

Investigación Operativa

Operations Research



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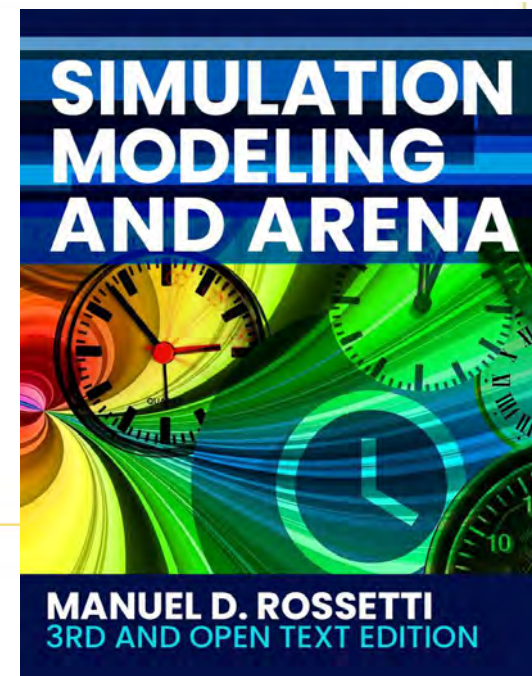
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Introduction to ARENA

Departamento de Organización Industrial

September 1, 2023

<https://rossetti.github.io/RossettiArenaBook/>



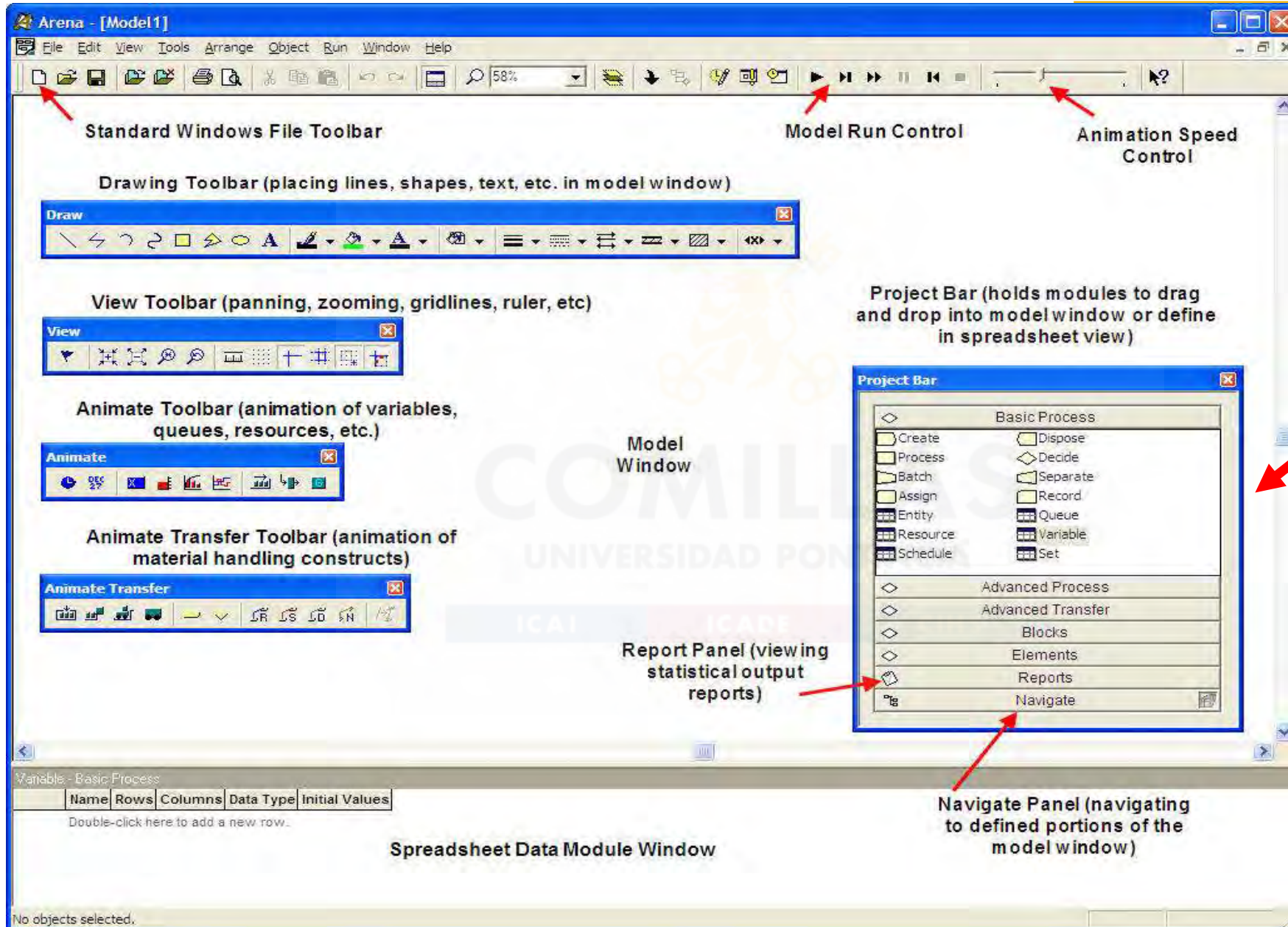
1. ARENA Basics
2. Example: The Pharmacist
3. Extended Example: The Pharmacist Continued

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ARENA Basics

Arena Environment



Modules:
CREATE
PROCESS
DISPOSE
...

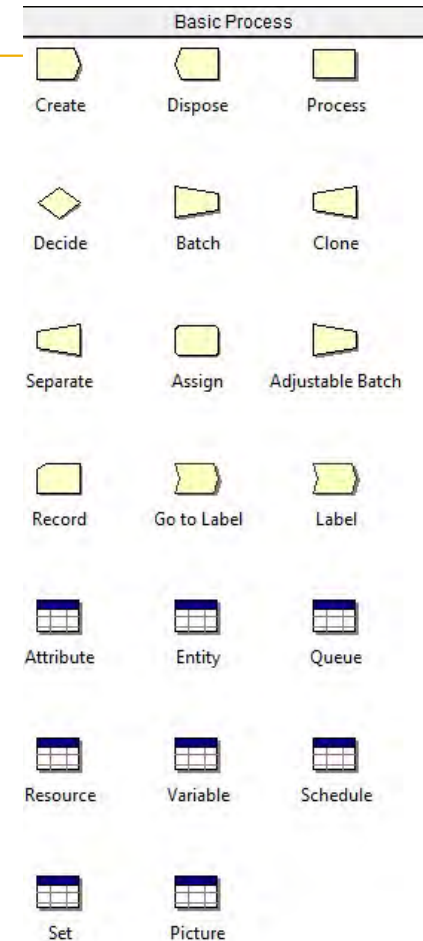
Processing Entities: Basic Process/Data Modules (i)

Basic Process templates:

- **CREATE:** To create entities that pass through the model
- **DISPOSE:** To dispose the entities
- **PROCESS:** Set of activities experienced by an entity
 - Delay (Delay entity for the service/activity; no recourse needed)
 - Seize Delay Release (Seize resource; delay for the service/activity; release resource)
- **DECIDE:** Direct the entity through the system by probabilistic and conditional mechanisms (if/else; while).

Basic Data templates:

- **Entity:** It is possible to create specific entities (not just generic)
- **Resource:** Define the resources of your problem.
- **Variable/Attribute:** Define state variables or Define entity attributes
- **Queue:** Queue of entities that form in front of processes.



Creating and Disposing of Entities in ARENA

- CREATE module: the way to introduce entities into a model

Time Between Arrivals

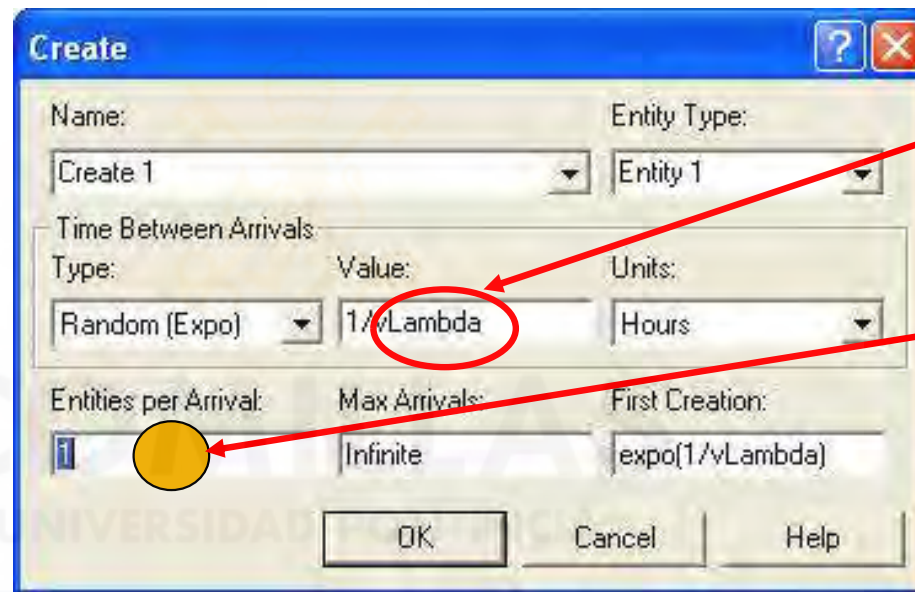
Types:

Random: Uses an Exponential distribution

Schedule: Nonhomogenous Poisson process with rates specified by Schedule module

Constant: Constant time

Expression: List of distributions or expressions:
Normal, Triangular, Beta, ...



