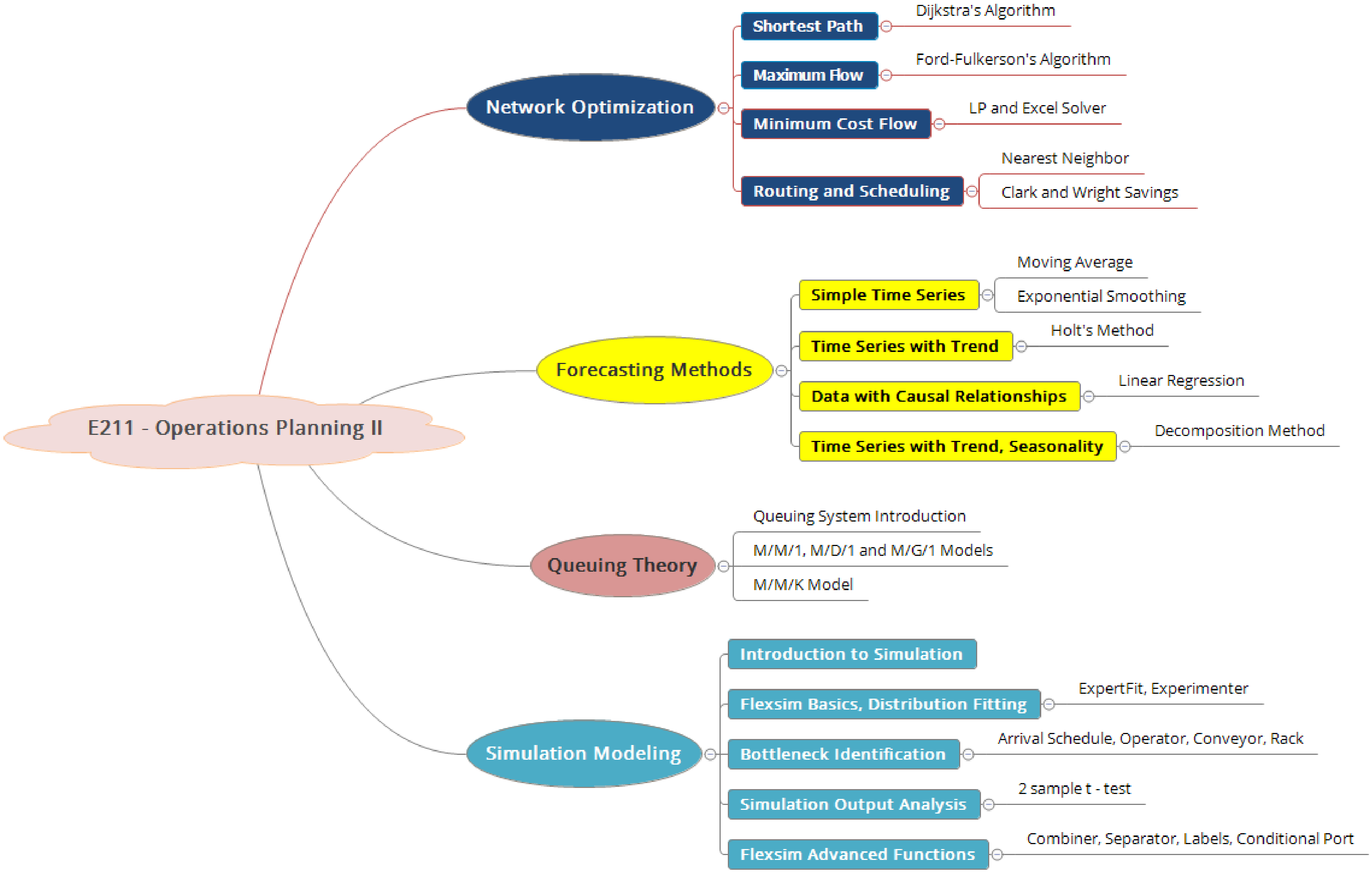
Problem 10

Analyzing the Packing Line

E211 – Operations Planning II

SCHOOL OF ENGINEERING

Module Coverage: E211 Topic Tree



What is Simulation?

- The imitation of the operation of a real-world process or system *over time…*
  - Most widely used tool (along LP) for decision making
  - Usually on a computer with appropriate software
  - An analysis (descriptive) tool – can answer what if questions
  - A synthesis (prescriptive) tool – if complemented by other tools

- Applications:
  - Manufacturing facility
  - Bank operation
  - Airport operations
  - Fast-food restaurant, etc…

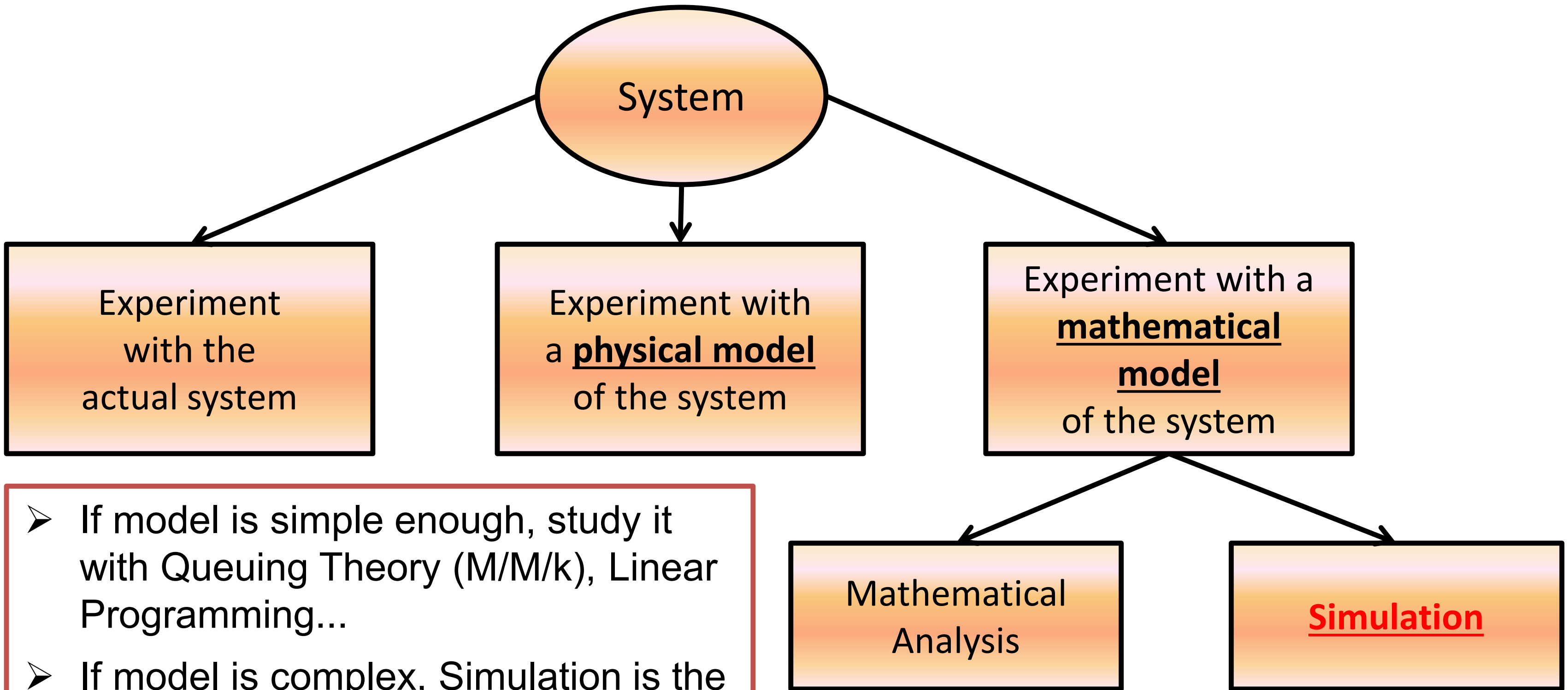
What is a System?

- Facility or process, actual or planned
- A set of interacting components or entities operating together to achieve a common goal or objective.
- Examples:
  - A manufacturing system with its machine centres, inventories, conveyor belts, production schedule, items produced.
  - A telecommunication system with its messages, communication network servers.
  - A theme park with rides, workers, customers, etc…

REAL WORLD SYSTEMS OF INTEREST ARE HIGHLY COMPLEX!!!

Why and How to Study a System

- Measure/estimate performance
- Improve operation and prepare for failures



- ➢ If model is simple enough, study it with Queuing Theory (M/M/k), Linear Programming...
- ➢ If model is complex, Simulation is the only way!!!

Components of a System

Entity: An object of interest in the system

- *Dynamic objects* - get created, move around, change status, affect and are affected by other entities, leave (maybe)
- Can have different types of entities concurrently
  - E.g. patients, visitors

Attribute: A characteristic of all entities, but with a specific value "local" to the entity that can differ from one entity to another.

  - E.g. Patient's gender, age, illness

Resources: What entities compete for

- Entity *seizes* a resource, uses it, releases it
- "A" resource can have several units of capacity which can be changed during the simulation
  - E.g. Doctors, nurses, X-ray machines

Components of a System, Cont.

Variable: A piece of information that reflects some characteristics of the whole system, not of specific entities

- Entities can access, change some variables
  - E.g. Number of idle doctors, number of patients in the system

State: A collection of variables that contains all the information necessary to describe the resources/entities/system at any time

  - E.g. Status of doctors, status of lab equipment (busy or idle or down).

