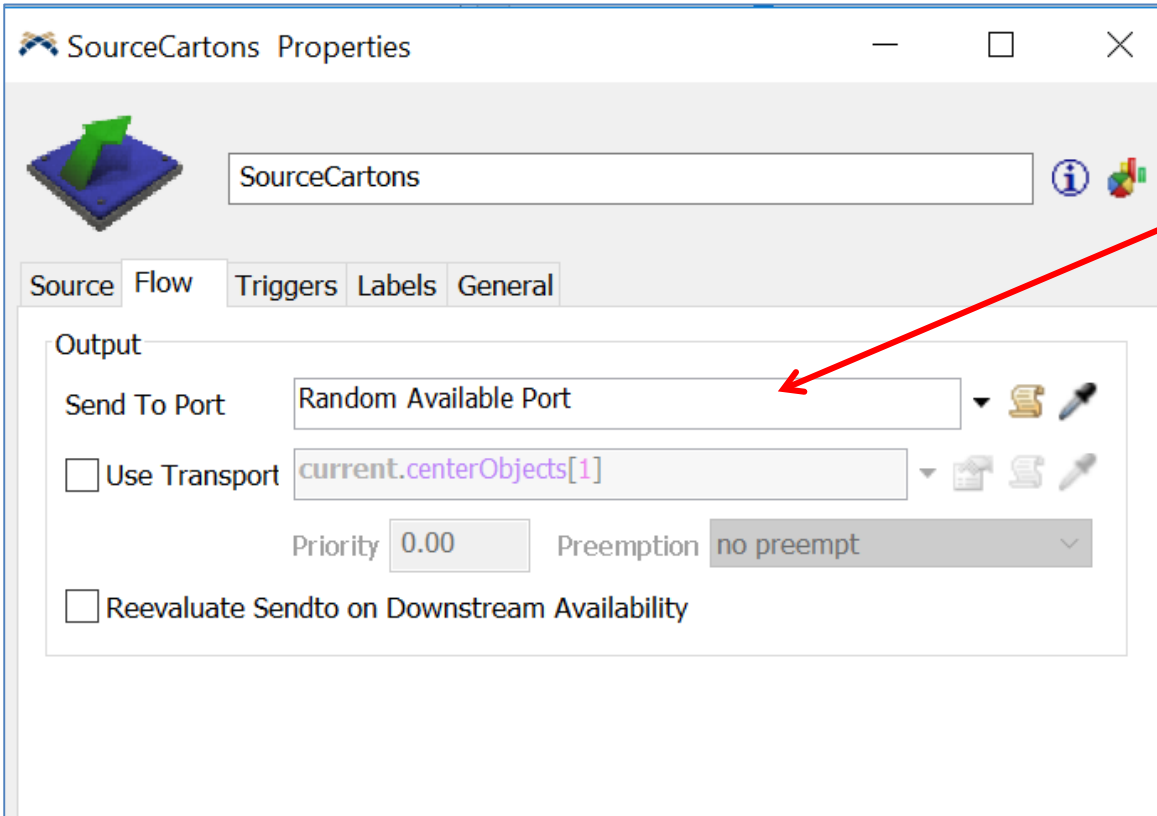
- Create an order release schedule: 96 carton boxes each hour at 3 consecutive hours