Arrival rate as a Variable

Compound arrival:

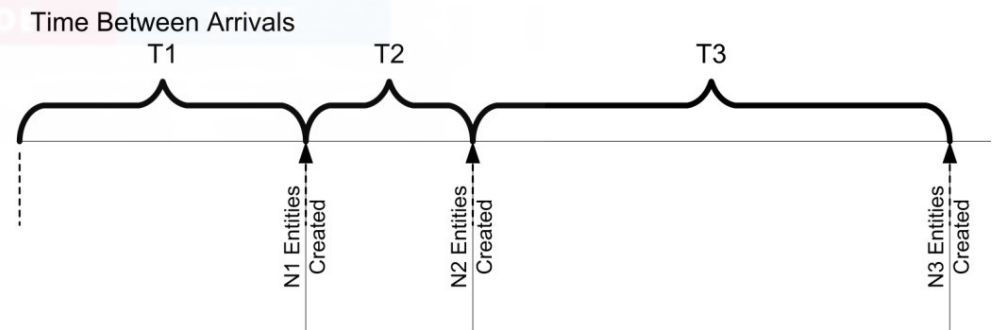
Disc(0.2,1, 0.5, 2, 1.0,3)

20% arrival of 1
30% arrival of 2
50% arrival of 3

Entities per Arrival: Number of entities that will enter the system at a given time with each arrival

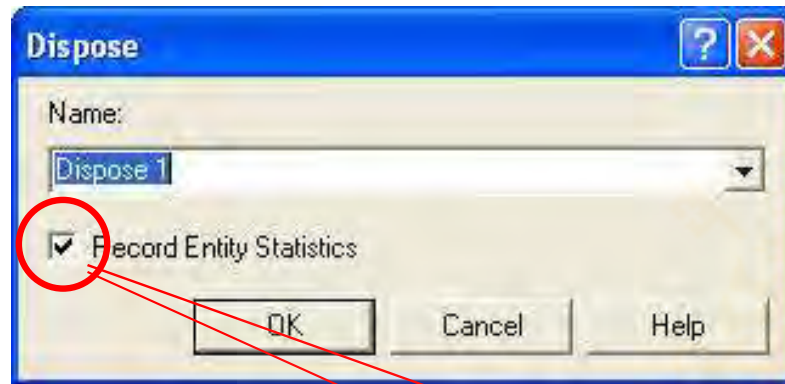
Max Arrivals: Maximum number of arrival events allowed by the module. It is useful to limit the number of entities flowing through the model.

First Creation: Starting time for the first entry to arrive at the system (not applied when the Type is Schedule)

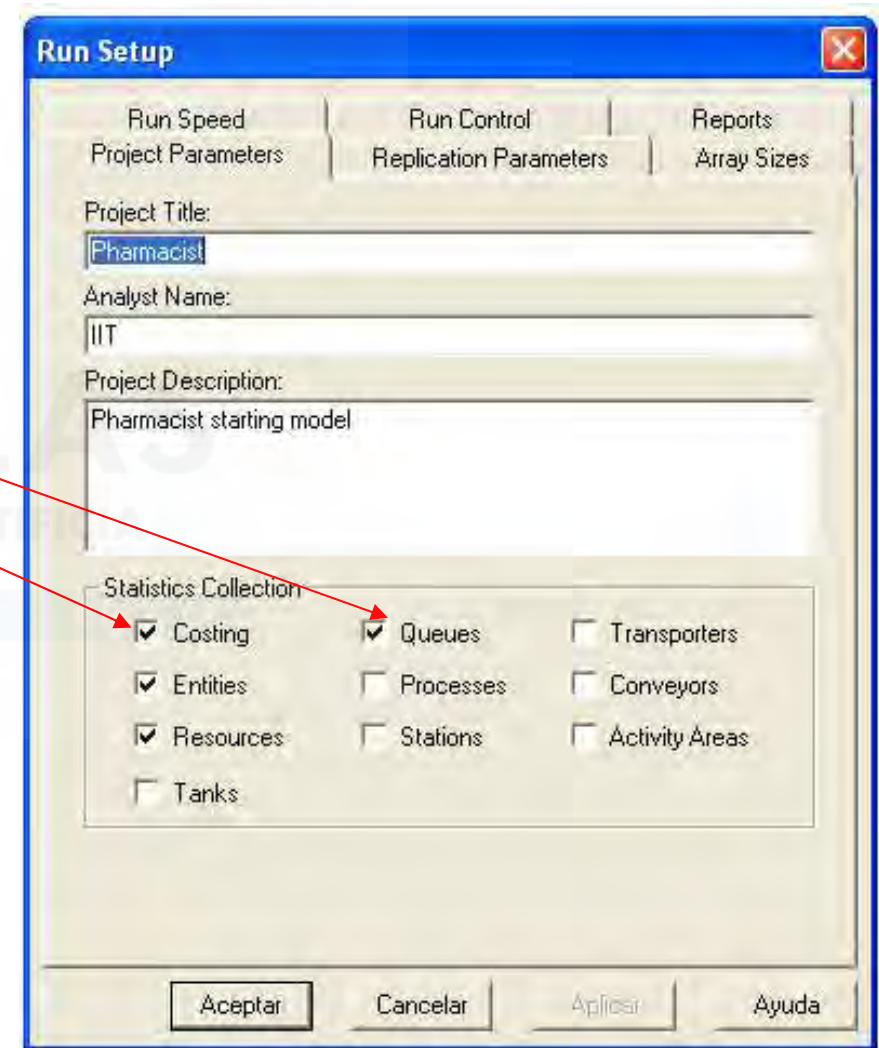


Creating and Disposing of Entities in ARENA

- DISPOSE module: the entities that come into this module **leave the model**



Run > Setup > Project Parameters



Time Statistics:

Value Added Time (VA Time)
Non-Value Added Time (NVA Time)
Wait Time
Total Time

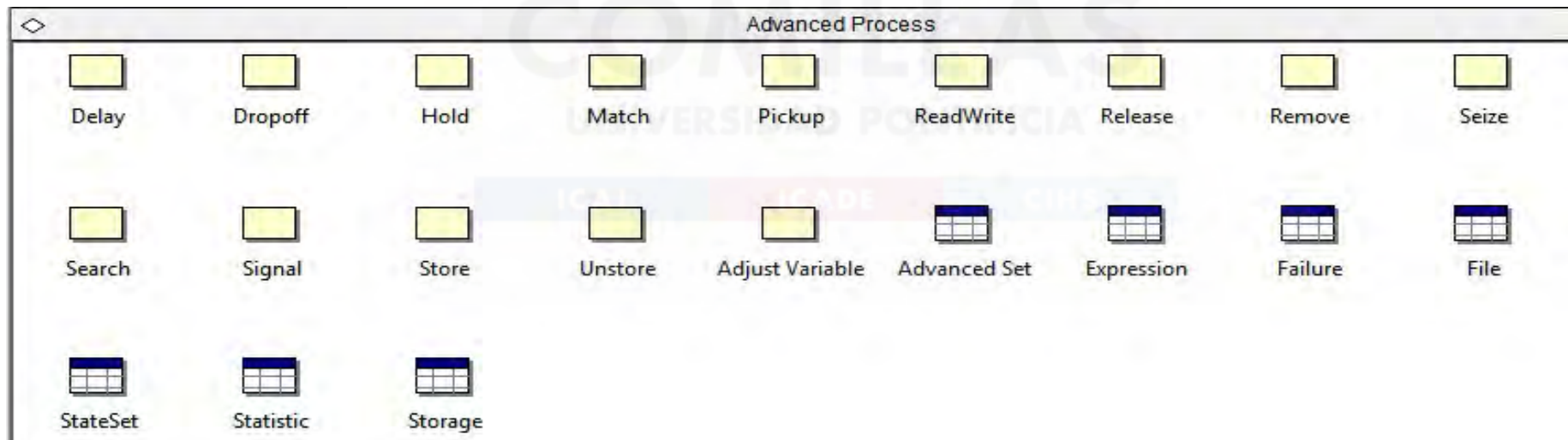
...

Cost Statistics:

Value Added Cost (VA Cost)
Non-Value Added Cost (NVA Cost)
Wait Cost
Total Cost,...

Processing Entities: Basic/Advanced Process Modules (ii)

- SEPARATE / BATCH: To duplicate or combine entities in a model
- ASSIGN: To change/update/initialize the value of various attributes and variables
- READWRITE / FILES: To handle inputs and outputs in a model
- RECORD / STATISTIC: To collect statistics in a module



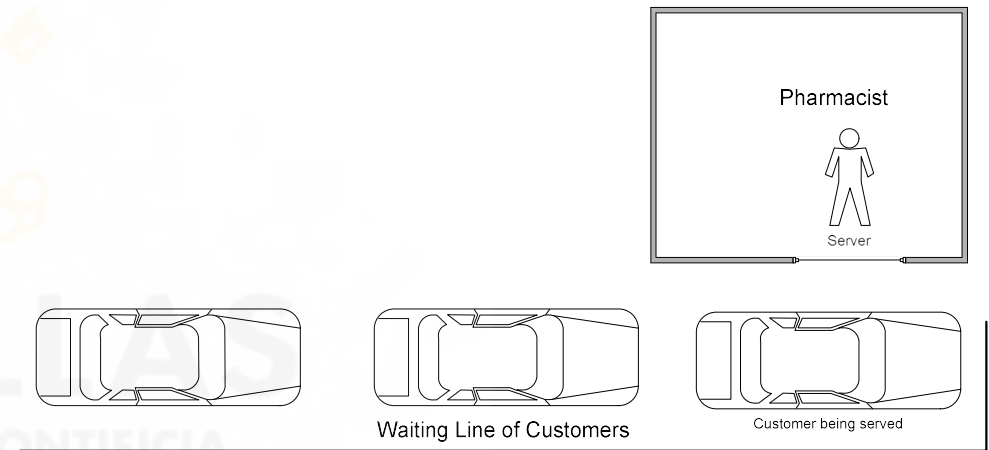
1. ARENA Basics
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Example 1: The Pharmacist