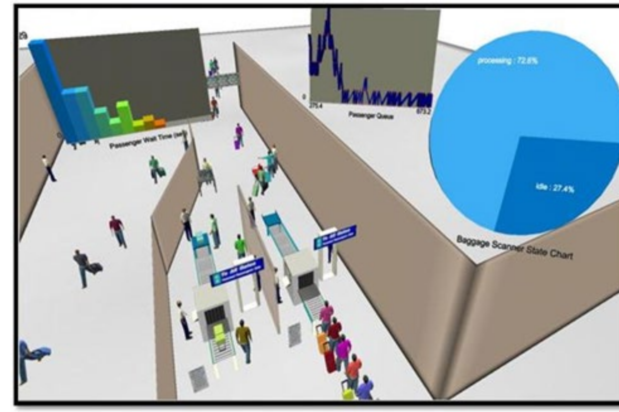
Event: An instantaneous occurrence that changes the state of the system

  - E.g. Arrival of a patient, completion of a service, failure of a machine

Activity: Represents a time period of specified length or a collection of operations that transform the state of an entity

  - E.g. X-ray scanning, surgery, checking temperature, etc.

Getting Answers from Models

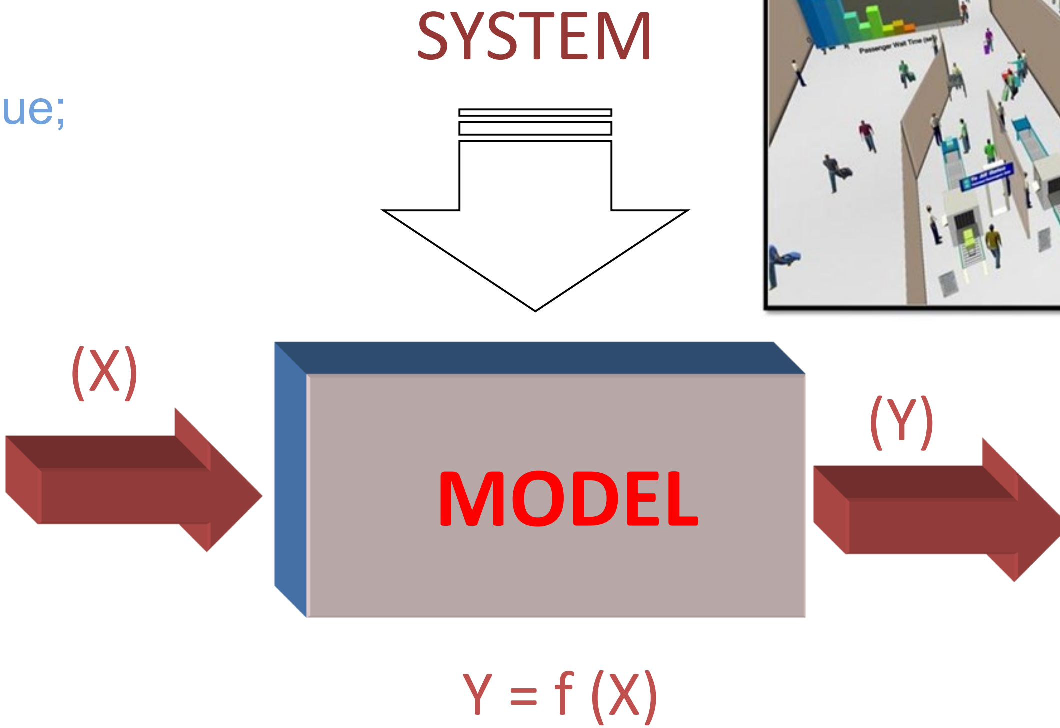


Arrival Characteristics

- Single, multi-queue; length
- Rule, e.g. FIFO
- Behaviour, e.g. balking

Server Characteristics

- No of servers
- Service time Distribution
- Single or multi-phase



Output

- Waiting time
- Queue length
- Utilization
- etc…

Classifications of Simulation Models

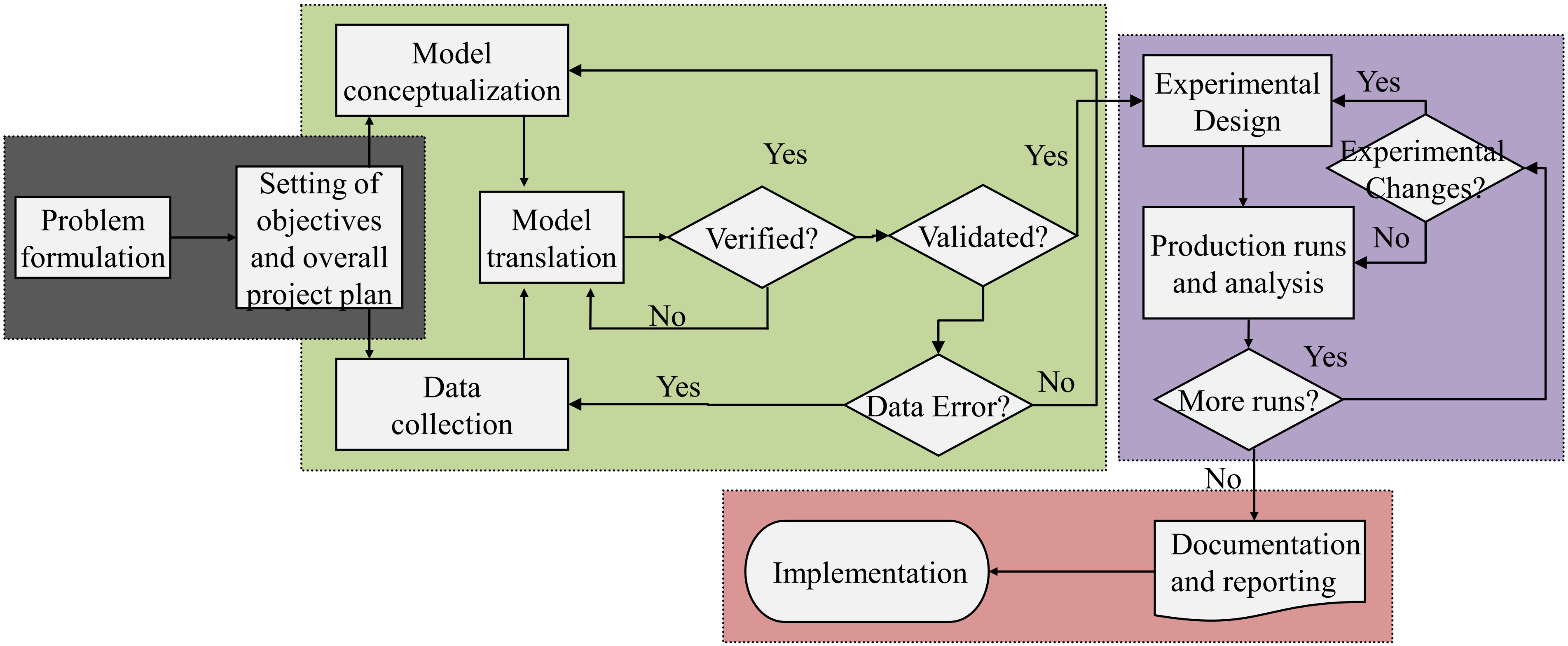
Static (Monte Carlo)

- Represents the system at a particular point in time
  - E.g. Risk Analysis in Business

Dynamic Systems

- Represents the system behaviour over time
  - **Continuous Simulation:**
    - (Stochastic) Differential Equations
    - E.g. Grain growth during crystallisation
  - **Discrete Event Simulation:**
    - System quantities (state variables) change with events
    - E.g. Queuing systems, Inventory systems

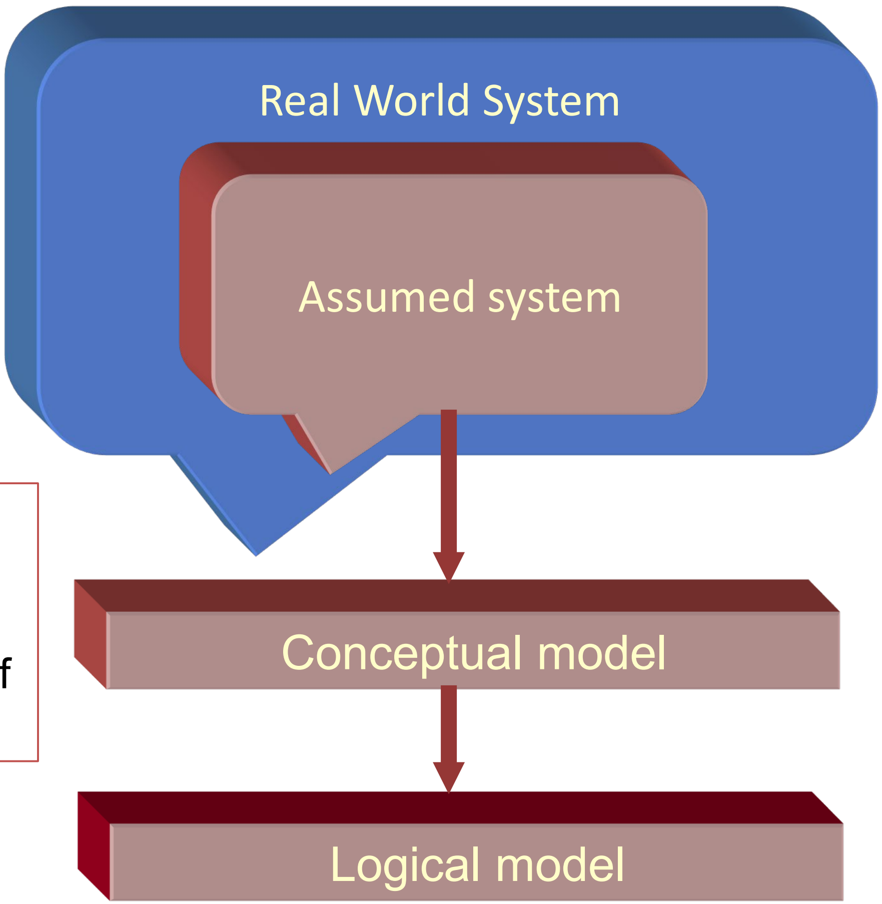
Steps in a Simulation Study



Problem Formulation (Step 1)