# Where do the Cartons Go?



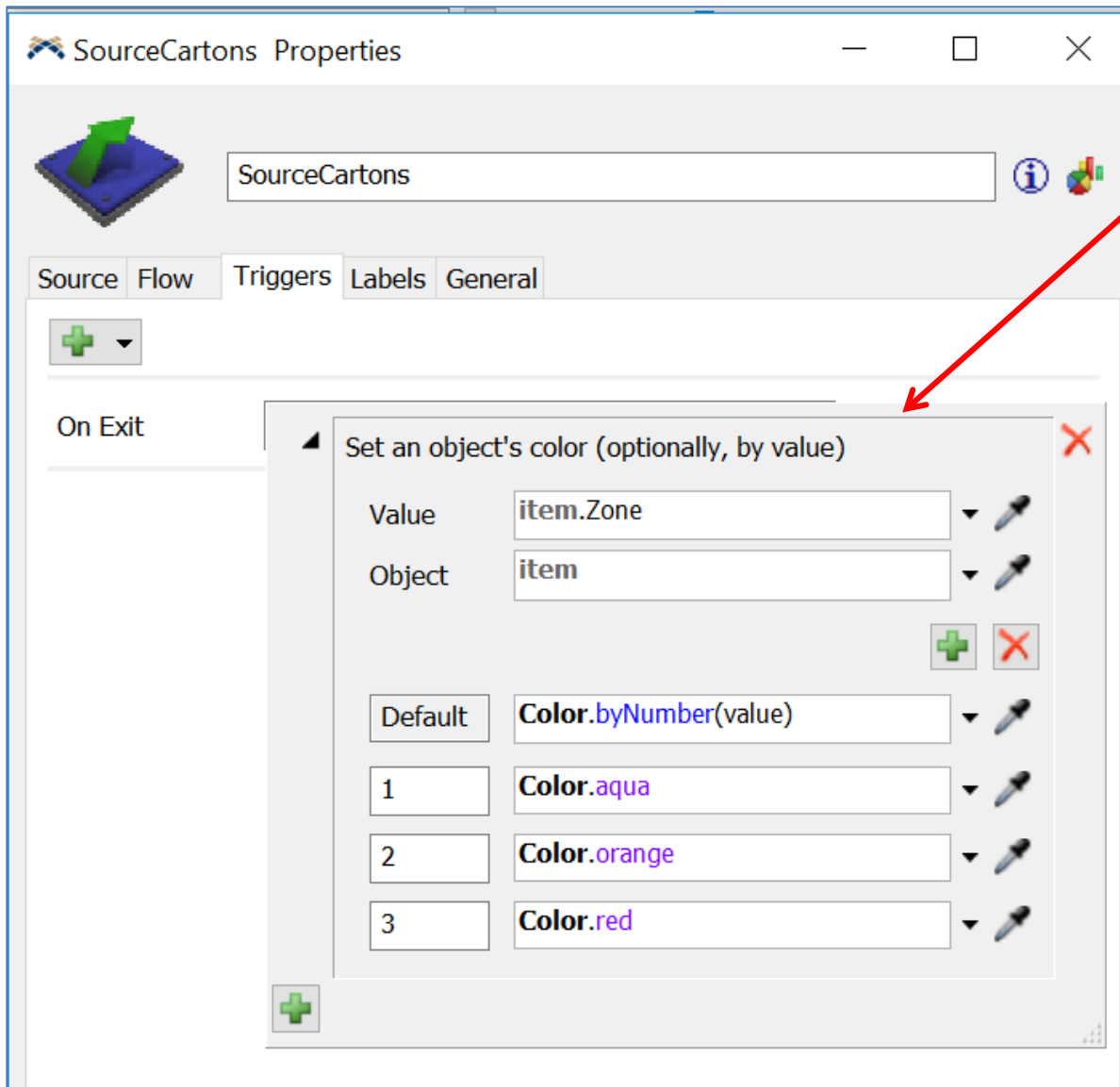
## Send to Port -

- 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



Rack1 Properties

Rack1

Rack SizeTable Flow Triggers Labels General

Visuals

☐ Floor Storage ☐ Mark shelves that have called a transporter

☒ Extend Columns ☐ Hide Floor

Shelf tilt amount 0.00 Picking/Placing Y Offset 0.00

Column Spacing 2 Opacity 1.00

Logic

Place in Bay Random Bay **if** Available

Place in Random Level **if** Available

Minimum Dwell By Expression

Maximum Content 150

## 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



Rack1 Properties

Rack1

Rack SizeTable Flow Triggers Labels General

Basic

Number of Bays  Number of Levels

Width of Bays  Height of Levels

Apply Basic Settings

Advanced

Bay 1

Bay Width

Level Location

Level Heights

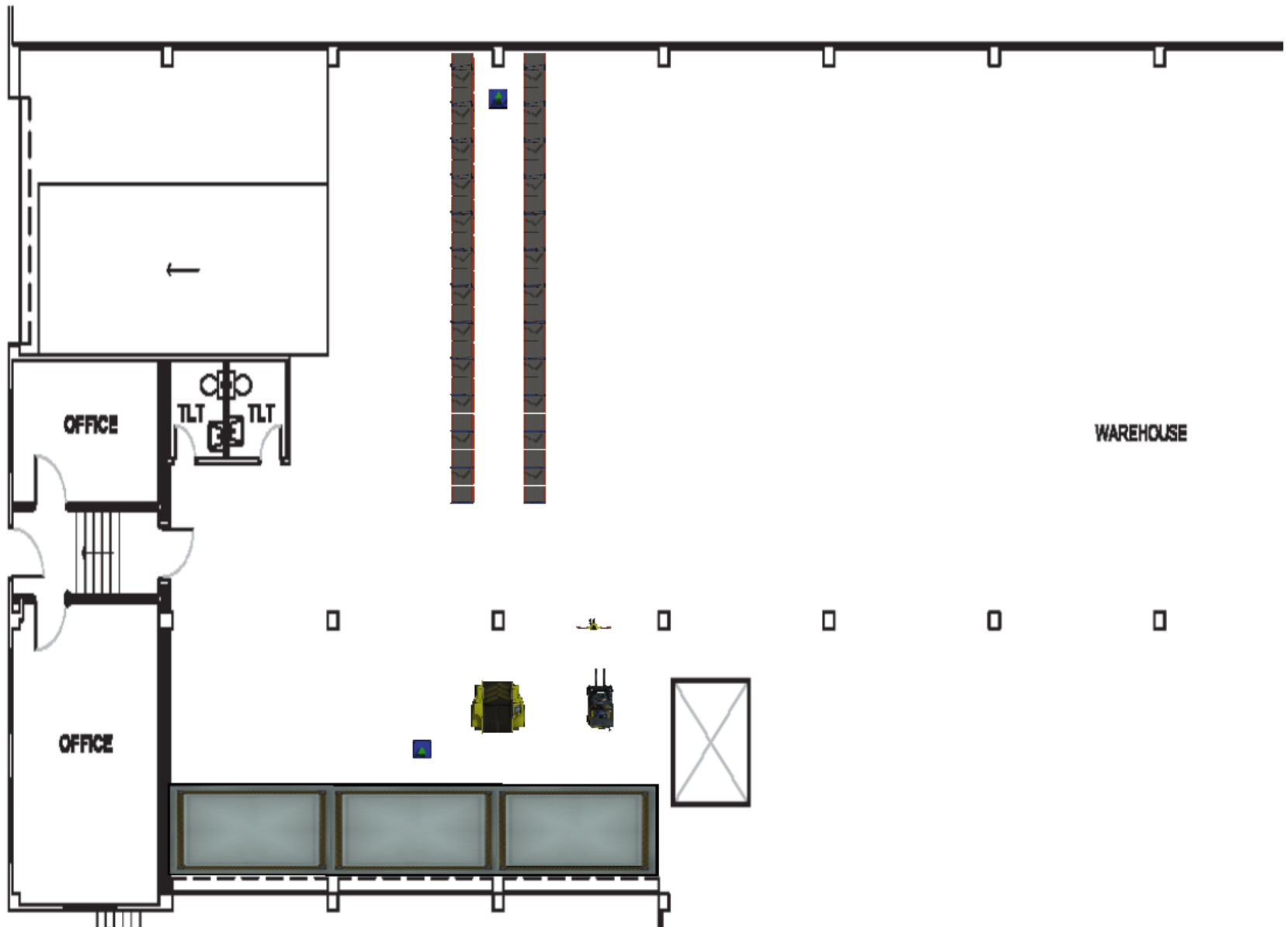
Level1	0.70
Level2	0.70
Level3	0.70

## 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



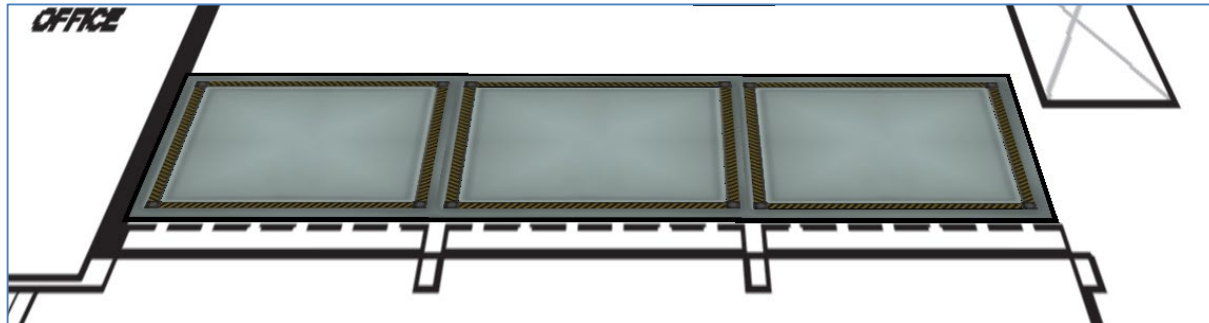
# *Buddy Pair-Up 1*

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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



Stretch Wrap Properties

Stretch Wrap

ProcessTimes Breakdowns Combiner Flow Triggers Labels General

Setup Time 0

☐ Use Operator(s) for Setup Number of Operators 1

☒ Use Setup Operator(s) for both Setup and Process

Process Time triangular(90, 180, 120, getstream(current))

☒ Use Operator(s) for Process Number of Operators 1

Pick Operator current.centerObjects[1]