A demo example

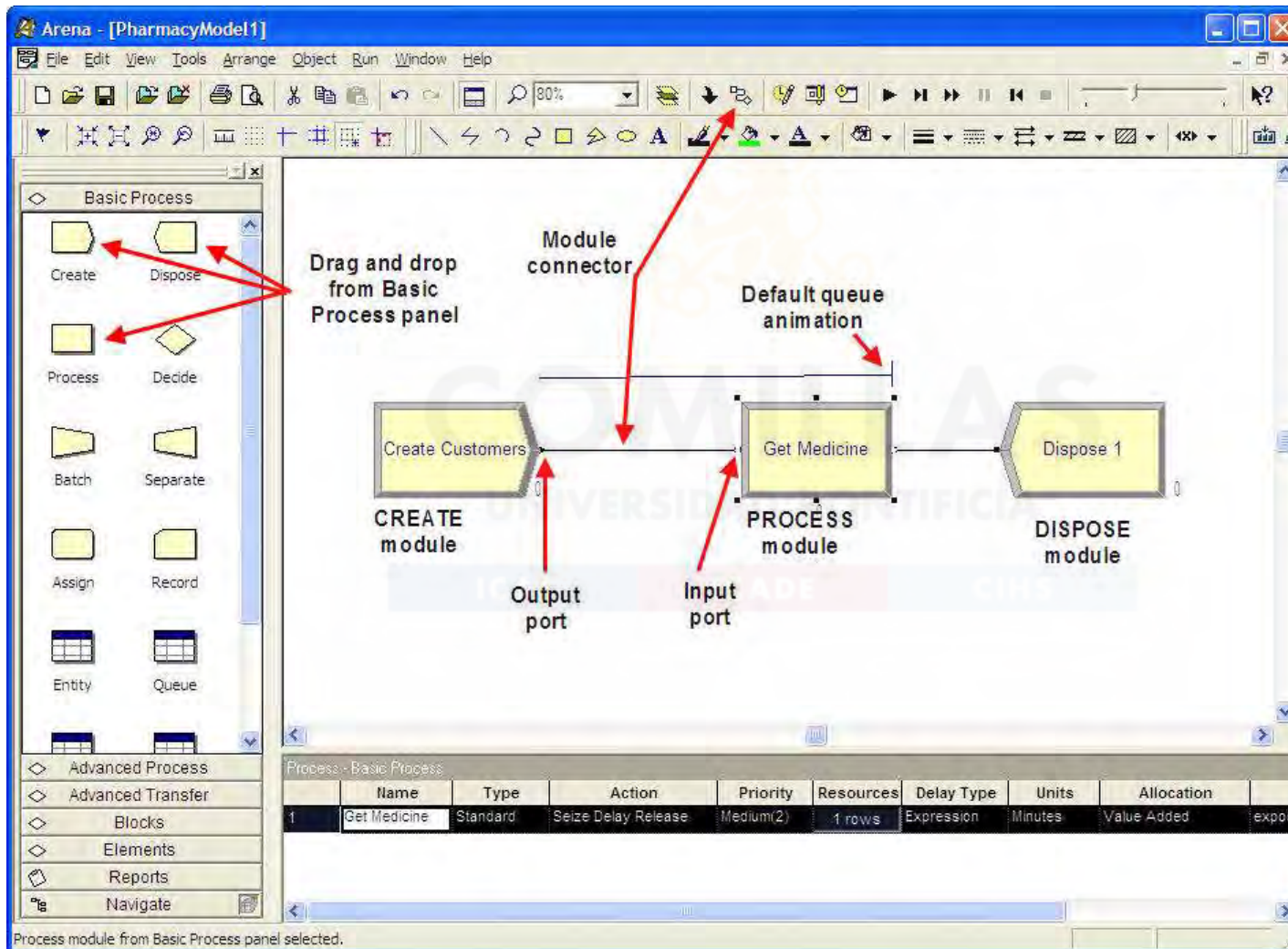
- Customers arrive at a drive-through pharmacy window according to a **Poisson distribution** with a **mean of 10 customers per hour**.
- The time it takes the pharmacist to serve the customer is random, and data indicate that the time is well modeled with an **exponential distribution** with a **mean of 3 minutes**.
- Customers who arrive at the pharmacy are **served in the order of arrival**, and we assume that **enough space is available** within the parking area to accommodate any waiting customers.



File: Pharmacist_chapter_1.doe

Implementing the demo model in Arena (i)

- Using the *Basic Process Panel Template*, drag the CREATE, PROCESS and DISPOSE into the model window, and connect them via the module connector.



Implementing the demo model in Arena (ii)

- Arrival Process
 - CREATE module: Poisson process with an arrival rate of 10 customers per hour (6 minutes between two consecutive arrivals)
 - Double-click on the icon to show its module panel and include parameters




The screenshot shows the 'Create' dialog box in Arena. The 'Name' field is set to 'Create Customers' and the 'Entity Type' is 'Customer'. Under 'Time Between Arrivals', the 'Type' is 'Random (Expo)', the 'Value' is '6', and the 'Units' are 'Minutes'. The 'Entities per Arrival' is '1', 'Max Arrivals' is 'Infinite', and 'First Creation' is 'expo(6)'. The dialog has 'OK', 'Cancel', and 'Help' buttons at the bottom.

Name:	Entity Type:	
Create Customers	Customer	
Time Between Arrivals:		
Type:	Value:	Units:
Random (Expo)	6	Minutes
Entities per Arrival:	Max Arrivals:	First Creation:
1	Infinite	expo(6)

Implementing the demo model in Arena (iii)

- ENTITY module

- ENTITY: Elements that flow through the system (pharmacist's customers)
- Add a new entry using the double-click in the spreadsheet window
- Associate a picture to the entity



	Entity Type	Initial Picture	Holding Cost / Hour	Initial VA Cost	Initial NVA Cost
1	Customer	Picture.Van	0.0	0.0	0.0

Double-click here to add a new row.

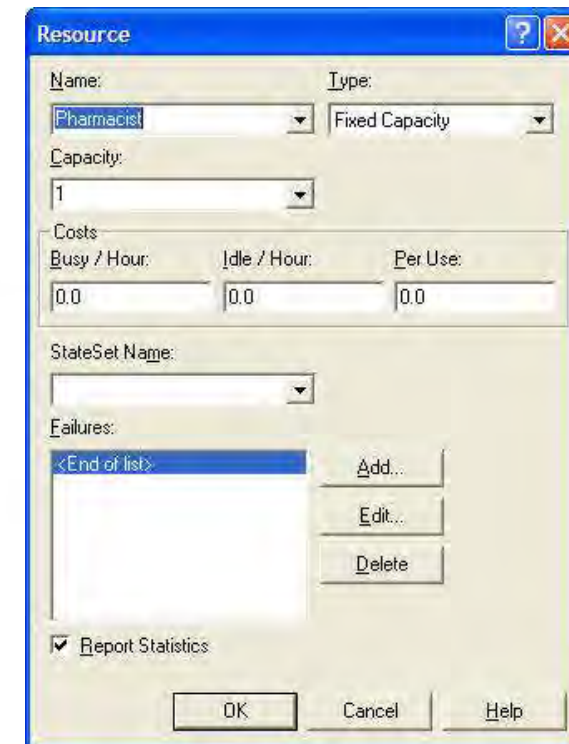
- RESOURCE module

- An element demanded by entities with finite capacity
- Edit the new entry by clicking the spreadsheet window



Name	Type	Busy / Hour	Idle / Hour	Per Use	Report Statistics
------	------	-------------	-------------	---------	-------------------

Double-click here to add a new row.



Resource

Name: Pharmacist Type: Fixed Capacity

Capacity: 1

Costs:
Busy / Hour: 0.0 Idle / Hour: 0.0 Per Use: 0.0

StateSet Name:

Failures:
<End of list>

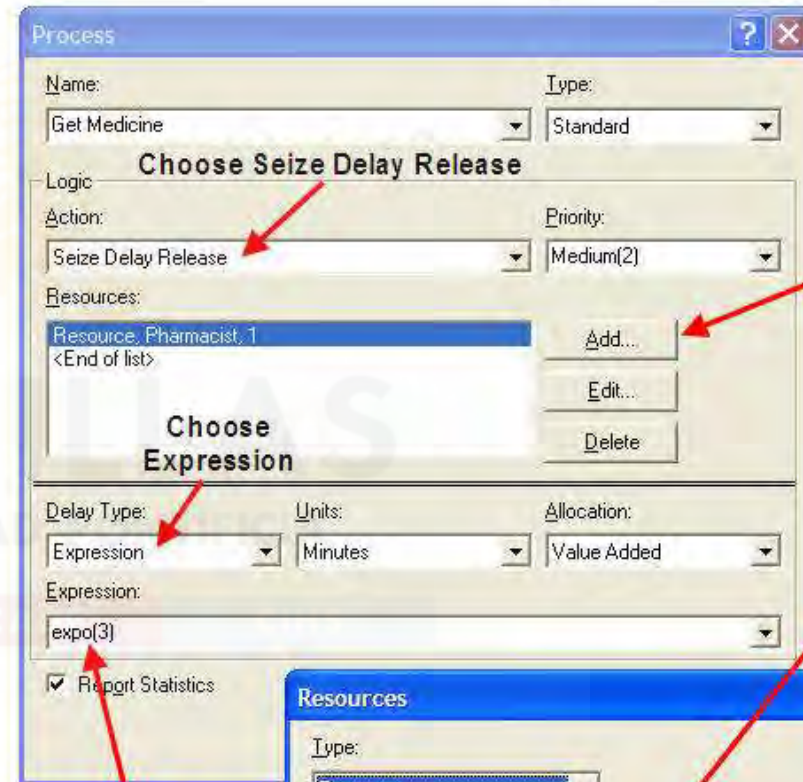
Report Statistics

Buttons: Add... Edit... Delete OK Cancel Help

Implementing the demo model in Arena (iv)

- PROCESS module

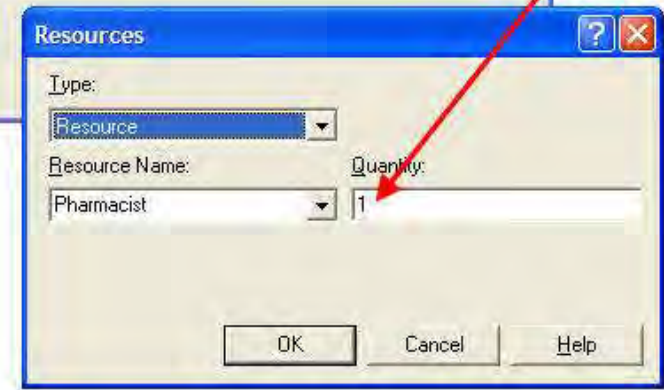
- PROCESS: Set of activities experienced by an entity
- Processes may be resource-unconstrained or constrained (example)
- Pharmacist's example:
 - Seize the pharmacist
 - Delay in the service
 - Release the pharmacist