- Kickoff meeting with project manager, simulation analysts and subject-matter experts (SME) to define:
  - Objectives: questions to be answered by the study
  - Performance measures to be used to evaluate the system performance
  - Scope of model and level of details
  - Time frame for the study and required resources

Model Conceptualization (Step 2)



***Conceptual model*:**
The mathematical / logical / verbal representation (mimic) of the problem under study

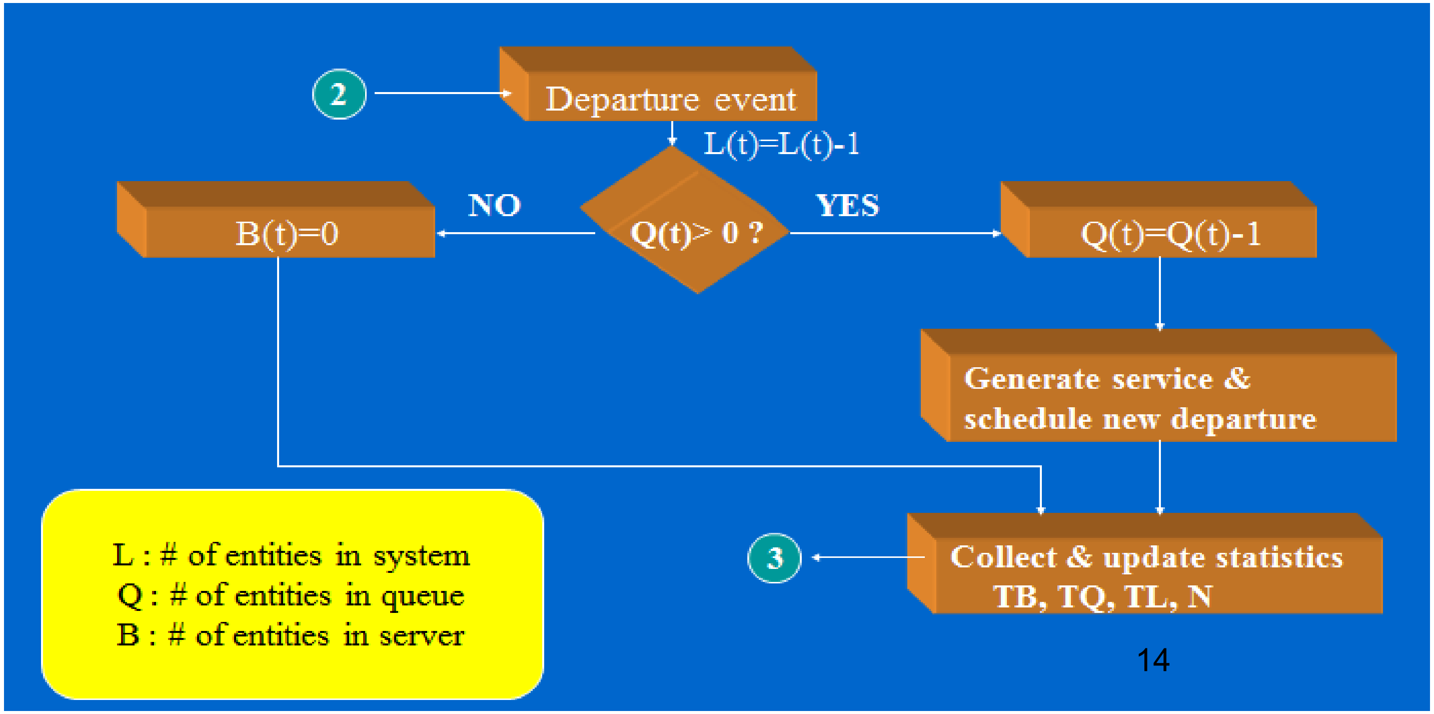
Logical model:
The model that shows the logical relationships among the elements of the conceptual model

Conceptual Model (Step 2 cont'd)

- The conceptual model is the mathematical / logical / verbal representation (mimic) of the problem under study.
- Abstract essential features
  - Events, activities, entities, attributes, resources, variables, and their relationships
  - Performance measures
  - Data requirements
- Select correct level of details (assumptions)

Logical Model (Step 2 cont'd)

- The logical model shows the logical relationships among the elements of the conceptual model.
- May involve equations, flowchart, pseudocode, etc.
- The flowchart below is a logical model showing how elements of a queuing system are related to one another and how they change when a customer leaves the queuing system after getting the service.



Process Mapping and Data Collection (Step 3)

- Use process maps to define system layout, process flow and operating procedure
- Data required are process timings, resource availability, demand pattern and existing system performance
- Sources of data are historical records, site observations, interviews with SMEs and vendors
- Analysis of the data
  - Determine the random variables
  - Fit distribution functions
- Document assumptions about the model

Selection of Simulation Package (Step 4)

- **Type:** Static or dynamic? Discrete-event or continuous?
- **Package Technical details:** User interface, functions, capabilities, data input and output analysis
- **Cost:** Initial cost, support and maintenance cost, upgrade cost, supported O/S. Perpetual license or time license?
- **Rating of vendor:** In terms of user base, time in business, technical support, training, modeling services and cost of ownership

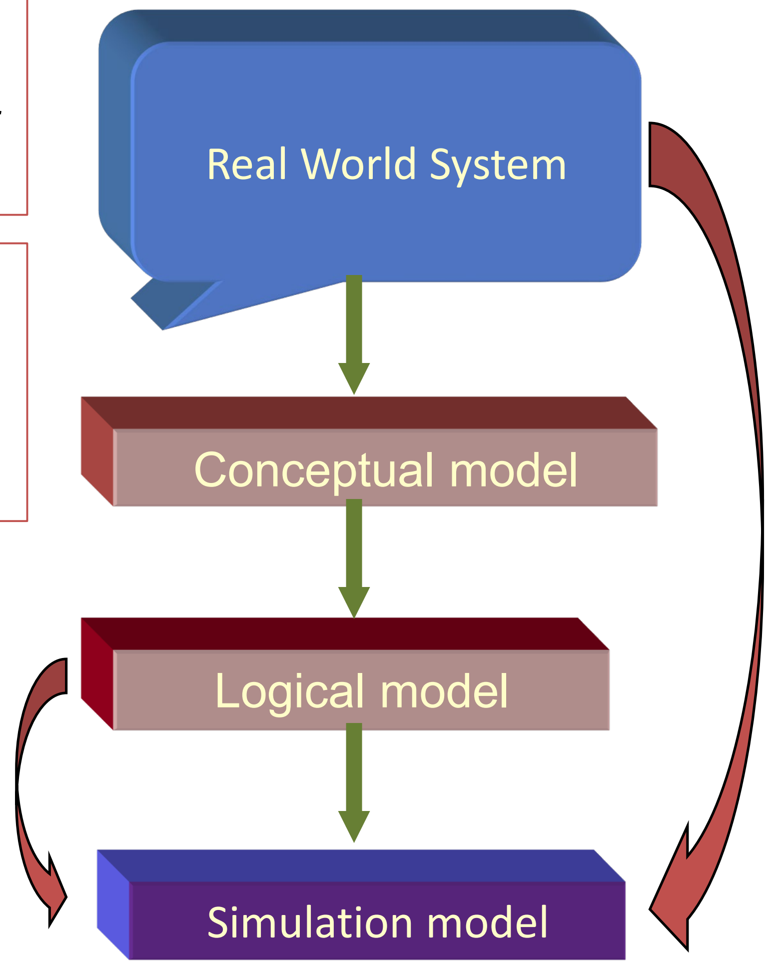
Verification and Validation (Step 5)

Conceptual model: The mathematical / logical / verbal representation (mimic) of the problem under study

Logical model: The model that shows the logical relationships among the elements of the conceptual model

Verification: The process of determining if the operational logic is correct.

- Debugging the simulation software



Validation: The process of determining if the model accurately represents the system.

- Comparison of model results with collected data from the real system

Simulation model: The conceptual / logical model implemented on a computer through *computer programming and implementation*.

Experimental Design & Analysis (Step 6)

- Design experiments
  - ❑ Are there alternative system configurations that may improve the current situation?
  - ❑ Could changing the process flow improve the problem?
  - ❑ What if there are changes to the important input parameters?