Priority 9.00 Preemption preempt only

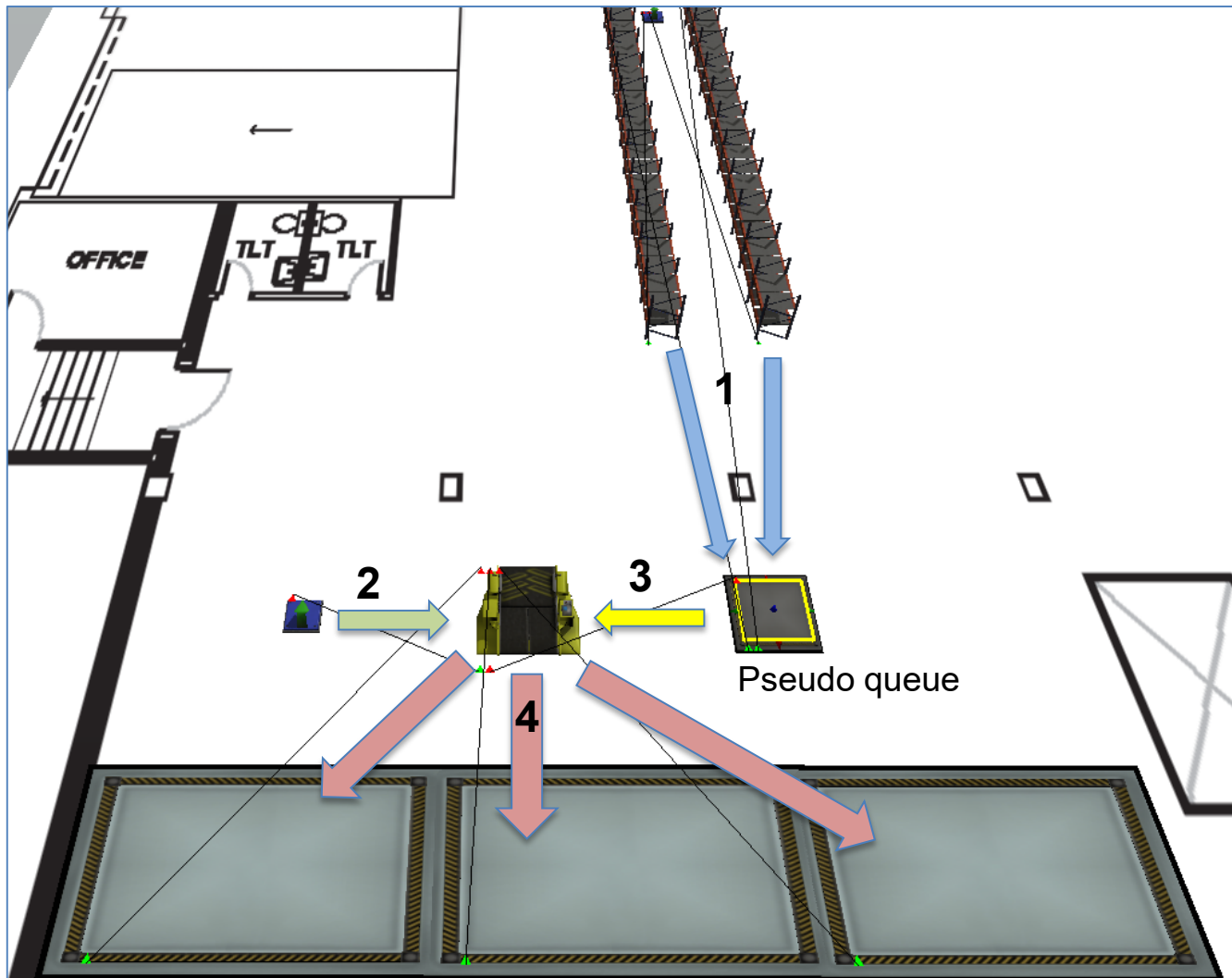
## Process Time -

- 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



Queue1

Queue Flow Triggers Labels General

Maximum Content 2

☐ LIFO

Batching

☐ Perform Batching

Target Batch Size 2

Max Wait Time 0.00

☐ Flush contents between batches

Visual

Queue1

Queue Flow Triggers Labels General

Output

Send To Port First available

☐ Use Transport current.centerObjects[1]

Priority 0.00 Preemption no preempt

☐ Reevaluate Sendto on Downstream Availability

Input

☒ Pull Strategy Longest Waiting

Pull Requirement No Requirement

## 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'.

Components List	Target Quantity
From Input Port 2	12.00

Specify number of items to pack coming from Port 2.

# Pallet Source for Combiner



PalletSource Properties

PalletSource

Source Flow Triggers Labels General

Arrival Style: Arrival Schedule

FlowItem Class: Pallet

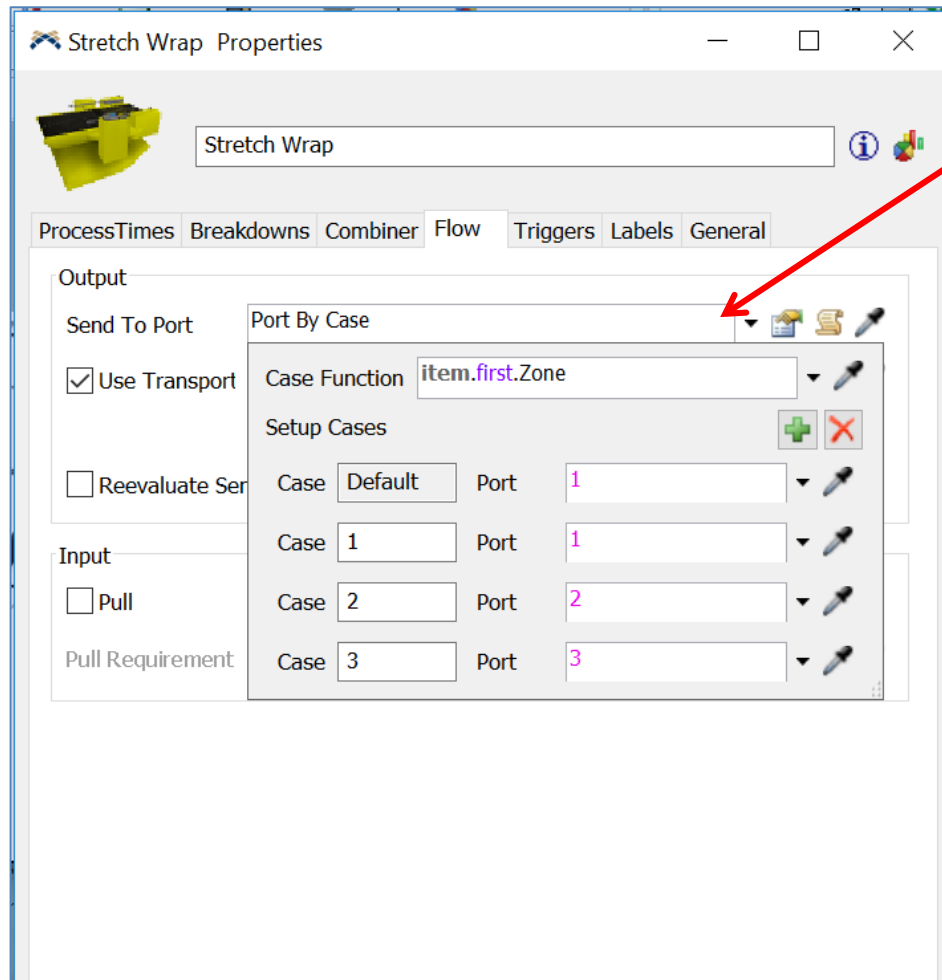
☐ Repeat Schedule/Sequence

Arrivals: 1 Labels: 0

	ArrivalTime	ItemName	Quantity
Arrival1		0 Product	24

- 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*

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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 Executors



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

The image displays two side-by-side property windows for simulation entities: 'Operator1' and 'Forklift1'. Both windows have tabs for 'Operator', 'Breaks', 'Collision', 'Triggers', 'Labels', and 'General'. A red rectangle highlights the 'General' tab settings for both entities.

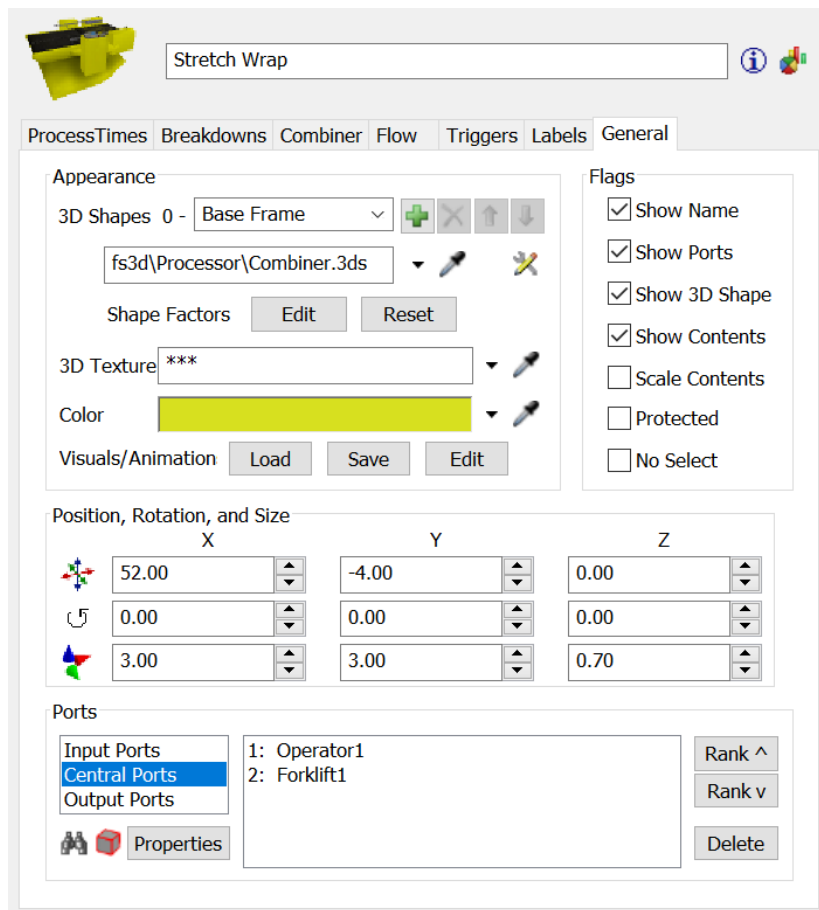
**Operator1 Properties (General Tab):**

- ☒ Do Operator Animations
- Shape: Male
- Capacity: 1
- Acceleration: 1.00
- Flip Threshold: 180
- Max Speed: 0.83
- Deceleration: 1.00
- ☒ Rotate while travelling
- Travel offsets for load/unload tasks
- Load: 2
- Unload: 2
- Break To: New Tasksequences Only
- Dispatcher: PassTo: First Available
- Queue Strategy: Sort by TaskSequence Priority
- Navigator: DefaultNavigator
- ☒ Fire OnResourceAvailable at Simulation Start