Click Add ... to get Resources usage dialog

This is the number of units of the resource needed by the entity NOT the resource capacity.

exponential services times with a mean of 3



Implementing the demo model in Arena (v)

- Run Setup

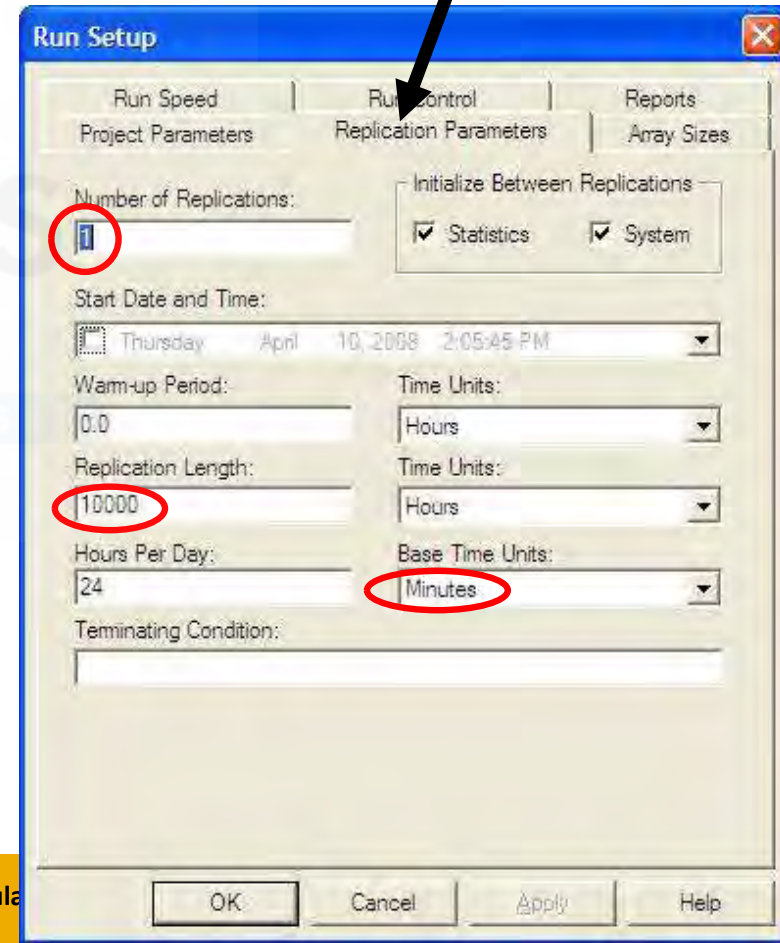
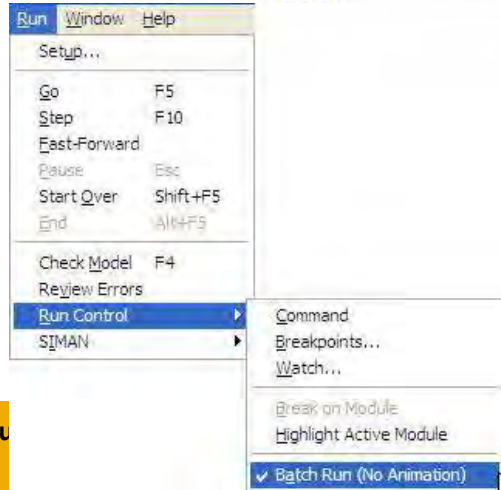
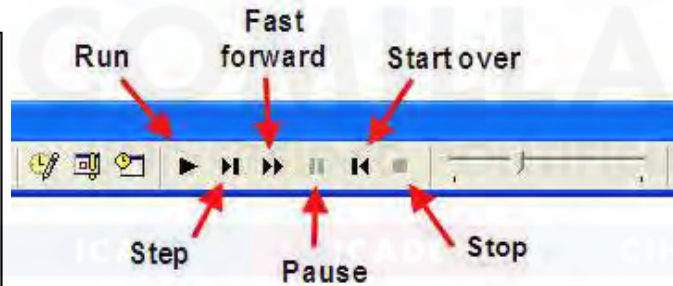
- Assumptions:

- The pharmacy is open 24 hours a day, 7 days a week
 - The arrival process does not vary over time
 - Simulation time: 10,000 hours of operation
 - Go to the *Run* menu item and choose *Setup*
 - The base time units are minutes for output reports
 - To run the model:
 - *Run* menu item
 - Run toolbar

Fast forward:
Run without animation (Batch mode)

Start over:
Stops the run and starts it again

Animation slider:
To slow down or speed up



Implementing the demo model in Arena (vi)

Half width of the confidence interval

- ANALYZE Results
 - Report Viewer:

Click + to drill down and see statistics for each category

Waiting Time		Average	Half Width	Minimum Value	Maximum Value
Get Medicine.Queue		3.0926	0.127711818	0.00	68.4229

Number Waiting		Average	Half Width	Minimum Value	Maximum Value
Get Medicine.Queue		0.5172	0.018576505	0.00	16.0000

Instantaneous Utilization		Average	Half Width	Minimum Value	Maximum Value
Pharmacist		0.5068	0.004501153	0.00	1.0000

Number Busy		Average	Half Width	Minimum Value	Maximum Value
Pharmacist		0.5068	0.004501153	0.00	1.0000

Number Scheduled		Average	Half Width	Minimum Value	Maximum Value
Pharmacist		1.0000	(Insufficient)	1.0000	1.0000

Scheduled Utilization		Value
Pharmacist		0.5068

51% busy

Total Number Seized		Value
Pharmacist		100351.00

Total # served customers

Implementing the demo model in Arena (vii)

- ANALYZE Results (cont.)
 - Text-based report: the file “modelname.out” in the directory associated to the model

PharmacyModel1 - Notepad

ARENA Simulation Results
Industrial Engineering

Summary for Replication 1 of 1

Project: unnamed Project
Analyst:
Run execution date : 4/10/2008
Model revision date: 4/10/2008

Replication ended at time : 600000.0 Minutes
Base Time Units: Minutes

TALLY VARIABLES

Identifier	Average	Half width	Minimum	Maximum	observations
Customer.VATime	3.0301	.02175	2.0142E-05	37.451	100350
Customer.NVATime	.00000	.00000	.00000	.00000	100350
Customer.waitTime	3.0926	.12771	.00000	68.422	100350
Customer.TranTime	.00000	.00000	.00000	.00000	100350
Customer.OtherTime	.00000	.00000	.00000	.00000	100350
Customer.TotalTime	6.1227	.14416	2.0142E-05	70.525	100350
Get.Medicine.Queue.waitingTime	3.0925	.12771	.00000	68.422	100351

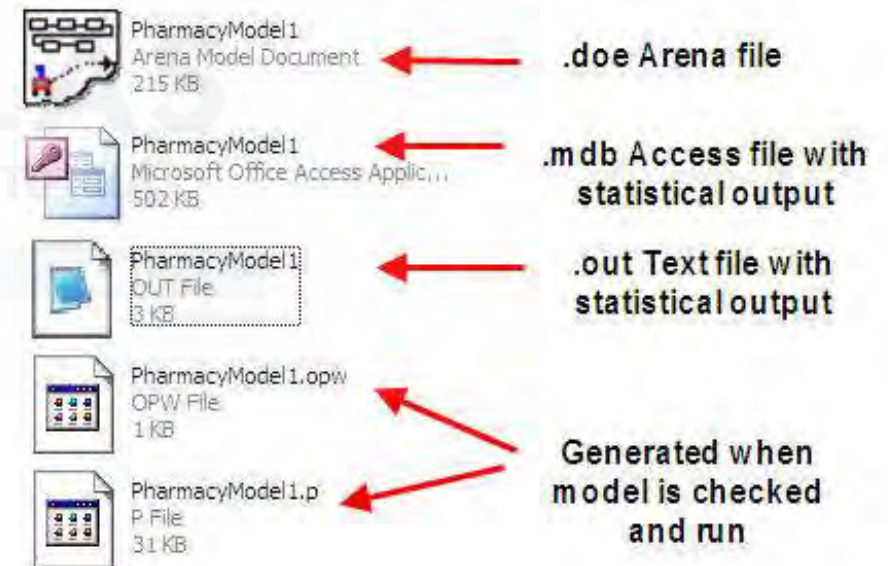
DISCRETE-CHANGE VARIABLES

Identifier	Average	Half width	Minimum	Maximum	Final Value
Customer.WIP	1.0240	.02218	.00000	17.000	1.0000
Pharmacist.NumberBusy	.50679	.00450	.00000	1.0000	1.0000
Pharmacist.NumberScheduled	1.0000	(Insuf)	1.0000	1.0000	1.0000
Pharmacist.Utilization	.50679	.00450	.00000	1.0000	1.0000
Get.Medicine.Queue.NumberInQueue	.51724	.01858	.00000	16.000	.00000

OUTPUTS

Identifier	Value
Customer.NumberIn	1.0035E+05
Customer.Numberout	1.0035E+05
Pharmacist.Numberseized	1.0035E+05
Pharmacist.Scheduledutilization	.50679
System.Numberout	1.0035E+05

Simulation run time: 0.02 minutes.
Simulation run complete.