- Conduct simulation runs and analyze output
  - ❑ Compare results from each scenario

Documentation and Reporting (Step 7)

- Program Documentation
  - Document assumptions and study's results to facilitate future modifications
  - Discuss model building and validation process to promote credibility
  - Use animation to communicate to managers and others who are not familiar with the system
  - Results are used in decision making if they are valid and credible.
- Progress Reports
  - Alternative scenarios, results of experiments
  - Performance measures or criteria used
  - Recommendations

Role of Statistics in Simulation

- Randomness of input data – what statistical distribution to use? E.g. use of Poisson distribution to represent arrival patterns.
- Determining how many runs to make – affects accuracy of result and confidence interval
- Hypothesis testing used in:
  - Validation: comparing simulation results and actual performance
  - Experimentation: comparing results of alternative system designs or scenarios

Advantages of Simulation

- ✓ When mathematical analysis methods are not available, simulation may be the only investigation tool
- ✓ When mathematical analysis methods are available, but are so complex that simulation may provide a simpler solution
- ✓ Allows comparisons of alternative designs or alternative operating policies without physical changes to the system
- ✓ Allows time compression or expansion

Disadvantages of Simulation

- For a stochastic model, simulation <u>estimates</u> the output while an analytical solution, if available, produces the exact output
- Often expensive and time consuming to develop
- An invalid model may result with confidence in wrong results.

Pitfalls to Successful Simulation

- Failure to have a well-defined set of objectives at start of study
- Inappropriate level of model detail or scope
- Failure to communicate with management throughout course of study
- Treating a simulation study like an exercise in computer programming
- Failure to collect good data
- Failure to have people with knowledge in simulation methodology and statistics
- Inappropriate simulation package

Introduction to Flexsim Simulation

- Flexsim is classified as a discrete-event simulation software program.
- Flexsim is a versatile tool that may be used to model a variety of operational scenarios.

Applications of Flexsim

- Three basic categories of problems can be solved with Flexsim:
  - Service problems – the need to process customers and their requests at the highest level of satisfaction for the lowest possible cost
  - Manufacturing problems – the need to make the right product at the right time for the lowest possible cost
  - Logistics problems – the need to get the right product to the right place at the right time for the lowest possible cost

Fit Distributions to Data Sets

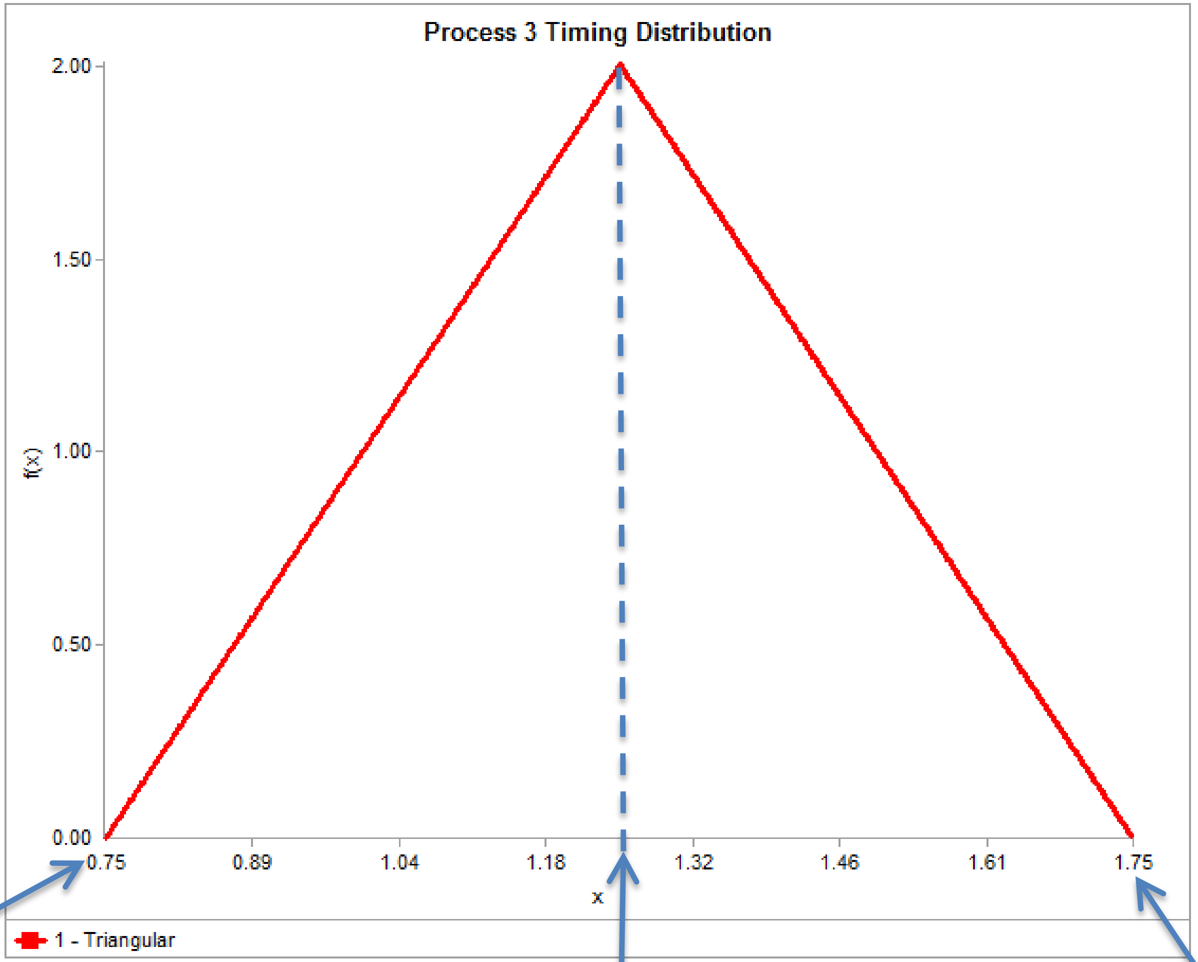
- A statistical software such as ExpertFit can help determine automatically which probability distribution best represents a data set.

- It also provides statistical tests (Goodness-of-Fit Test) to evaluate how well the selected distribution fits the data.

- One way to overcome lack of data is to seek advice from domain experts and then account for the variability by estimating the minimum, maximum and mode values. These values can be translated and used as the parameters of a triangular distribution.

Adopting Triangular Distribution (Example)

Parameters required are: Min, Max and Mode



Minimum value

Most-likely (mode)
Value = 1.25

Maximum value

Using ExpertFit to Determine Distribution for Random Data (Example)

Automated-Fitting Results

Relative Evaluation of Candidate Models

Model	Relative Score	Parameters	
1 - Gamma	87.10	Location	0.00000
		Scale	0.03619
		Shape	38.65267
2 - Erlang	85.48	Location	0.00000
		Scale	0.03682
		Shape	38
3 - Gamma(E)	85.48	Location	0.00190
		Scale	0.03625
		Shape	38.54506

32 models are defined with scores between 0.81 and 87.10

Absolute Evaluation of Model 1 - Gamma

Evaluation: Good

Suggestion: Additional evaluations using Comparisons Tab might be informative.
See Help for more information.

Additional Information about Model 1 - Gamma

"Error" in the model mean relative to the sample mean 0

Gamma distribution best represents Process 1 timings.

Parameters of the recommended distribution.

Anderson-Darling Test

Anderson-Darling Test with Model 1 - Gamma

Sample size 20
Test statistic 0.29238

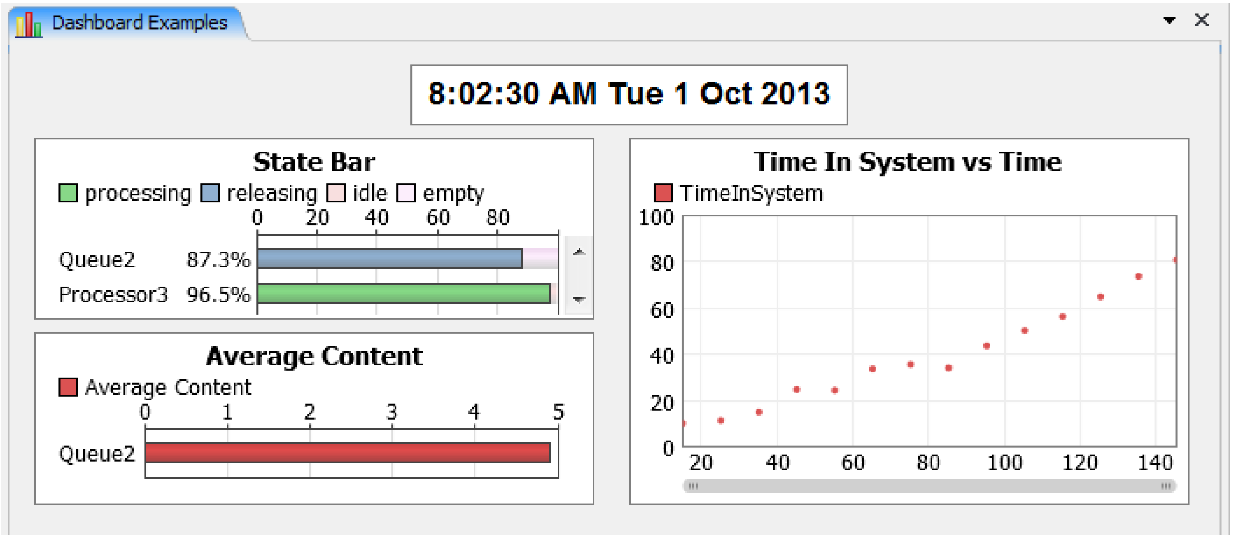
Note: The following critical values are approximate.