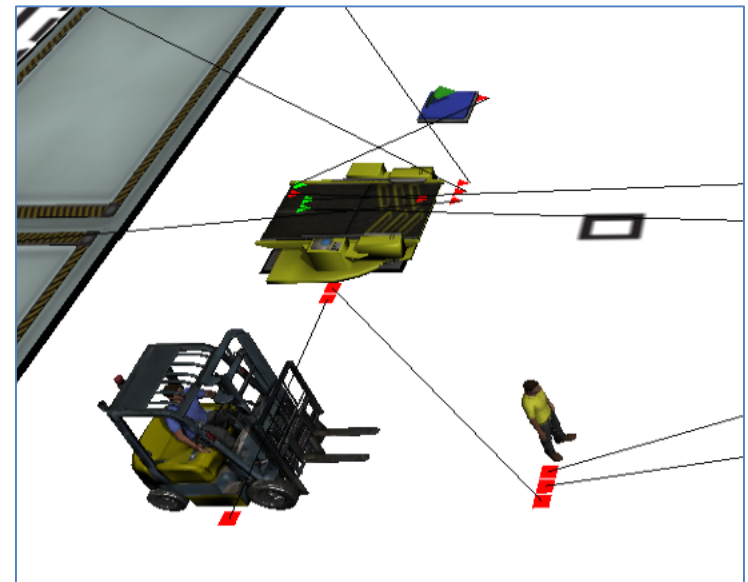
**Forklift1 Properties (General Tab):**

- ☒ Do Transporter Animations
- Lift Speed: 1.00
- Capacity: 1
- Acceleration: 1.00
- Flip Threshold: 180
- Max Speed: 2.00
- Deceleration: 1.00
- ☒ Rotate while travelling
- Travel offsets for load/unload tasks
- Load: 5
- Unload: 5
- Break To: New Tasksequences Only
- Dispatcher: PassTo: First Available
- Queue Strategy: Sort by TaskSequence Priority
- Navigator: DefaultNavigator
- ☒ Fire OnResourceAvailable at Simulation Start

# Connecting Task Executors: 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.

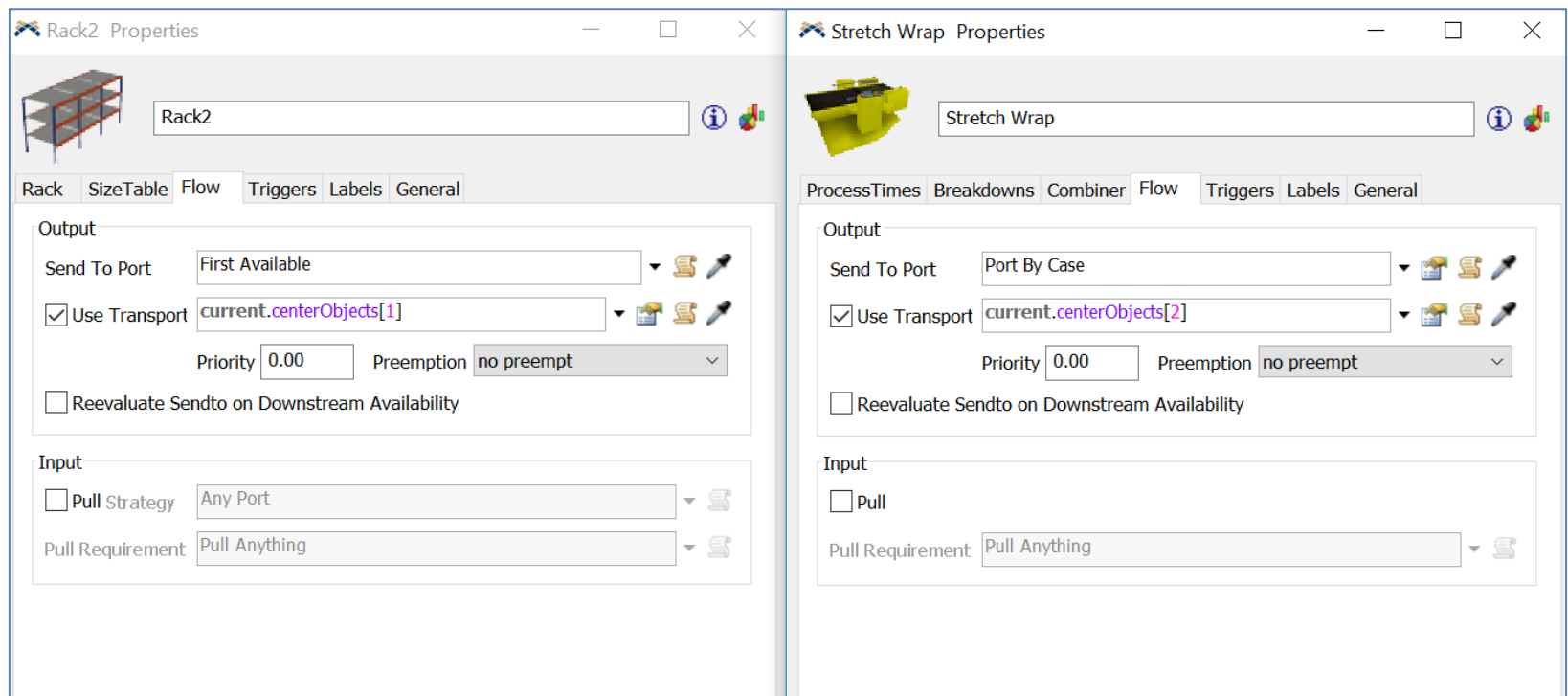


- Connect Operator to the 2 racks and the combiner.
- Connect Forklift to the combiner
- Verify the connections in object properties page