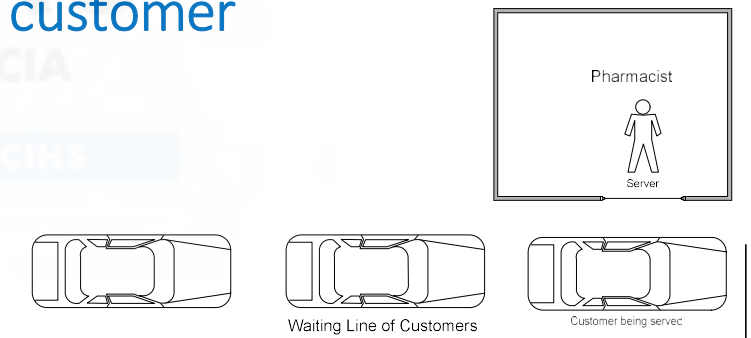
1. ARENA Basics
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Extended Example: The Pharmacist Continued

Extending/modifying the demo example

- Compound Arrivals: 20% 1 customer, 30% 2 c., and 50% 3 c.
- Customers who arrive at the pharmacy have 1, 2, or 3 prescriptions with 50%, 30%, and 20% probabilities
- The service time mean is 3, 4, and 5 minutes, respectively
- Statistics to collect are the **average number of prescriptions** in the system and the **average time spent by the customer**
- Collecting only the first 30 arrivals



File: [Pharmacist_chapter2.doe](#)

Defining Variables and Attributes

- VARIABLES: quantities that are properties of the [system](#) that may change
 - Suggestion: its name starts with v (for example, *vLambda*)
 - Variables are used to share information across all modules in the model
 - To define a variable is possible through the spreadsheet view or through a dialog box

Variable - Basic Process

	Name	Rows	Columns	Data Type	Clear Option	Initial Values	Report Statistics
1	vScalar			Real	System	0 rows	<input type="checkbox"/>
2	v1DArray	3		Real	System	3 rows	<input type="checkbox"/>
3	v2DArray	2	5	Real	System	10 rows	<input type="checkbox"/>

Double-click here to add a new row.

Initial Values

	1	2	3	4	5
1	1.1	1.2	3.1	9.0	99.9
2	10.5	4.3	0.0	2.9	27.4

Variable - Basic Process

	Name	Rows	Columns	Data Type	Clear Option	Initial Values	Report Statistics
1	vScalar			Real	System	0 rows	<input type="checkbox"/> Click to enter values
2	v1DArray	3		Real	System	3 rows	<input type="checkbox"/>
3	v2DArray	2	5	Real	System	10 rows	<input type="checkbox"/>

Double-click here to add a new row.

Variable

Name: v1DArray

Rows: 3 Columns:

Clear Option: System

Data Type: Real

Initial Values:

1.0 Add...
 3.0 Edit...
 7.0 Delete
 <End of list>

OK Cancel Help

Defining Variables and Attributes (cont.)

- **ATTRIBUTE:** It is a named property or characteristic of an entity
 - **Suggestion:** its name starts with *my* (for example, *myArrivalTime*)
 - For example: dimensions, color, reference, ...
 - There are predefined attributes that ARENA uses to track entities
 - **IDENT:** to identify entities (each entity has a different value)
 - **Entity.SerialNumber:** this number is unique when the entity is created, but it is the same if the entity is cloned
 - **Entity.Type:** It is useful to distinguish entities after they are created. Also, it is used for the entity picture and cost attributes

Predefined attributes

User-defined attributes

IDENT	Entity.SerialNumber	Entity. Type	Size	Weight	Processing Time
1	1001	1	2	33	20
2	1002	2	3	22	55
3	1003	2	1	11	44
4	1004	1	2	33	20
5	1005	1	5	10	14
6	1006	3	4	14	10

System Performance of the demo model

Variables:

- **vNumPrescriptions**: Scalar variable that counts the total number of prescriptions in the system (initial v.=0)
- **vNP**: a 1D variable with 3 rows and counts the number of customers having 1, 2, and 3 prescriptions currently in the system
- **vServiceMean**: a 1D variable with 3 rows representing the mean of the service distributions for the 3 prescription quantities (initial values = 3, 4, and 5)

	Name	Rows	Columns	Data Type	Clear Option	Initial Values	Report Statistics
1	vNumPrescriptions			Real	System	0 rows	<input checked="" type="checkbox"/>
2	vNP	3		Real	System	0 rows	<input type="checkbox"/>
3	vServiceMean	3		Real	System	3 rows	<input type="checkbox"/>
4	vEventType			Real	System	0 rows	<input type="checkbox"/>

Double-click here to add a new row.

1	3.0
2	4.0
3	5.0

Click on initial values button to edit initial values

Causes time based statistics to be collected

ASSIGN module (where values of variables/attributes are assigned)

Click Add... to add new assignments

Select the type of assignment (attribute, variable, etc.)

Enter or select the variable or attribute to which the assignment is being made

Enter the expression that will be assigned

Expression Builder

Expression Type: Cumulative Probabilities and Values (P1,V1,P2,V2,...): [0.2, 1, 0.5, 2, 1, 0, 3]

Random Distributions: Beta, Continuous Probability, Discrete Probability, k-Erlang, Exponential, Gamma, Johnson, Lognormal, Normal, Poisson

Current Expression: DISC[0.2, 1, 0.5, 2, 1, 0, 3]

DISC($cp_1, v_1, cp_2, v_2, \dots$)
 Discrete probability function with probabilities:

$$P(X = v_i) = cp_i - cp_{i-1}$$

The order of assignments is very important!

	Type	Variable Name	Row	Attribute Name	New Value
1	Attribute	Variable 1		myNP	DISC(0.5, 1, 0.8, 2, 1.0, 3)
2	Variable	vNumPrescriptions	1	Attribute 2	vNumPrescriptions + myNP
3	Variable Array (1D)	vNP	myNP	Attribute 3	vNP(myNP) + 1
4	Attribute	Variable 4		myArriveTime	TNOW
5	Variable	vEventType		Attribute 5	1

Arrival Event

Current Simulation time

Assign - Basic Process

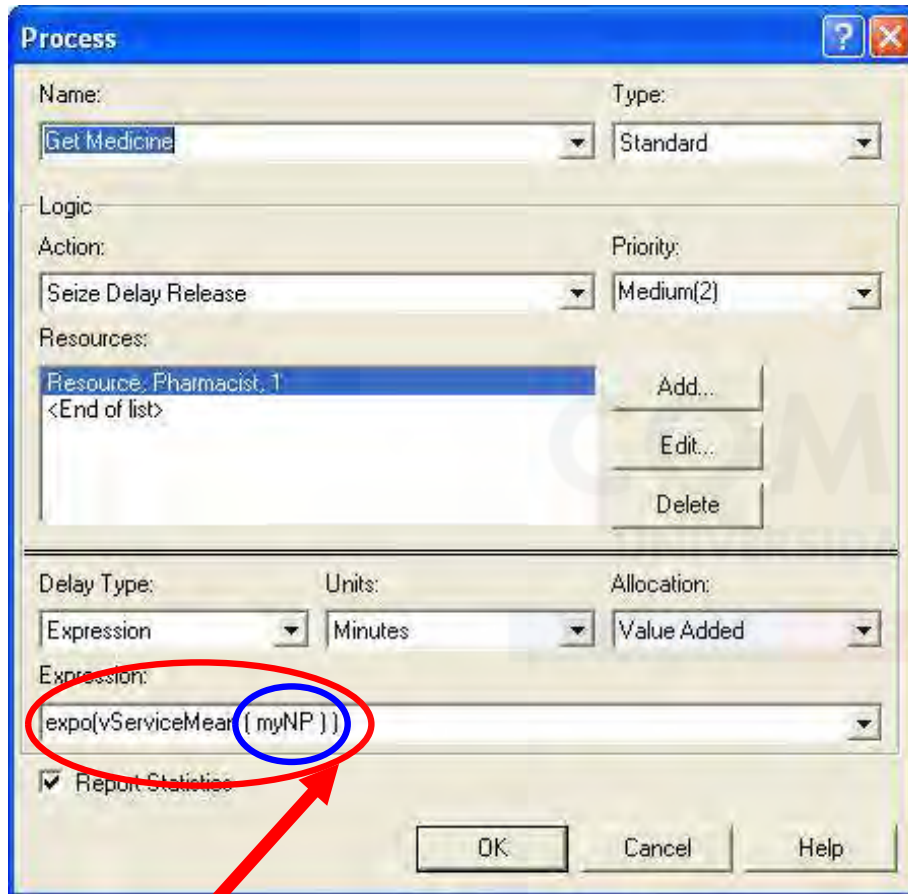
	Name	Assignmen
1	Assign Number of Prescriptions	5 rows
2	Decrement For Departing Customers	3 rows