	Critical Values for Level of Significance (alpha)					
Sample Size	0.250	0.100	0.050	0.025	0.010	0.005
20	0.470	0.632	0.753	0.874	1.036	1.161
Reject?	No					

Goodness-of-fit test indicates that there is no strong evidence to reject the null hypothesis: The data set follows Gamma Distribution.

e-learning video in the link below for a demonstration of how to use Expertfit.
https://drive.google.com/file/d/0B9sGwZfXz0MkRUtvTlVaWXJxWmc/view?usp=sharing

Dashboard Concepts

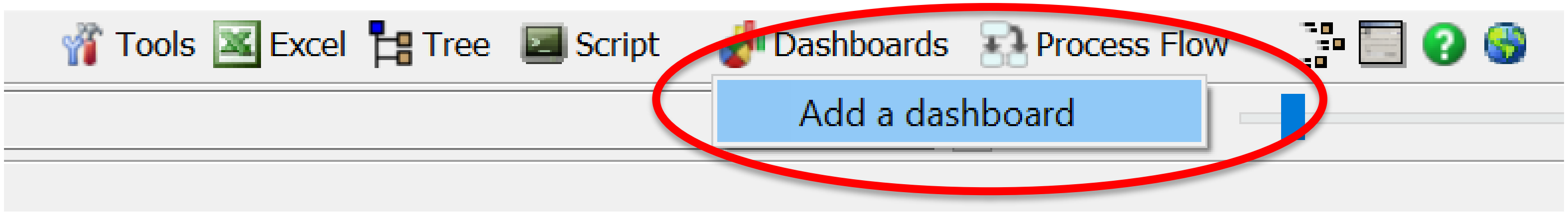


The Dashboard window allows you to view graphs and statistics for the model as it runs. It is especially useful for comparing objects side by side.

For more information on the different graph types, see the Reference page.

Note: Not all statistics make sense for all objects. If a selected object does not have the statistic specified, the graph will not display data for that object.

To add a dashboard to your model, go to the Dashboards > Add a dashboard



P10 Suggested Solution

What and How Data Are to Be Collected

What:

- ✓ Incoming – arrival pattern of the incoming boxes for packing
- ✓ Nos. of 'servers' – Manpower, label printers
- ✓ Duration of each activity
- ✓ Re-work rates

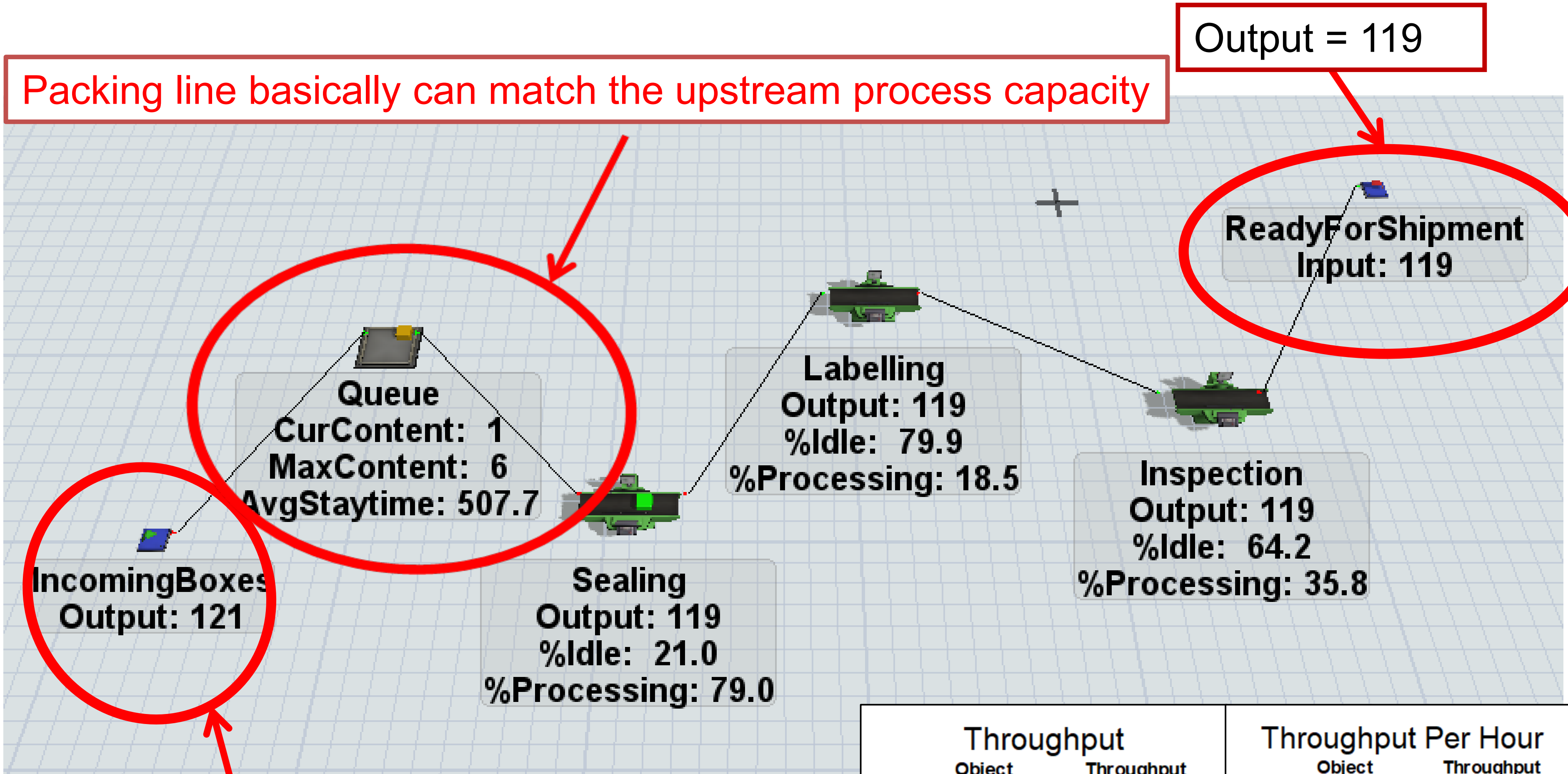
How:

- ✓ Interviewing staff
- ✓ Observation/ time study of various process/stations
- ✓ Past data

Components of the Packing Line Simulation System

- Events – E.g. arrival of product, completion of packing, failure of product
- Entity – E.g. incoming products, Sealed products, labelled products, inspected products
- Activity – E.g. receiving, sealing, labelling, inspection, correcting
- Attributes – E.g. type of product, type of labels required, years of experiences of staff, label printer status
- Resources – E.g. label printer, human packers
- State – E.g. status of human packers, label printers (busy or idle or down)

Current Packing Line before Introducing the New Refrigerator Model



Throughput

Object	Throughput
IncomingBoxes	121.00
Queue	120.00
Inspection	119.00
ReadyForShipment	119.00

Throughput Per Hour

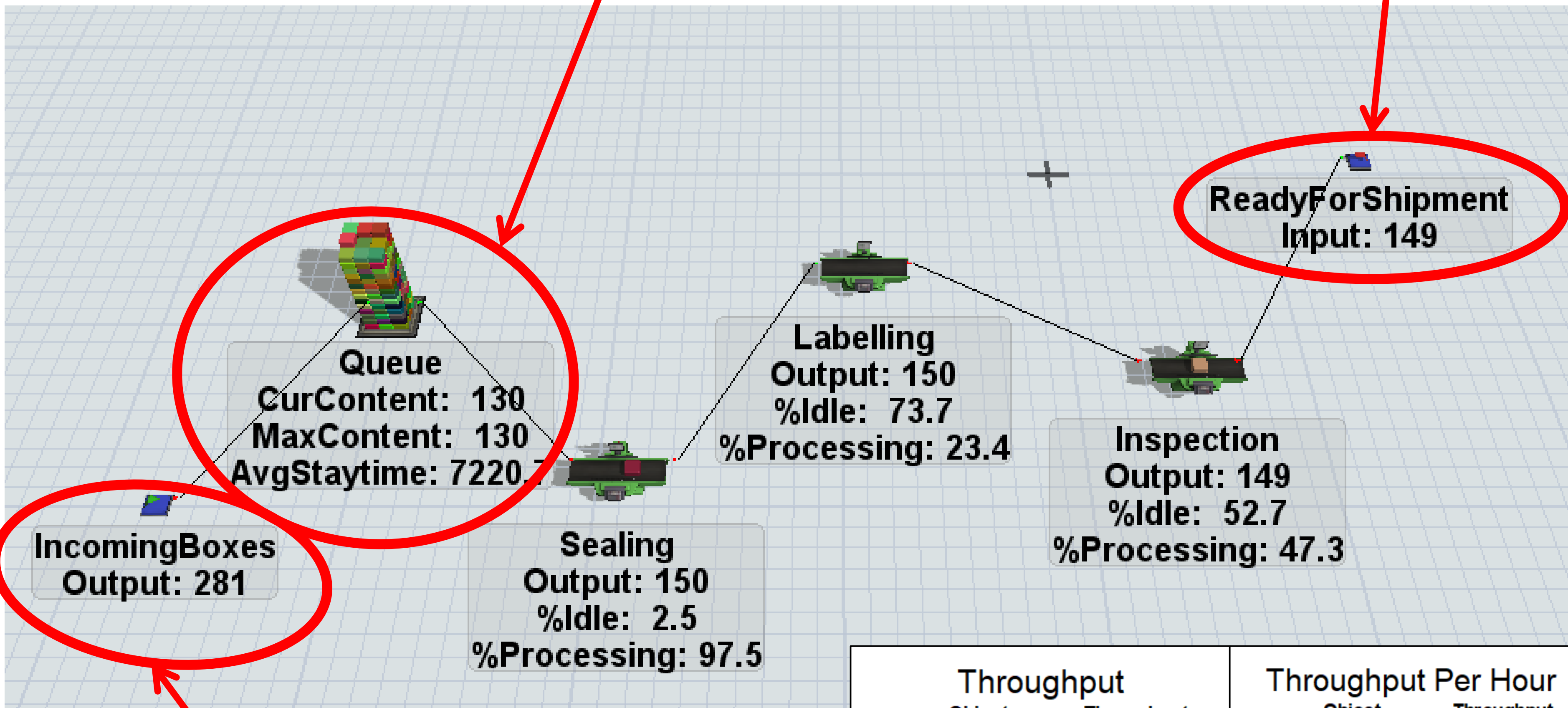
Object	Throughput
IncomingBoxes	12.10
Queue	12.00
Inspection	11.90
ReadyForShipment	11.90