# 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)

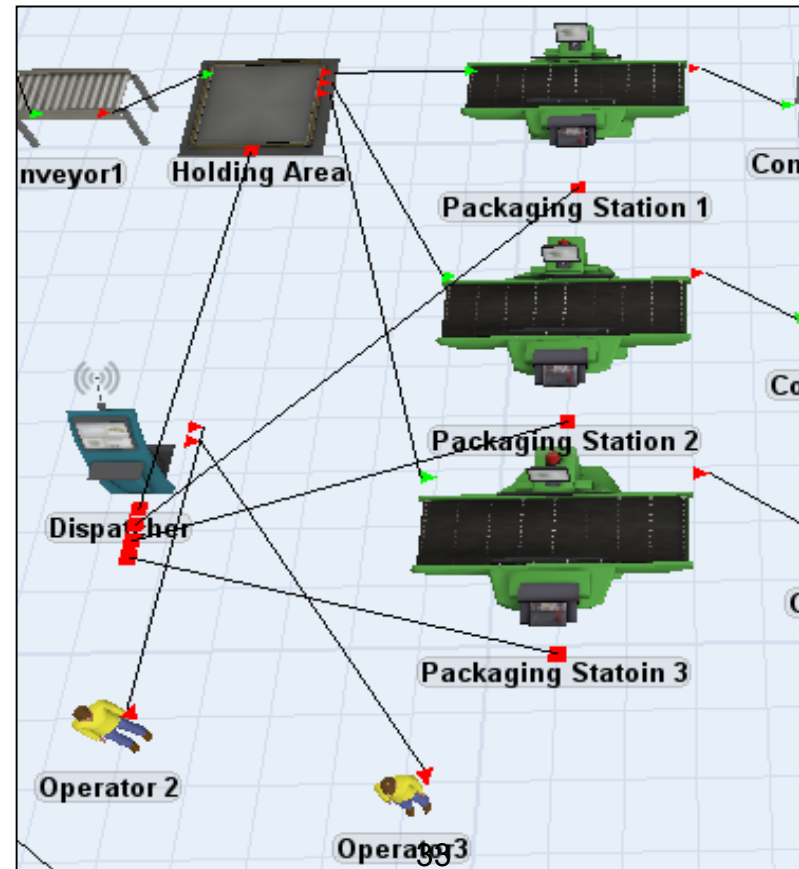
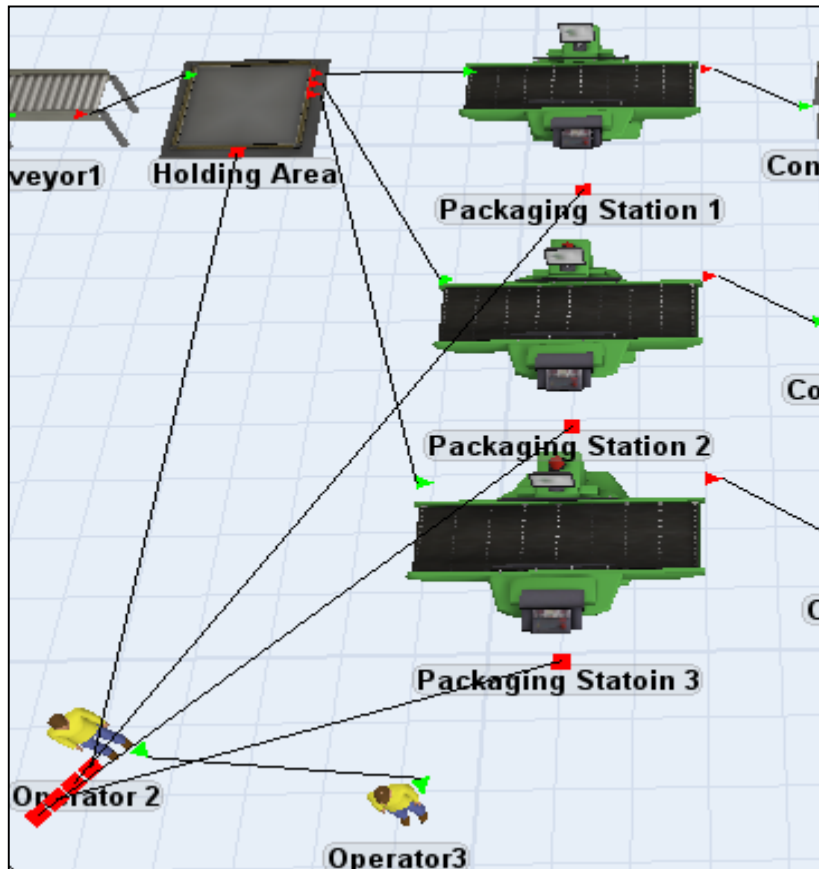


+ check 'Use operator' for Stretch Wrap process

# 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)



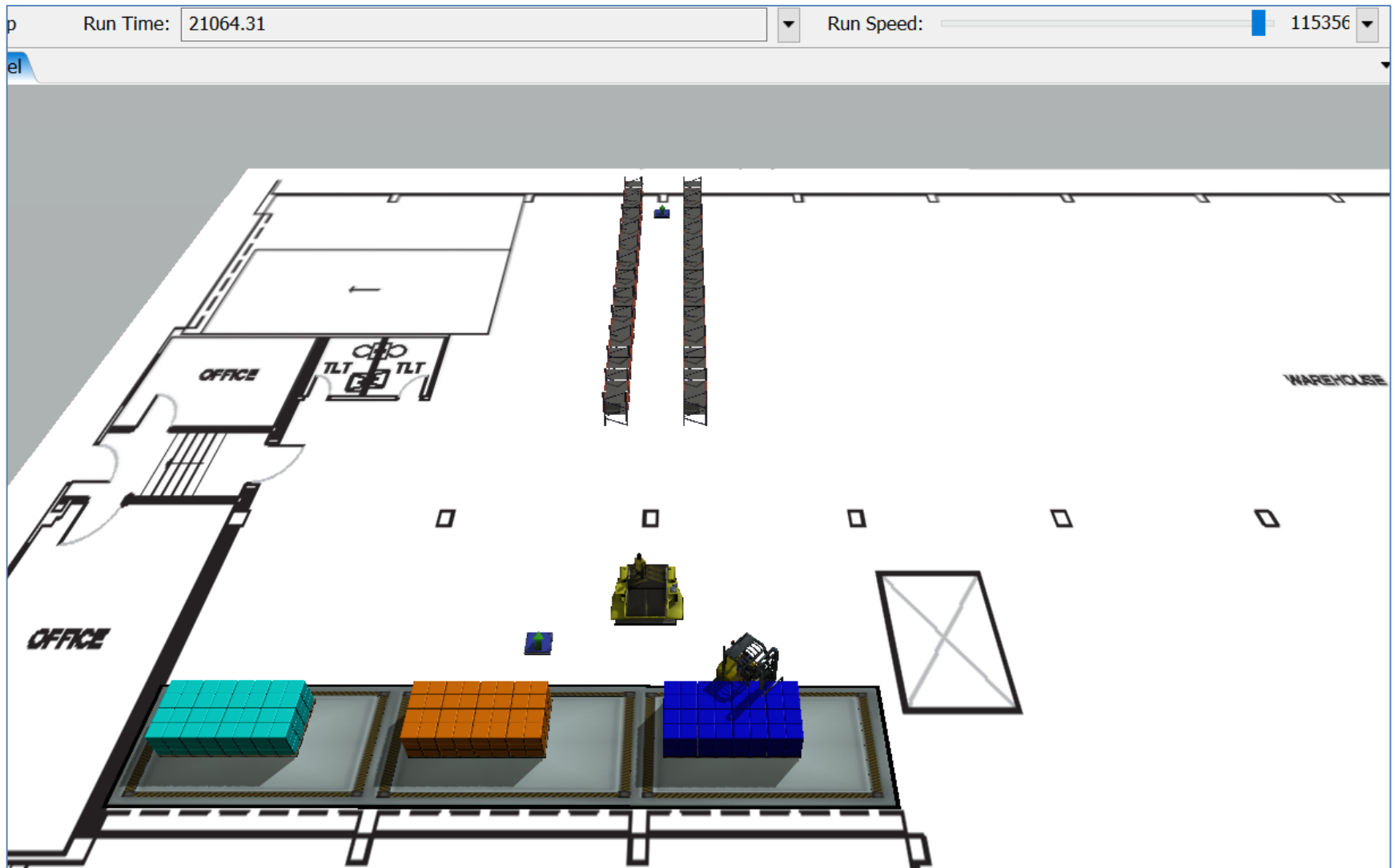
## *Buddy Pair-Up 3*

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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

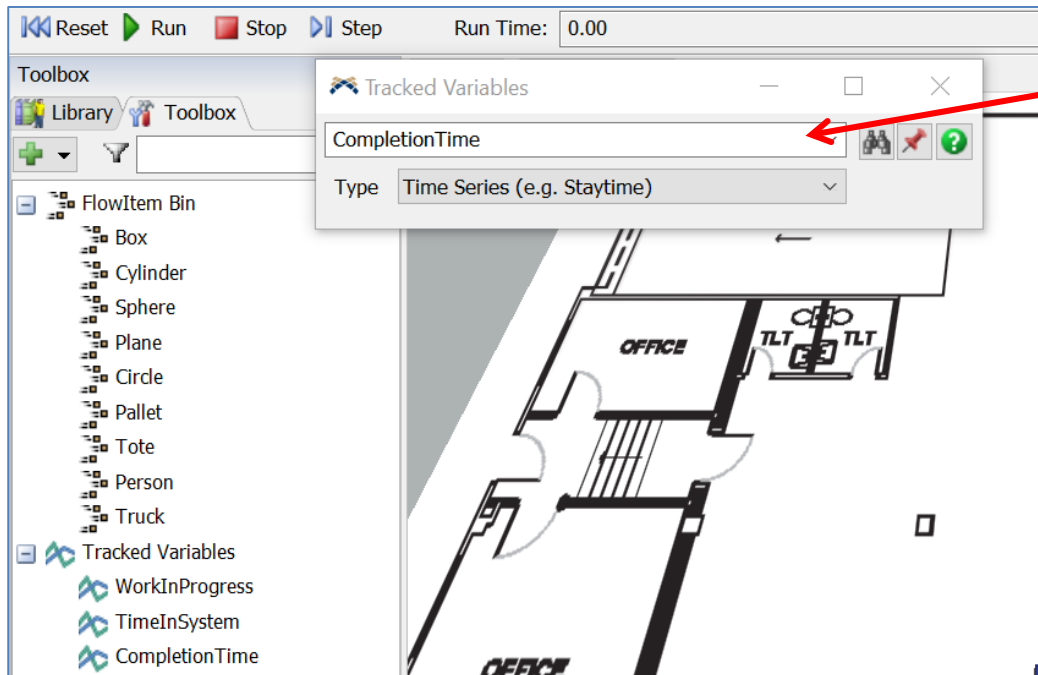


The screenshot shows a software interface for tracking resource utilization. The left sidebar contains a list of templates under 'State Templates' and 'Zone Templates'. The 'State Pie' template is selected. The main area shows the 'State Pie' configuration window. The 'Objects' list includes 'Operator1', 'Stretch Wrap', and 'Forklift1'. The 'States' table lists various states with their analysis status and color.