Click to see spreadsheet view of ASSIGN module

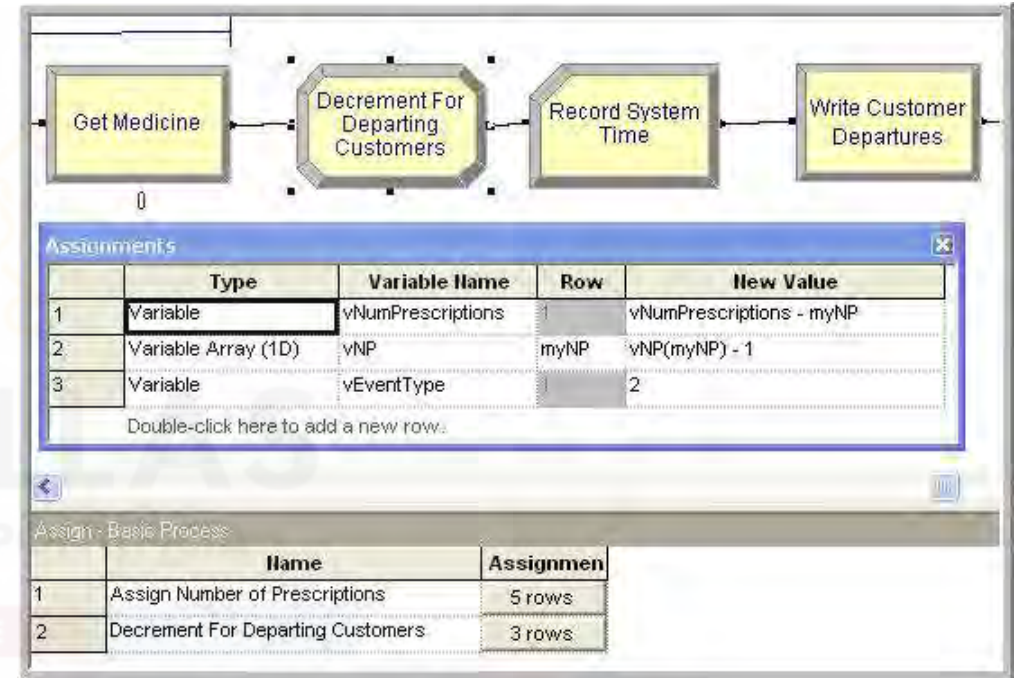
PROCESS module

Updated statistics with ASSIGN

- Including the service time mean dependent on the number of prescriptions



This way to index arrays is very common

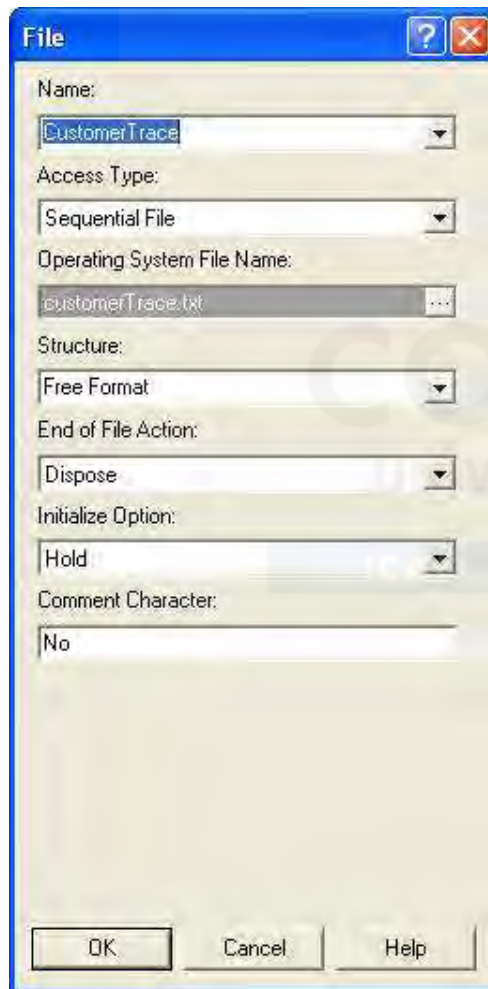


Updated variables:

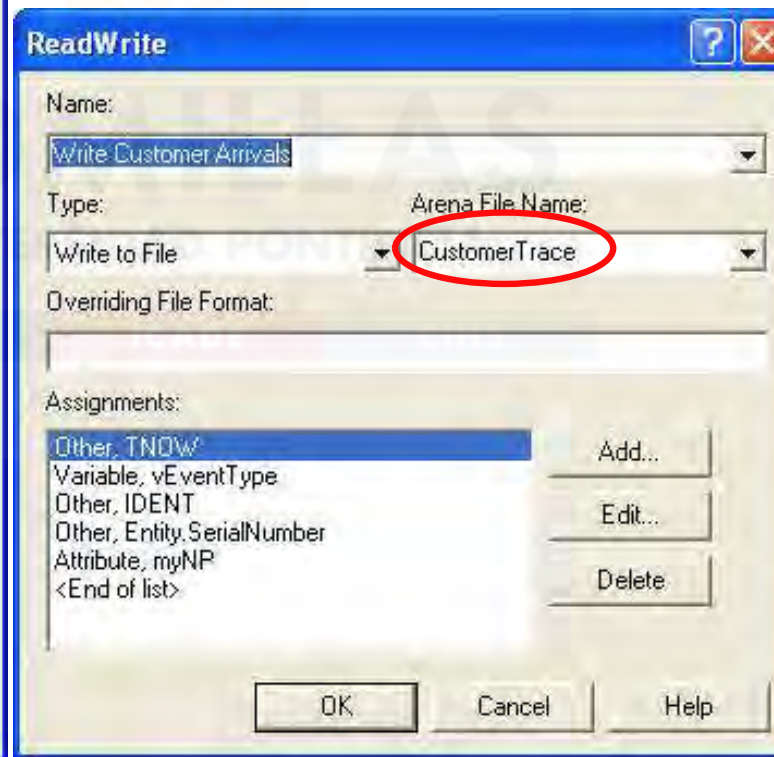
- vNumPrescriptions**: Subtracting *myNP*
- vNP**: Subtracting only one from the *myNP* count
- vEventType**: Set to 2 as a departure event

READWRITE module (read from/write to a file)

- The READWRITE module helps to **debug the model** (analyzing arrival and departure times) in the Advanced Process Panel
- First, it is necessary to define a FILE in the Advanced Process Panel



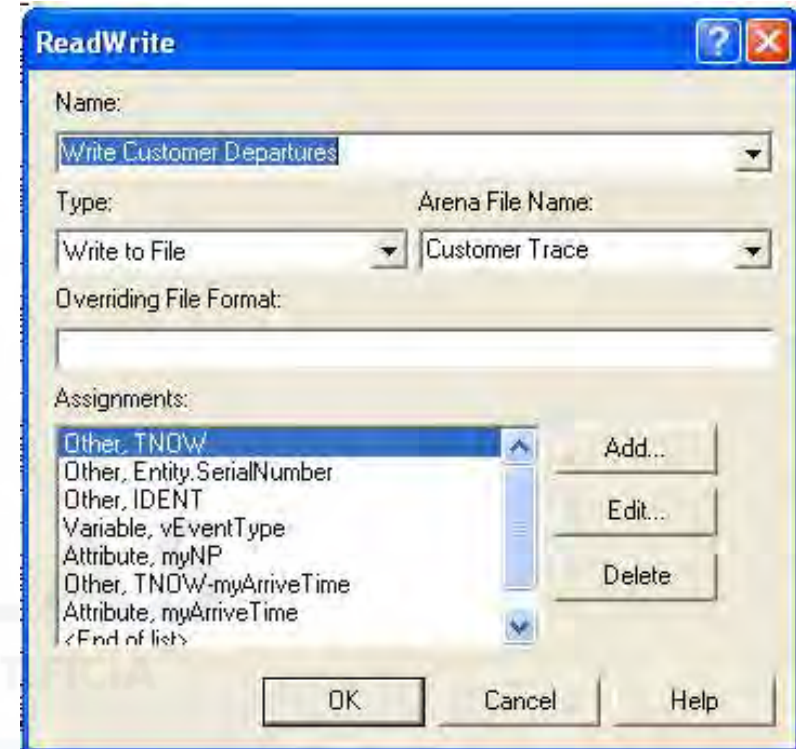
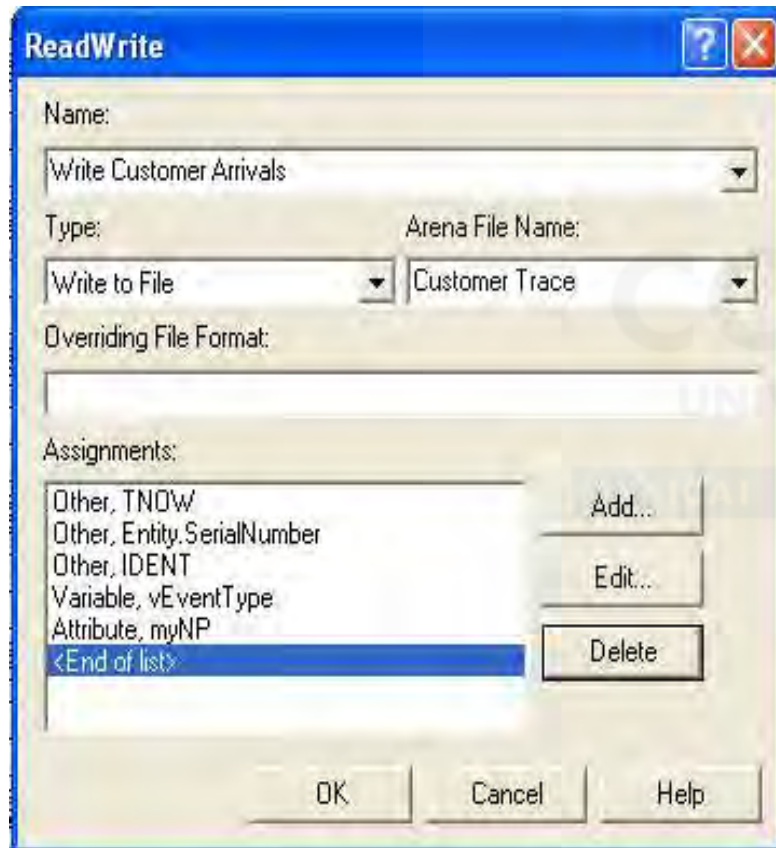
Sequential File: A text file whose records will be in the same sequence as they are written
Free format: each value in the file is separated by a space



Written Information

TNOW: Current Simulation Time
vEventType: Type of Event
IDENT: Entity identity number
Entity.SerialNumber
myNP: number of prescriptions for the customer

READWRITE to FILE

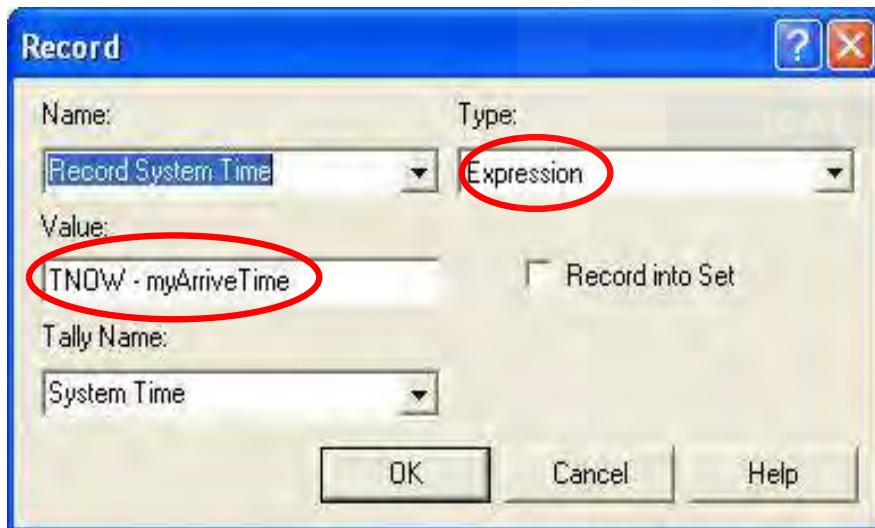


FILE: Customer Trace.txt

2.076914	1.000000	2.000000	1.000000	1.000000	
2.076914	2.000000	4.000000	1.000000	1.000000	
2.498945	1.000000	2.000000	2.000000	1.000000	0.422032 2.076914
6.400697	3.000000	3.000000	1.000000	3.000000	
6.400697	4.000000	6.000000	1.000000	1.000000	
6.400697	5.000000	7.000000	1.000000	3.000000	
11.064971	2.000000	4.000000	2.000000	1.000000	8.988057 2.076914
26.578563	3.000000	3.000000	2.000000	3.000000	20.177866 6.400697
26.941828	4.000000	6.000000	2.000000	1.000000	20.541131 6.400697
30.096515	5.000000	7.000000	2.000000	3.000000	23.695817 6.400697
37.113203	6.000000	5.000000	1.000000	1.000000	