- ❑ Output per hour is 11.9 units

Current Packing Line with the New Refrigerator Model

Packing line cannot match the upstream process capacity

Output = 149



Input = 281

Throughput

Object	Throughput
IncomingBoxes	281.00
Queue	151.00
Inspection	149.00
ReadyForShipment	149.00

Throughput Per Hour

Object	Throughput
IncomingBoxes	28.10
Queue	15.10
Inspection	14.90
ReadyForShipment	14.90

- Output per hour is 14.9 units

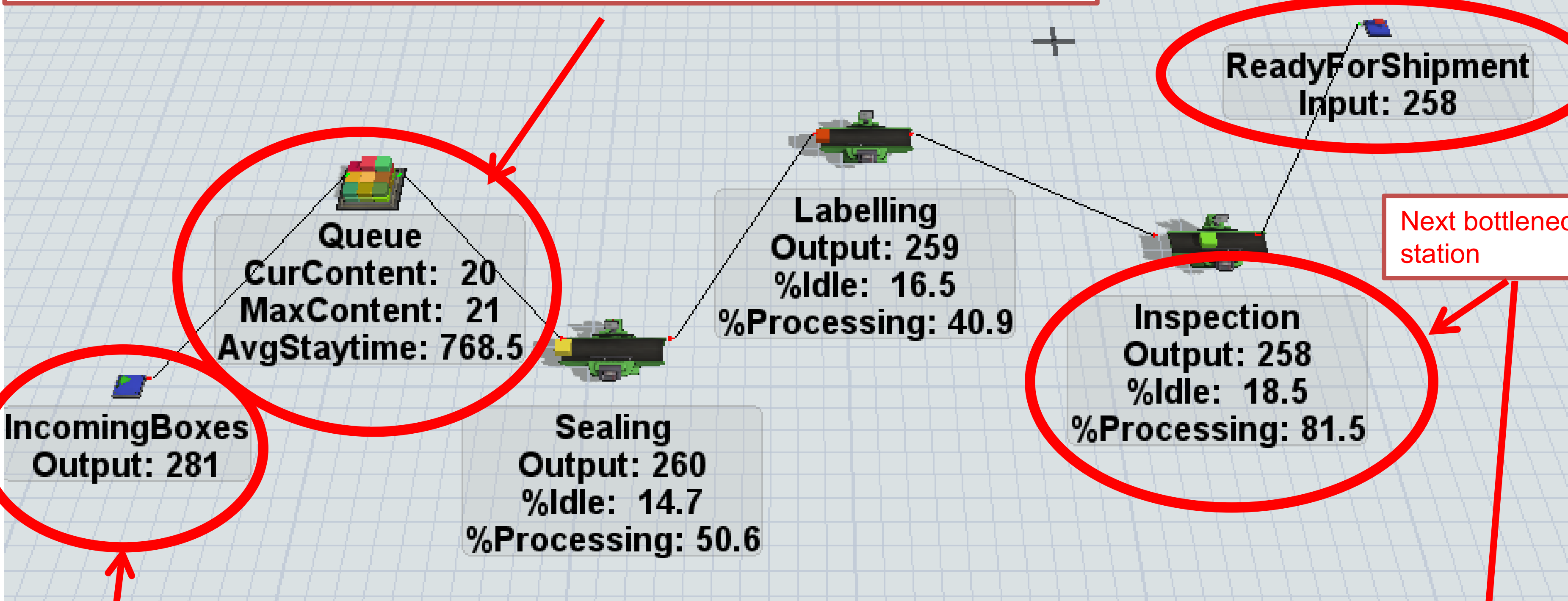
Analysis of Current Packing Line with the New Refrigerator Model

- Incoming boxes ready for sealing build up a long queue in front of the sealing operation of the packing line
- The capacity of the packing line cannot match the upstream process capacity
- Average output per hour is ~ 14.9 units; total output in a day is ~149 units
- The number of boxes waiting to be packed is 130, which accounts for ~ 46.26% of the total incoming boxes
- Currently, the bottleneck operation of the packing line is the sealing operation with % processing of ~97.5%

Improved Packing Line with Automatic Sealing Machine A

Output = 258

Packing line still cannot match upstream process capacity



Next bottleneck station

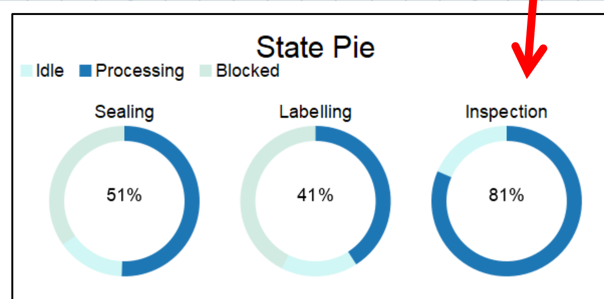
Input = 281

Throughput

Object	Throughput
IncomingBoxes	281.00
Queue	261.00
Inspection	258.00
ReadyForShipment	258.00

Throughput Per Hour

Object	Throughput
IncomingBoxes	28.10
Queue	26.10
Inspection	25.80
ReadyForShipment	25.80

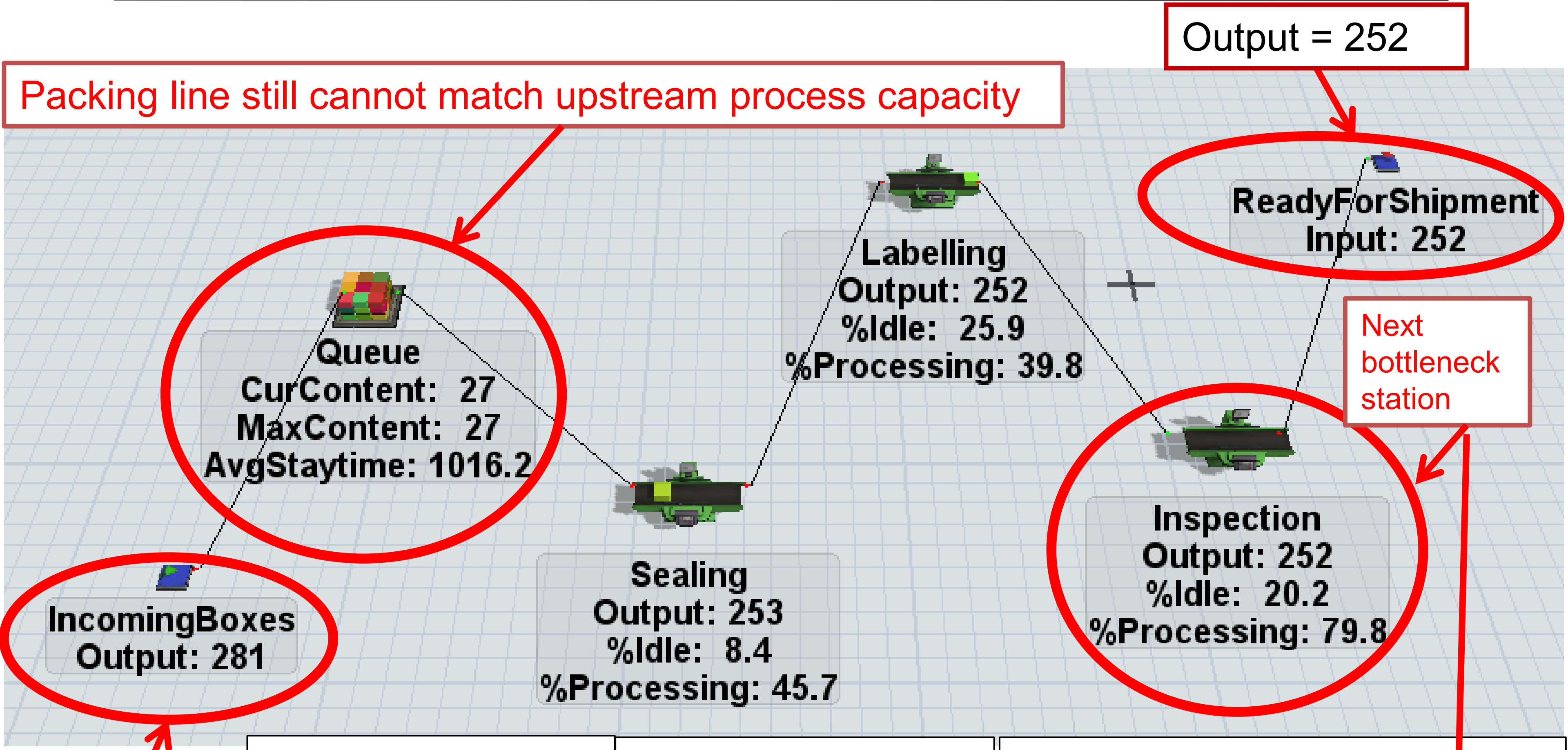


- ❑ Output per hour is 25.8 units

Analysis of Improved Packing Line with Sealing Machine A

- The automation of the sealing operation helps to improve the packing line capacity
- However, incoming boxes ready for sealing still build up a queue (20 boxes) in front of the sealing operation of the packing line, which account for 7.12% of the incoming boxes
- Average output per hour is ~ 25.8 units
- Total output in a day is ~ 258 units (> 85% of the total number of refrigerators produced during the day)
- The bottleneck operation of the packing line is now the inspection operation
- May deploy one more inspector at the inspection step or do sampling check