	Display Name	Analysis	Visible	Color
idle - 1	Idle		✓	
processing - 2	Processing	Utilized	✓	
blocked - 4	Blocked		✓	
collecting - 7	Collecting		✓	
waiting for operator - 9	Waiting for operat		✓	
waiting for transport - 10	Waiting for transp		✓	
travel empty - 14	Travel empty	Utilized	✓	
travel loaded - 15	Travel loaded	Utilized	✓	
offset travel empty - 16	Offset travel empt	Utilized	✓	

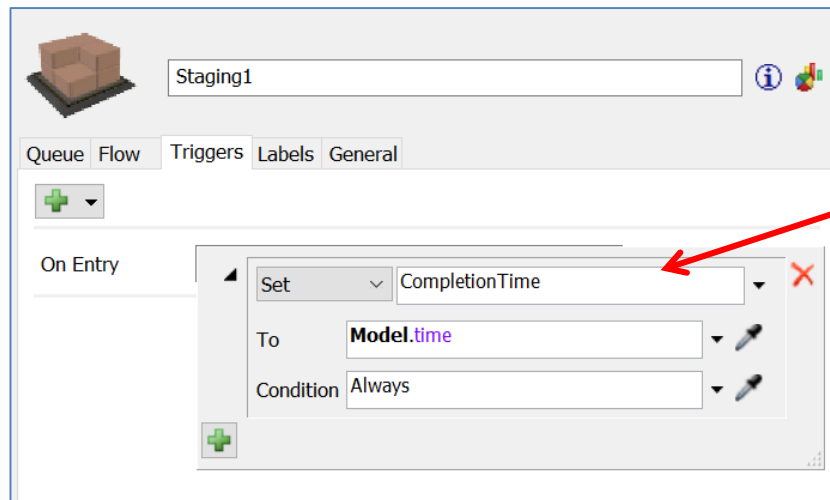
- Add '**State Pie**' from Dashboard library
- Add Operator, Stretch Wrap and Forklift objects to track
- Click on 'collecting – 7' cell under Analysis until the cell is blank. This is to ensure that collecting state is not considered as part of utilization.

# 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

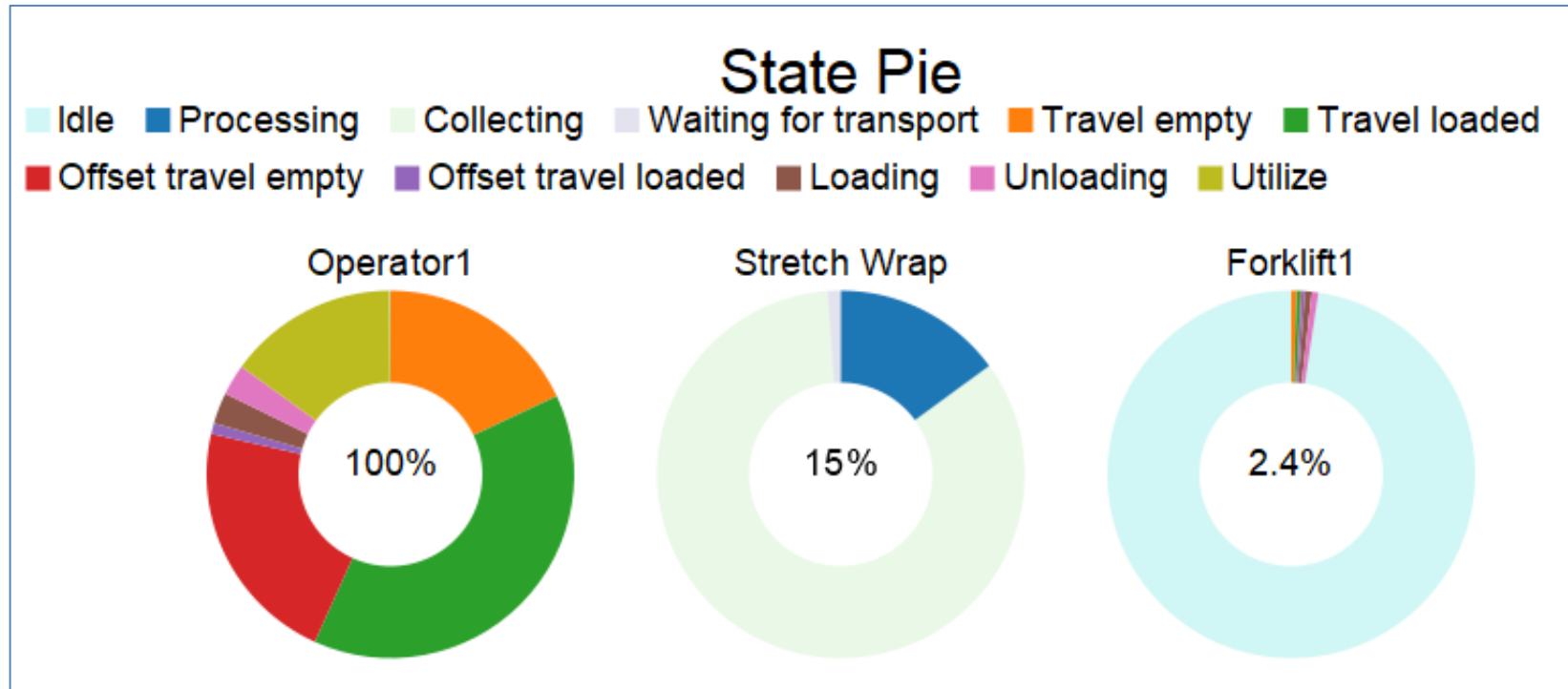
# Team Discussion

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- 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?*

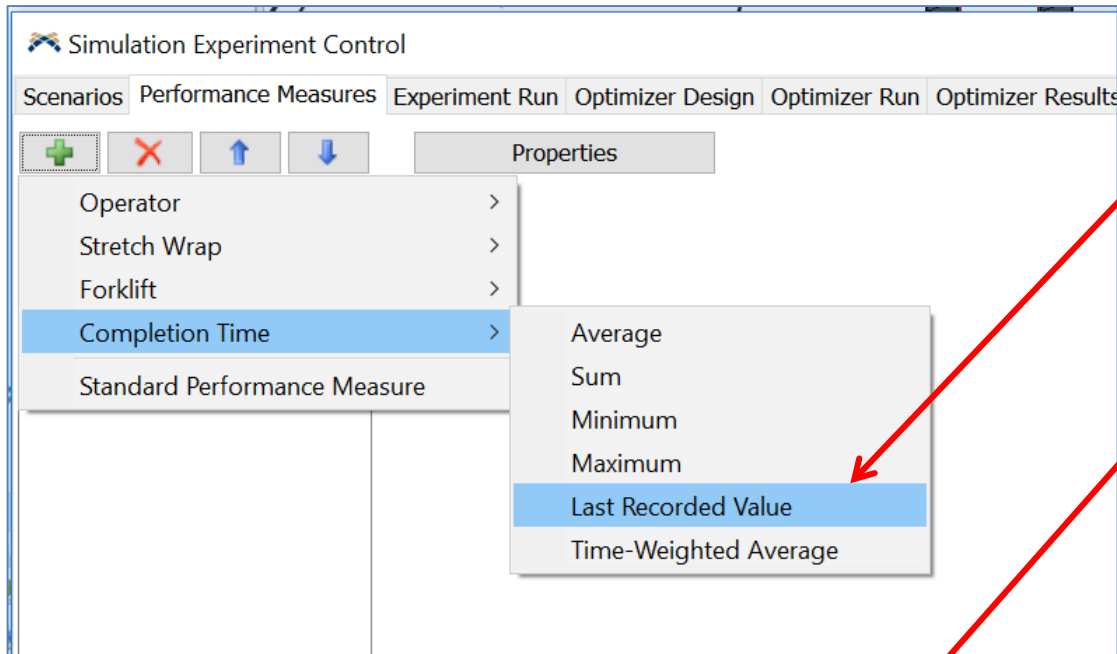
*What does the Stretch Wrap machine do most of the time?*