RECORD module

- Module in the Basic Process Panel
- This module “records” information each time an entity passes through it
- It is necessary to compute the average time in the System
- The options included are:
 - **Count**: Increase or decrease the value of the named counter by a specified value (useful to obtain statistics about how many entities flow through the model)
 - **Entity Statistics**: Generate general entity statistics (time and cost/duration information)
 - **Time Interval**: To calculate and record the difference between a specified attribute value and the current simulation time
 - **Time Between**: To track and record the time between entities entering the module
 - **Expression**: To record the value of the specified expression



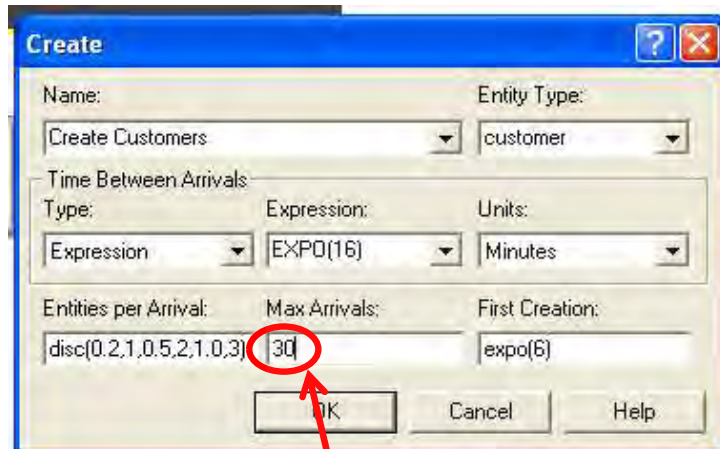
The screenshot shows the 'Tally' table with the following data:

Expression	Average	Half Width	Minimum Value	Maximum Value
Record System Time	14.8424	0.638379141	0.00002686	157.58

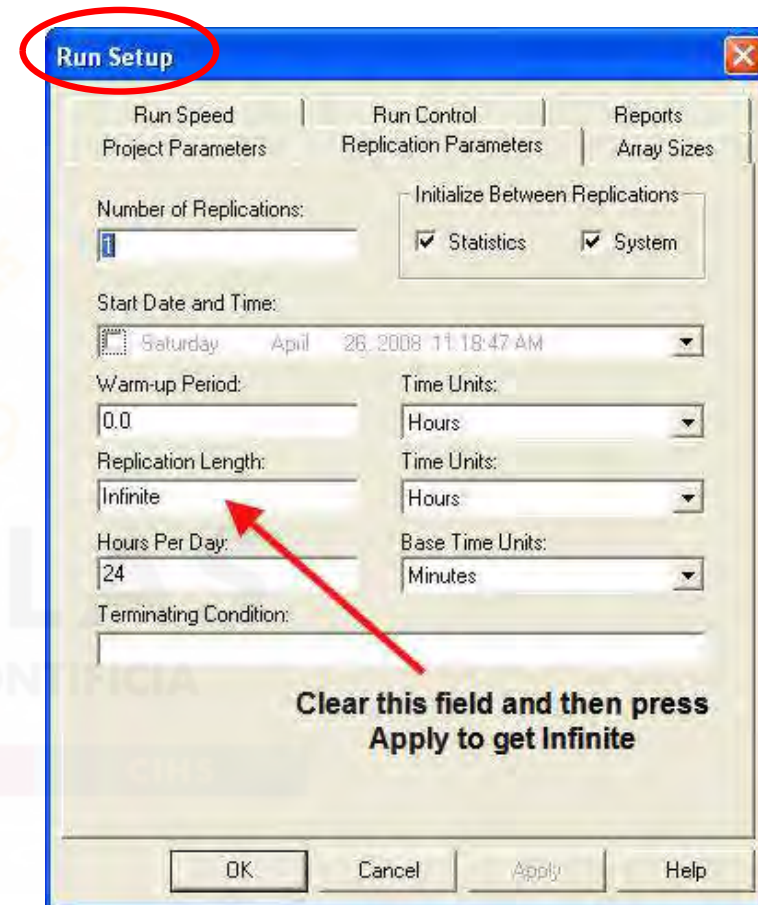
Time Persistent

Variable	Average	Half Width	Minimum Value	Maximum Value
vNumPrescriptions	3.7162	0.155226793	0.00	71.0000