Improved Packing Line with Sealing Machine B



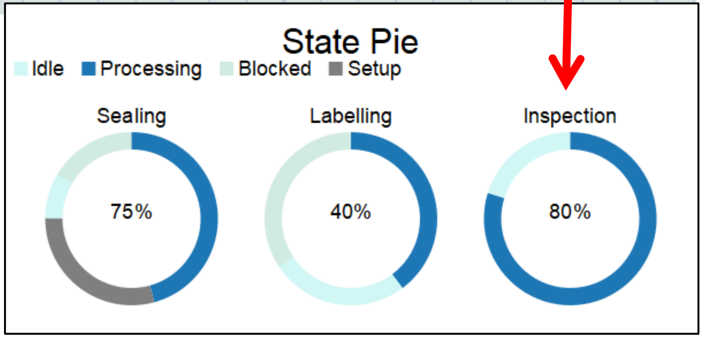
Input = 281

Throughput

Object	Throughput
IncomingBoxes	281.00
Queue	254.00
Inspection	252.00
ReadyForShipment	252.00

Throughput Per Hour

Object	Throughput
IncomingBoxes	28.10
Queue	25.40
Inspection	25.20
ReadyForShipment	25.20



- Output per hour is 25.2 units

Analysis of Improved Packing Line with Sealing Machine B

- The automation of the sealing operation helps to improve the packing line capacity
- However, incoming boxes ready for sealing still build up a queue (27 boxes) in front of the sealing operation of the packing line, which account for 9.61% of the incoming boxes
- Average output per hour is ~ 25.2 units
- Total output in a day is ~ 252 units (> 85% of the total number of refrigerators produced during the day)
- The bottleneck operation of the packing line is now the inspection operation
- May deploy one more inspector at the inspection step or do sampling check

Expertfit Result for Machine C Set up time

Automated-Fitting Results

Relative Evaluation of Candidate Models

Model	Relative Score	Parameters	
1 - Log-Logistic	86.61	Location	0.00000
		Scale	16.60316
		Shape	3.45093
2 - Log-Logistic(E)	84.82	Location	0.00293
		Scale	16.60007
		Shape	3.45020
3 - Pearson Type VI	79.46	Location	0.00000
		Scale	418.32847
		Shape #1	4.36705
		Shape #2	99.99405

29 models are defined with scores between 0.00 and 86.61

Absolute Evaluation of Model 1 - Log-Logistic

Evaluation: Good

Suggestion: Additional evaluations using Comparisons Tab might be informative.
See Help for more information.

Additional Information about Model 1 - Log-Logistic

"Error" in the model mean
relative to the sample mean -0.68941 = 3.74%

Anderson-Darling Test

Anderson-Darling Test with Model 1 - Log-Logistic

Sample size 20
Test statistic 0.22302

Note: The following critical values are exact.

Sample Size	Critical Values for Level of Significance (alpha)					
	0.250	0.100	0.050	0.025	0.010	0.005
20	0.421	0.556	0.652	0.760	0.895	0.998
Reject?	No					

Enter Parameters for Machine C Set up time

Automated-Fitting Results

Relative Evaluation of Candidate Models

Model	Relative Score	Parameters	
1 - Log-Logistic	86.61	Location	0.00000
		Scale	16.60316
		Shape	3.45093
2 - Log-Logistic(E)	84.82	Location	0.00293
		Scale	16.60007
		Shape	3.45020
3 - Pearson Type VI	79.46	Location	0.00000
		Scale	418.32847
		Shape #1	4.36705
		Shape #2	99.99405

29 models are defined with scores between 0.00 and 86.61

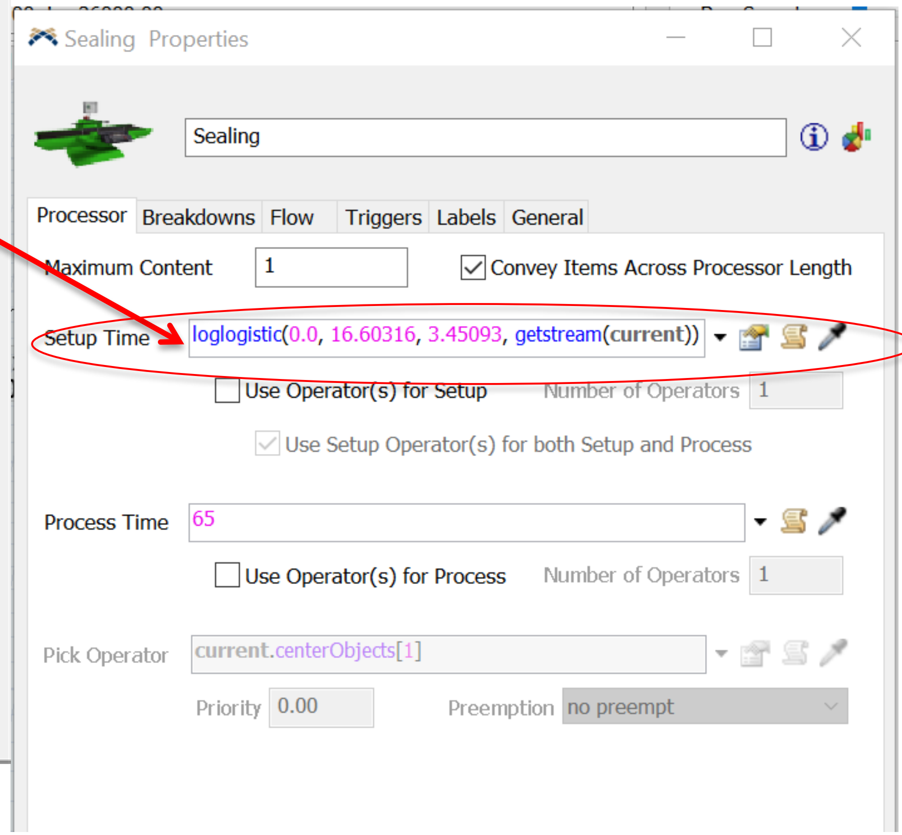
Absolute Evaluation of Model 1 - Log-Logistic

Evaluation: Good

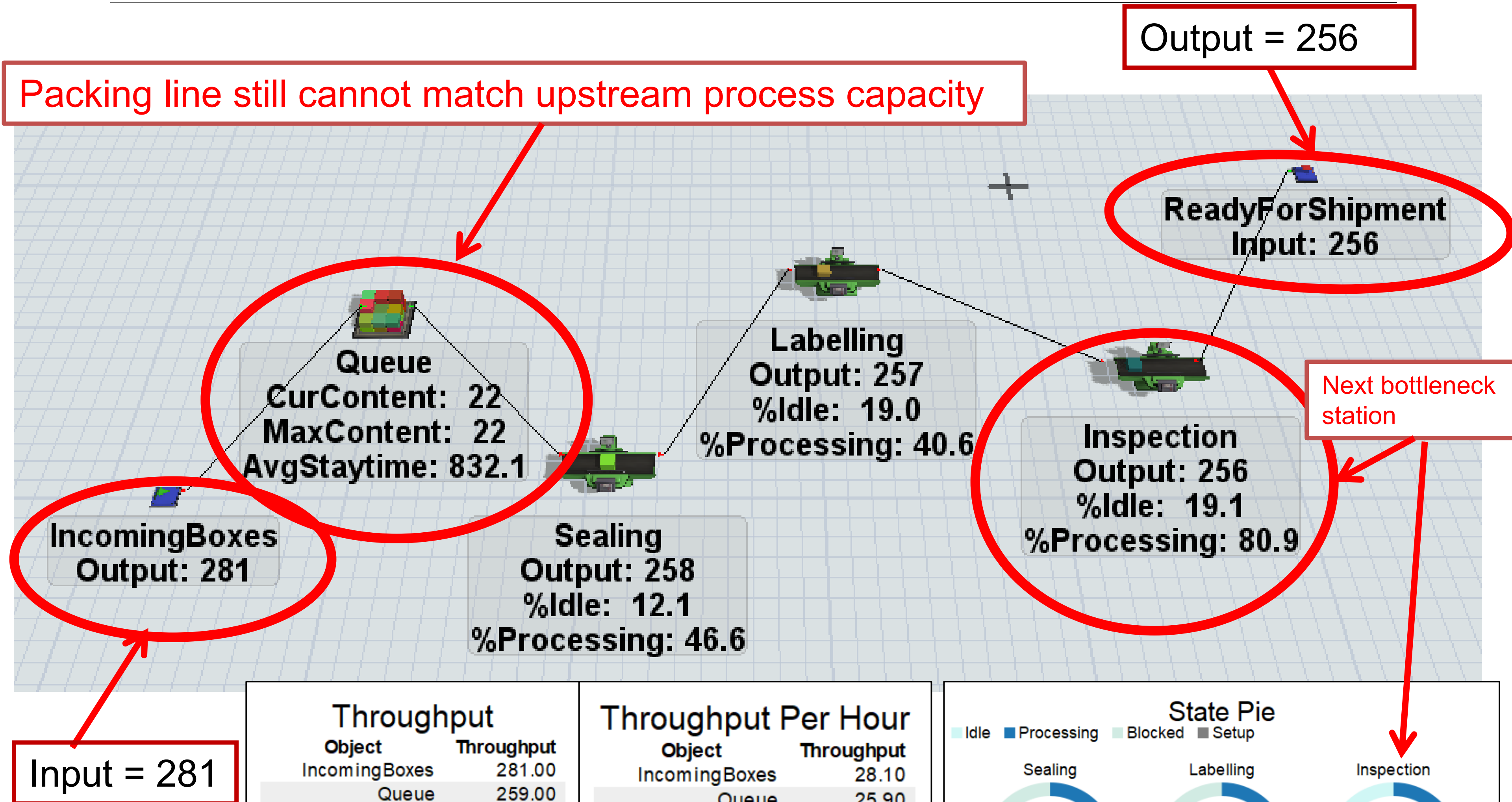
Suggestion: Additional evaluations using Comparisons Tab might be informative.
See Help for more information.