# 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

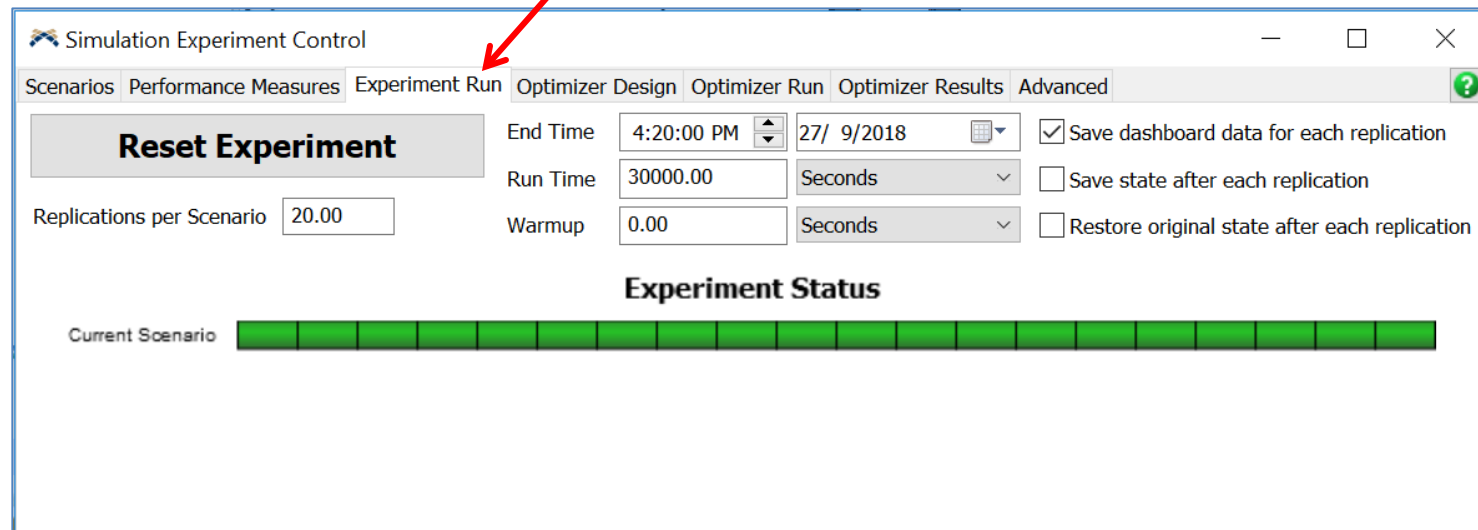


## Performance Measures -

- Add Completion Time 'Last Recorded Value'

## Experiment Run -

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

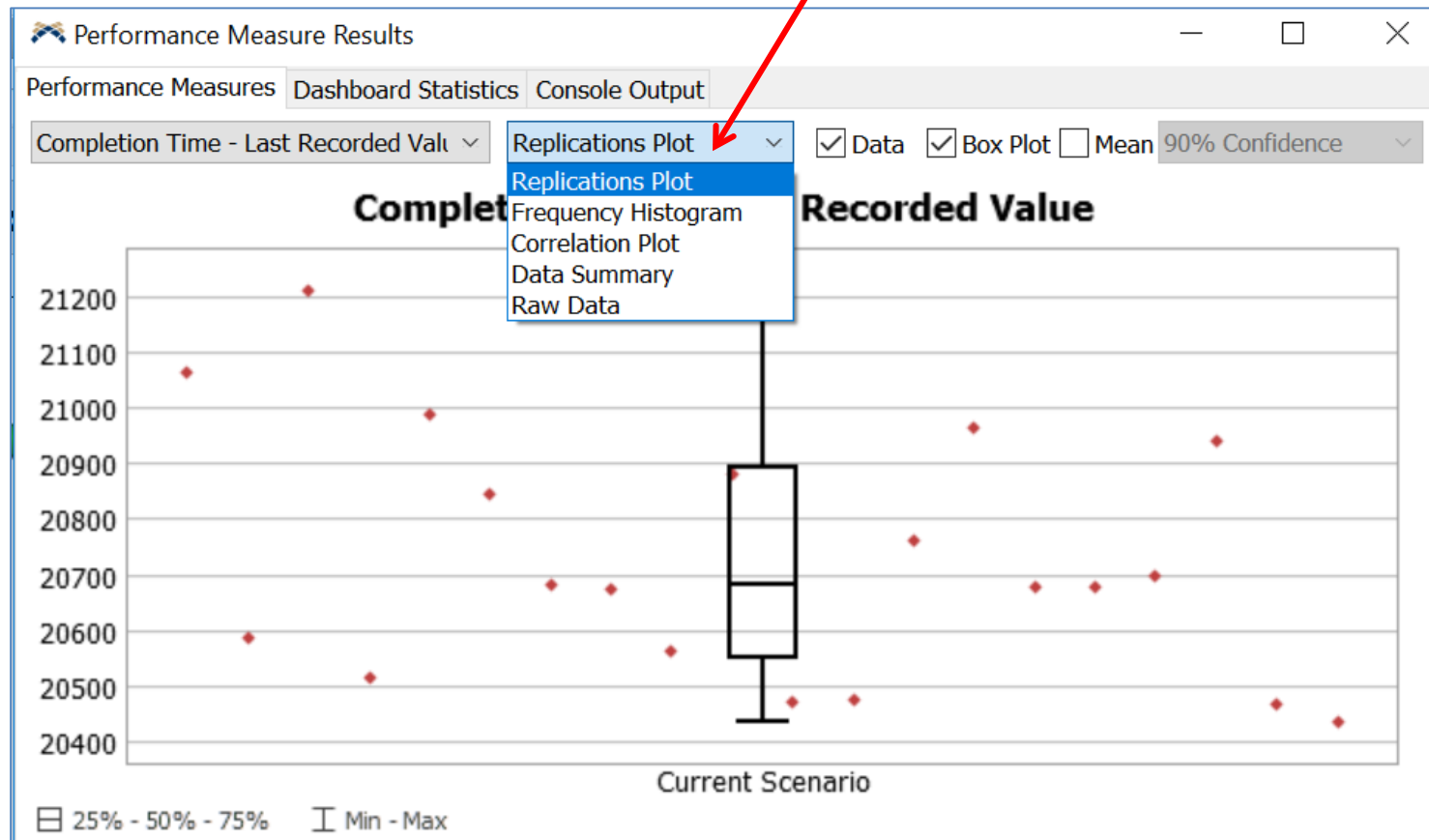


# Performance Measure Results



## Results -

- Which one have you seen in P11?