Run the model with 30 first arrivals

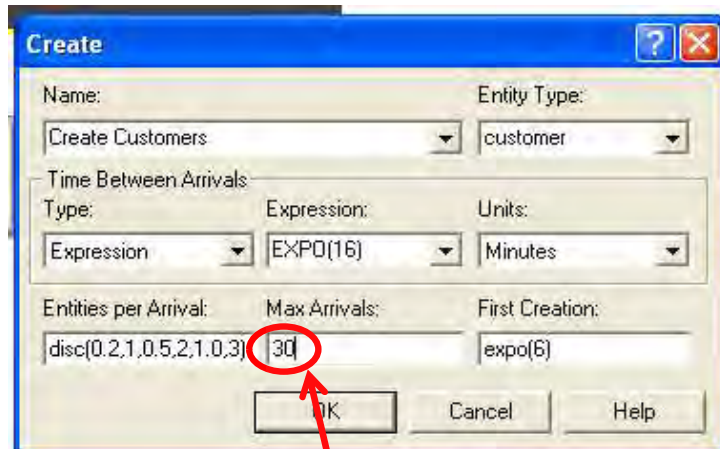


Maximum number of customers

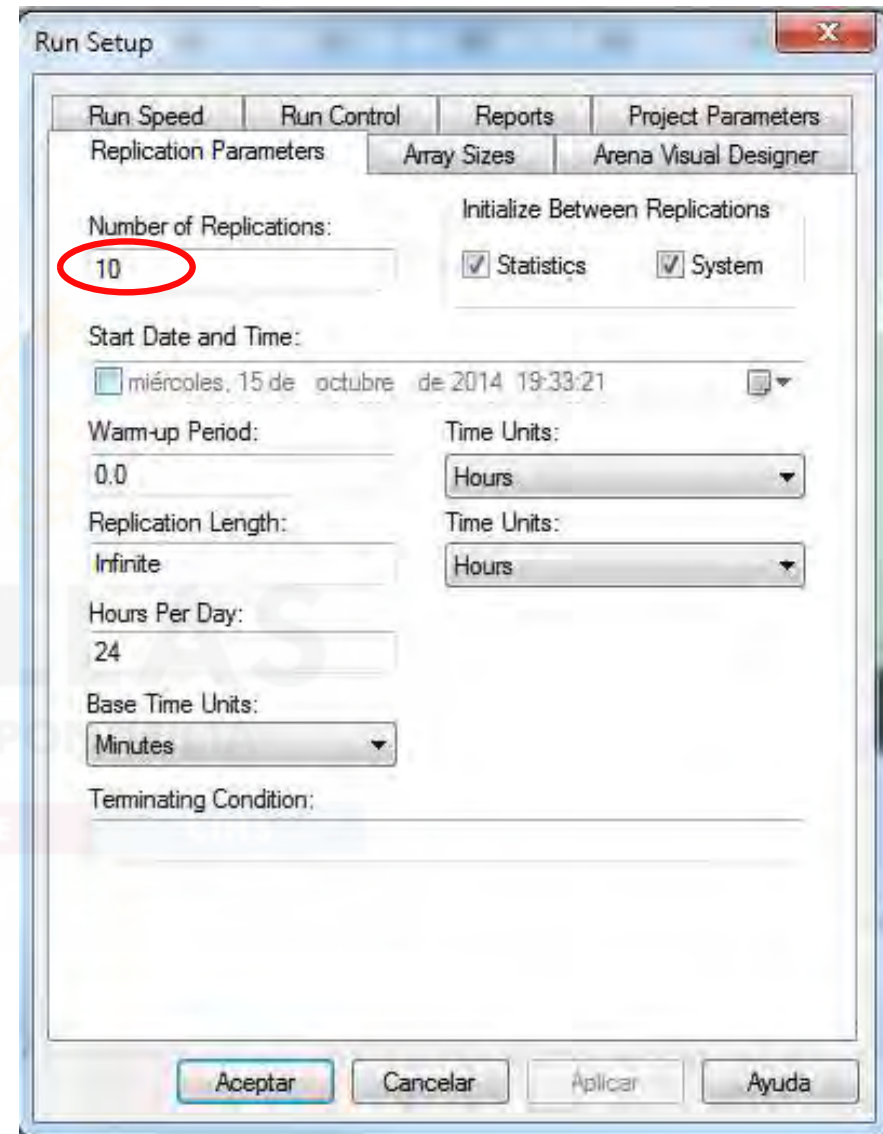


Clear this field and then press
Apply to get Infinite

Run the model with 10 replications of 30 first arrivals



Maximum number of customers



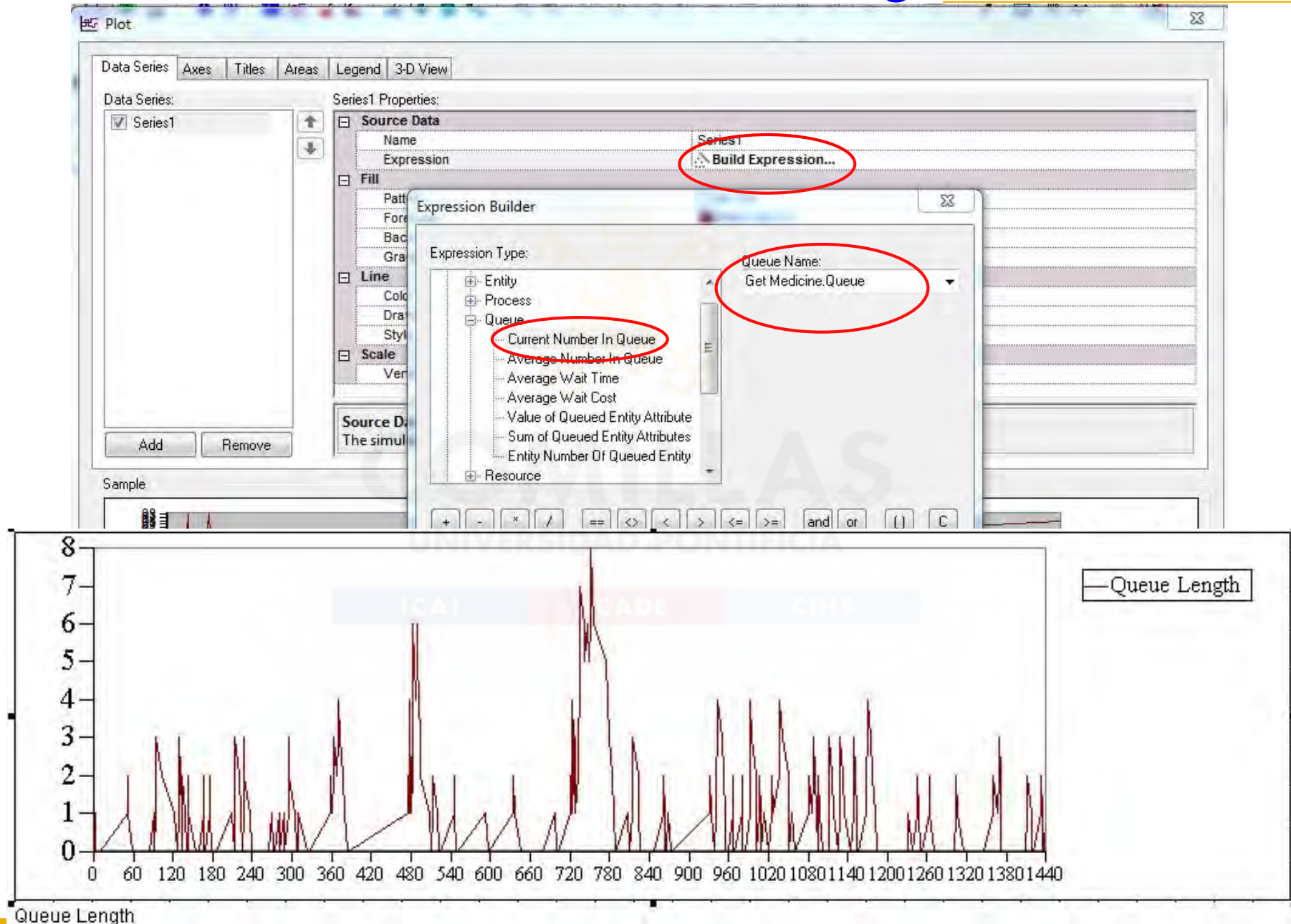
Augment the simulation: Displaying variable values

- Display the number of prescriptions in the System (*vNumPrescriptions*)

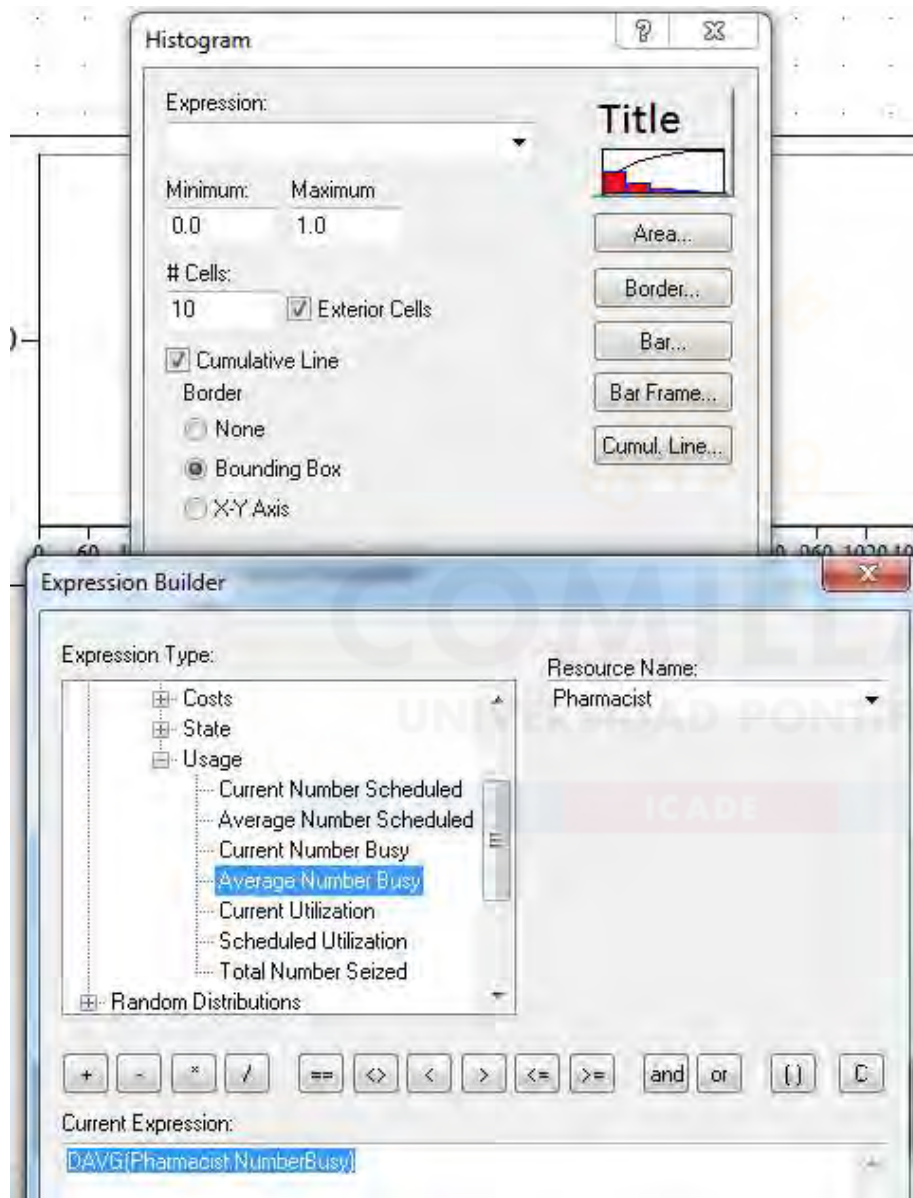
The image illustrates the process of displaying a variable value in a simulation. It consists of three main parts:

- Animate Toolbar and Menu:** The 'Animate' toolbar is shown with red arrows pointing to the 'Variables', 'Queues', and 'Resources' icons. The 'Animate' menu is open, showing options like Standard, Draw, Animate, Integration, View, Arrange, Run Interaction, Record Macro, AVI Capture, Animate Transfer, and Dialog Design.
- Variable Dialog Box:** A dialog box titled 'Variable' is shown. The 'Expression' field contains 'vNumPrescriptions'. The 'Format' field is set to 'xxxx'. The 'Alignment' is set to 'Right'. The 'Title' section has 'Use Title' checked, 'Percent Height' set to 25.0, 'Vart. Alignment' set to 'Top', and 'Horiz. Alignment' set to 'Left'. The 'Title Text' field is empty. The 'OK', 'Cancel', and 'Help' buttons are visible at the bottom.
- Simulation Diagram:** A diagram showing a process flow with two activity boxes: 'Get Medicine' and 'Decrement For Departing Customers'. Below the diagram is a variable box labeled 'vNumPrescriptions' with a blue oval indicating the variable's value.

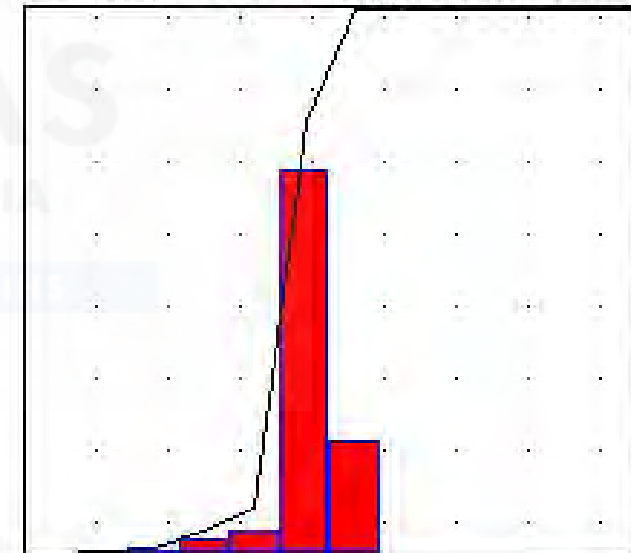
Augment the simulation: Plot the Current Number in Queue along the Simulation



Augment the simulation: Plot a histogram of the pharmacist current utilization



Pharmacist Average Utilization



ARENA Typical Commands – Distributions/Other commands

Examples of distributions

- Exponential: EXPO(value)
- Triangular: TRIA(minimum, value, maximum)
- Normal: NORM(mean, standard deviation)
- Uniform: UNIF(minimum, maximum)
- DISC: Discrete cumulative distribution function. DISC(cumulative probability 1, value 1, cumulative prob.1, value 2, ..., c.p.N, value N).

Other useful stuff

- TNOW: Current simulation time. TNOW records the simulation clock time as the model progresses.
- TFIN: Final simulation time. TFIN is the ending time scheduled for the replication; it is a real-valued quantity.

Commands for resources

- MR(Resource ID): Resource capacity.
- MR returns the capacity units currently defined for the specified Resource ID.
- NR(Resource ID): Number of busy resource units.
- ResUtil(Resource ID): Resource utilization. ResUtil returns the instantaneous utilization of a resource as a real number between 0 and 1, inclusive.

Check out the ARENA Variables Guide

<https://cours.etsmtl.ca/gpa662/documents/Cours/Arena%20Variables%20Guide.pdf>



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