Additional Information about Model 1 - Log-Logistic

"Error" in the model mean
relative to the sample mean -0.68941 = 3.74%



Improved Packing Line with Sealing Machine C

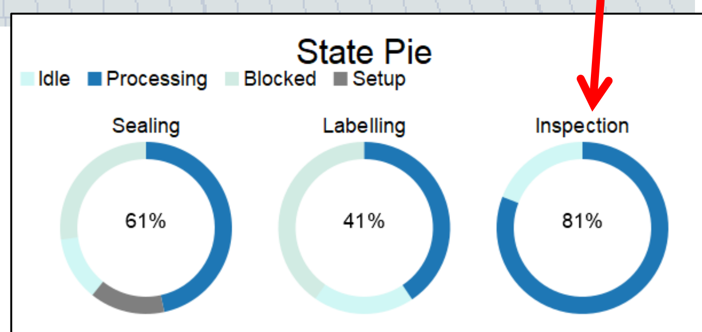


Throughput

Object	Throughput
IncomingBoxes	281.00
Queue	259.00
Inspection	256.00
ReadyForShipment	256.00

Throughput Per Hour

Object	Throughput
IncomingBoxes	28.10
Queue	25.90
Inspection	25.60
ReadyForShipment	25.60



- Output per hour is 25.6 units

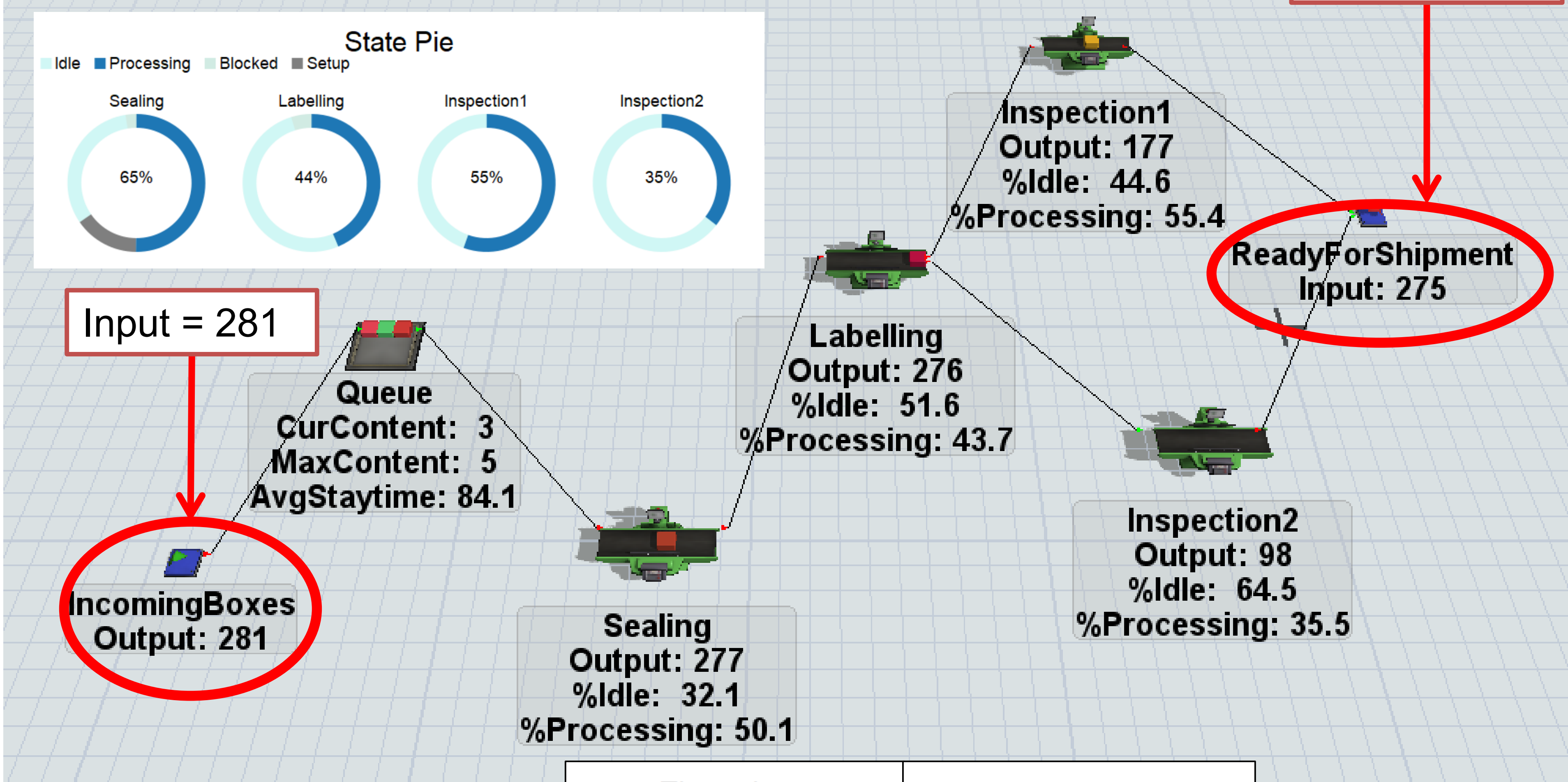
Analysis of Improved Packing Line with Automatic Sealing Machine C

- The automation of the sealing operation helps to improve the packing line capacity
- However, incoming boxes ready for sealing still build up a queue (22 boxes) in front of the sealing operation of the packing line, which account for 7.83% of the incoming boxes
- Average output per hour is ~ 25.6 units
- Total output in a day is ~ 256 units (> 85% of the total number of refrigerators produced during the day)
- The bottleneck operation of the packing line is now the inspection operation
- May deploy one more inspector at the inspection step or do sampling check

Improved Packing Line with Sealing Machine C and One More Inspector

Packing line now basically can match the upstream process capacity

Output = 275



- Output per hour is 27.5 units

Throughput

Object	Throughput
IncomingBoxes	281.00
Queue	278.00
Inspection1	177.00
Inspection2	98.00
ReadyForShipment	275.00

Throughput Per Hour

Object	Throughput
IncomingBoxes	28.10
Queue	27.80
Inspection1	17.70
Inspection2	9.80
ReadyForShipment	27.50

Analysis of Improved Packing Line with Sealing Machine C and One More Inspector

- The packing line now can basically match the upstream process capacity
- Average output per hour is ~ 27.5 units
- Total output in a day is ~ 275 units
- May test other alternatives, such as reducing inspection time or performing sampling inspection

Analysis of Improved Packing Line with various Sealing Machines and One More Inspector

- While all three machines can achieve the objectives, Machine C may be chosen considering cost and daily throughput of the packing line.
- Will also need to consider maintenance, salvage cost, down time, etc … if such information is available

Conclusion

- Simulation can be used in many applications and gives greater insight into a problem to help make more informed decisions
- It is especially useful if analytical and experimental approaches are not suitable
- In today’s problem, it may be difficult to calculate queue performances for a multi-stage queuing system
- Use of simulation in today’s problem can provide realistic visualization and allows for distribution of results to be computed

Learning Objectives

- Interpret the meaning of “system” in simulation context.
- Recognise the necessity of simulation.
- Explain the steps involved in simulation study.
- Discuss the advantages and disadvantages of simulation.
- Use Flexsim to model simple real life queuing scenario.
- Apply knowledge to link objects in Flexsim to represent flow of items.
- Collect and fit appropriate distributions to collected data sets.
- Apply knowledge to input properties of objects in Flexsim in accordance with their statistical properties.
- Evaluate simulation model results and make recommendations.

Overview of E211 Operations Planning II Module