# Simulation Result – Completion Time



Performance Measures		Dashboard Statistics		Console Output	
Completion Time - Last Recorded Value		Data Summary		Mean Based on 90% Confidence	
Completion Time - Last Recorded Value					
	Mean (90% Confidence)		Sample Std Dev		Min Max
Current Scenario	20645 < 20730 < 20816		221		20439 21208

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



# Scenario: Semi-auto Stretch Wrap

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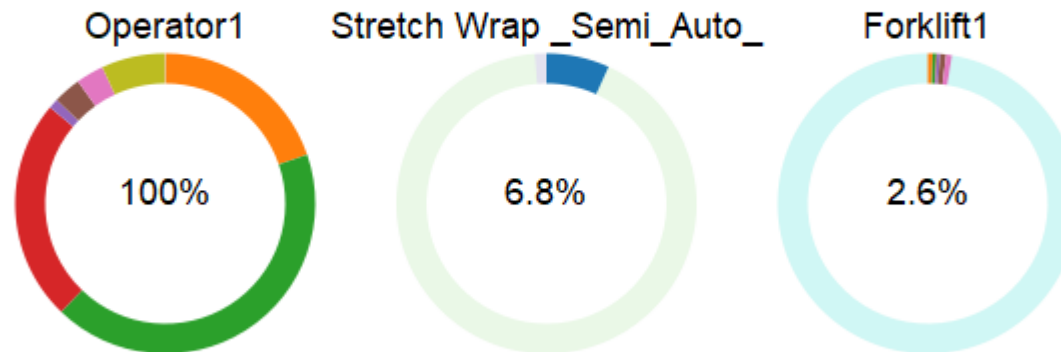
- Management's question : Can a semi-auto stretch wrap machine reduce the warehouse outbound time by 30 minutes or more?
- Assume that a shortlisted machine has a process time approximated by normal distribution of mean 55 secs and standard deviation 5 secs.
- Modify your baseline model to simulate this option (save as separate file).

# Simulation Results



## State Pie

■ Idle ■ Processing ■ Collecting ■ Waiting for transport ■ Travel empty ■ Travel loaded  
■ Offset travel empty ■ Offset travel loaded ■ Loading ■ Unloading ■ Utilize



## 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

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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		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	19219.56
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

t-Test: Two-Sample Assuming Equal Variances

Input

Variable 1 Range:

Variable 2 Range:

Hypothesized Mean Difference:

☐ Labels

Alpha:

Output options

☐ Output Range:

☒ New Worksheet Ply:

☐ New Workbook

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):  
 $t\text{-statistic} < \text{critical value}$
- ❑ Or compare P-value with level of significance (one-tail):  
 $P\text{-value} > 0.05$
- ❑ 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

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- 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.

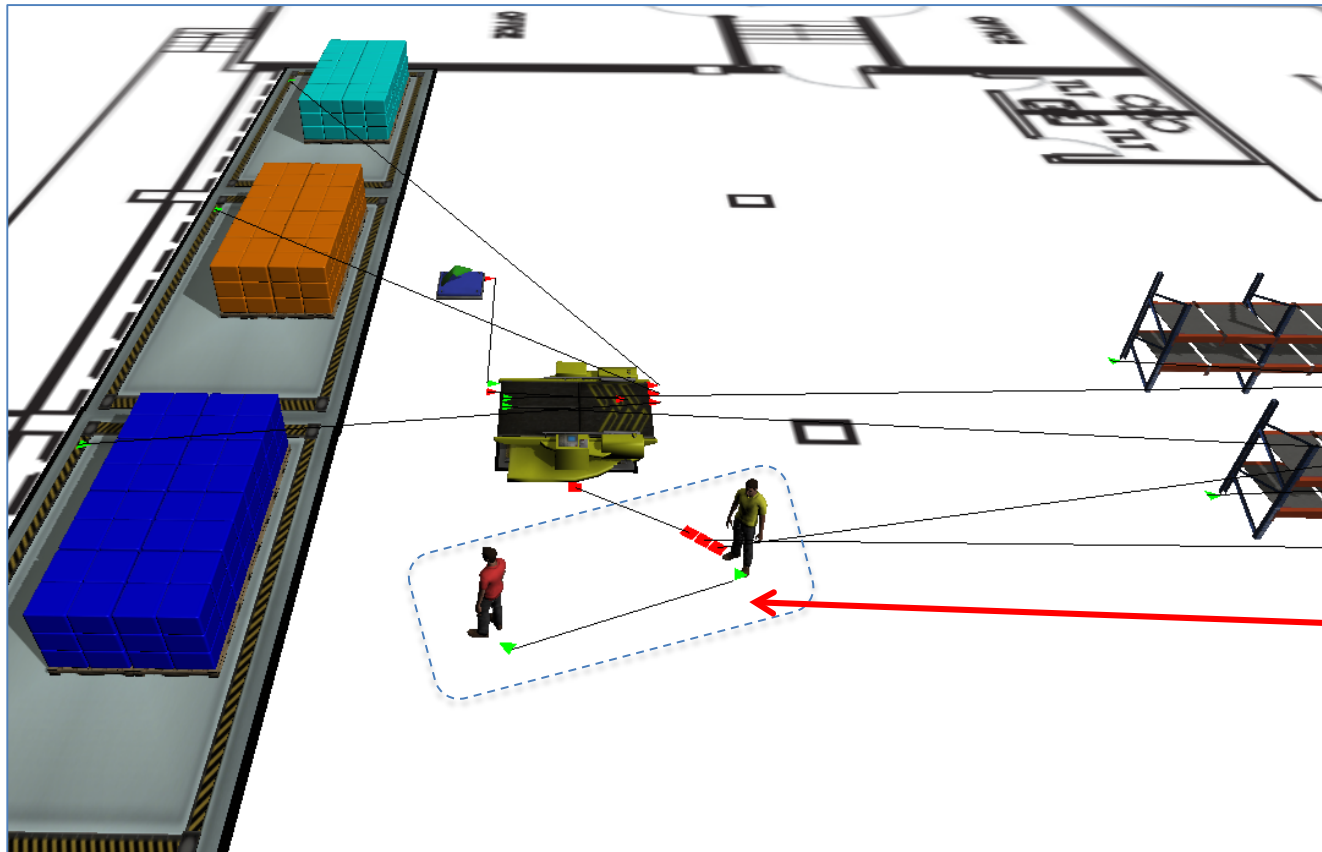
# Proposed Alternative

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- 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

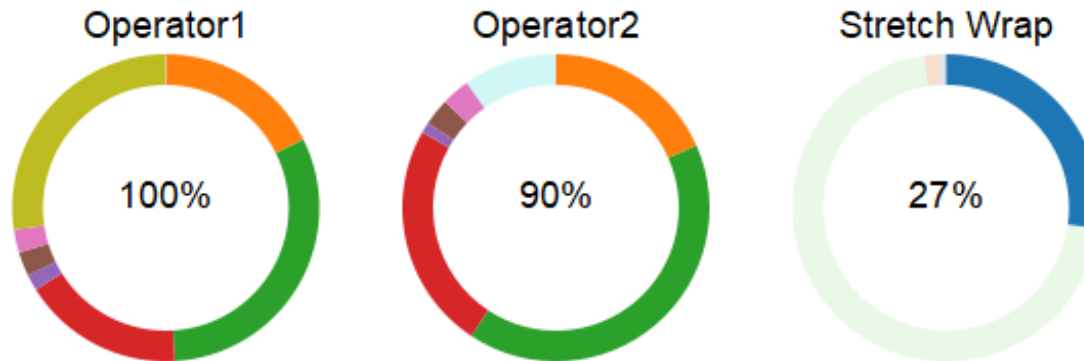
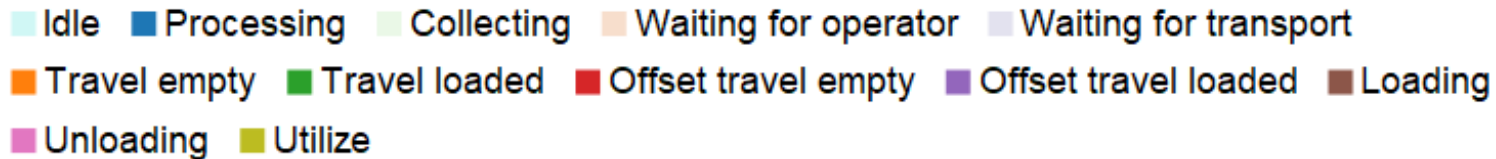


Daisy chain connection:  
'A' key connection  
from Operator 1  
(who is connected  
to Objects) to  
Operator 2

# Simulation Results



## State Pie



## 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	

- 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.

Average

# 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

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- 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

