

Modeling Basic Operations and Inputs

Chapter 4

Simulation with Arena, 3rd ed. Chapter 4 – Modeling Basic Operations and Inputs Slide 1 of 66

What We'll Do ...

- **Model 4-1: Electronic assembly/test system**
 - Modeling approaches
 - New Arena modules (Decide, Record)
- **Model 4-2: Enhanced electronic assembly/test**
 - Resource Schedules, States, and Failures
 - Frequency outputs
 - More on utilizations
- **Model 4-3: Enhancing the animation**
 - Queues, Entity Pictures, Resource Pictures
 - Adding Plots and Variables

Simulation with Arena, 3rd ed. Chapter 4 – Modeling Basic Operations and Inputs Slide 2 of 66

What We'll Do ... (cont'd.)

- **Model 4-4: Adding entity travel times**
 - Modify with Stations, Transfers, Routes, animation of entity movement
- **Input analysis**
 - Specifying input distributions, parameters
 - Deterministic vs. random input
 - Collecting and using data
 - Fitting input distributions via the Input Analyzer
 - No data?
 - Nonstationary arrival processes
 - Multivariate and correlated input data

Simulation with Arena, 3rd ed. Chapter 4 – Modeling Basic Operations and Inputs Slide 3 of 66

Run Conditions, Output

- Start empty & idle, run for four 8-hour shifts (1,920 minutes)
- Collect statistics for each work area on
 - Resource utilization
 - Number in queue
 - Time in queue
- For each exit point (Shipped, Salvaged, Scrapped), collect total time in system (a.k.a. cycle time)


Simulation with Arena, 3rd ed. Chapter 4 – Modeling Basic Operations and Inputs Slide 7 of 66

Developing a Modeling Approach

- Define pieces of model, modules, data structures, control logic
- Appropriate level of detail – judgment call
- Often multiple ways to model, represent logic
- This model:
 - Entities are the individual parts (two types)
 - Separate Create modules for two part types
 - Separate Process modules for each Prep area
 - Process modules for Sealer and Rework, each followed by a Decide module (2-way by Chance)
 - Depart modules for Shipped, Salvaged, Scrapped
 - Attribute *sealer_time* assigned after Creates in Assign modules (parts have *different* times at the Sealer)
 - Record modules just before Departs for time in system

Simulation with Arena, 3rd ed. Chapter 4 – Modeling Basic Operations and Inputs Slide 8 of 66

Building the Model

- New model window
- Attach Basic Process panel (if needed)
- Place modules
 - Create (x 2)
 - Assign (x 2)
 - Process (x 4)
 - Decide (x 2)
 - Record (x 3)
 - Dispose (x 3)
- Right click — repeat last action (place module)
- Auto-Connect, or manually connect via 

Alternate strategy – place one module at a time, fill it out completely

Simulation with Arena, 3rd ed. Chapter 4 – Modeling Basic Operations and Inputs Slide 9 of 66

Part A Create Module

- **Name:** Part A Arrive
- **Entity Type:** Part A
- **Time Between Arrivals**
 - Type: **Random (Expo)**
 - Pull-down list with options
 - Value: 5
 - Units: **Minutes**
 - Pull-down list with options
- **Default what's not mentioned above**

Once these entries are made, they are placed on the list for names of that type (Module Name, Entity Type, etc.) and will appear on future pull-down lists for that type of name.

Simulation with Arena, 3rd ed. Chapter 4 – Modeling Basic Operations and Inputs Slide 10 of 66

Part B Create Module

- **Name:** Part B Arrive
- **Entity Type:** Part B
- **Time Between Arrivals**
 - Type: **Random (Expo)**
 - Pull-down list with options
 - Value: 30
 - Units: **Minutes**
 - Pull-down list with options
- **Entities per Arrival:** 4

Simulation with Arena, 3rd ed. Chapter 4 – Modeling Basic Operations and Inputs Slide 11 of 66

Part A Attributes Assign Module

- **Name:** Assign Part A Sealer and Arrive Time
- **Add button:**
 - Type: **Attribute**
 - Attribute Name: **Sealer Time**
 - New Value: **TRIA(1, 3, 4)**
- **Add button:**
 - Type: **Attribute**
 - Attribute Name: **Arrive Time**
 - New Value: **TNOW** (to compute time in system on exit)

TNOW is the internal Arena variable name for the simulation clock; see *Help > Arena Help > Contents > Variables, Functions, and Distributions > Date and Time Variables*

Simulation with Arena, 3rd ed. Chapter 4 – Modeling Basic Operations and Inputs Slide 12 of 66

Part B Attributes Assign Module

- **Name:** Assign Part B Sealer and Arrive Time
- **Add button:**
 - Type: **Attribute**
 - Attribute Name: **Sealer Time**
 - New Value: **WEIB(2.5, 5.3)**
- **Add button:**
 - Type: **Attribute**
 - Attribute Name: **Arrive Time**
 - New Value: **TNOW**

Names for things in Arena
– Default names usually suggested
– Names placed on appropriate pull-down lists for future reference
– All names in a model must be unique (even across different kinds of objects)

Simulation with Arena, 3rd ed. Chapter 4 – Modeling Basic Operations and Inputs Slide 13 of 66

Process Module Actions

- **Delay**
Entity just sits here for the specified time; no Resource involved, so multiple entities could be undergoing this Delay simultaneously
- **Seize Delay**
Entity must first Seize the specified number of units of a Resource (possibility for Queueing if they're not available), then undergoes the Delay ... assume that the entity will Release the Resource units at another downstream module
- **Seize Delay Release**
Like Seize Delay, but entity releases Resource units after Delay (*what we want in this model*)
- **Delay Release**
Assumes entity had already Seized Resource units at another upstream module, now Delays and Releases Resource units

Simulation with Arena, 3rd ed. Chapter 4 – Modeling Basic Operations and Inputs Slide 14 of 66

Prep A Process Module

- **Name:** Prep A Process
- **Action:** Seize Delay Release
- **Resources subdialog (Add button):**
 - Type: **Resource** (a pull-down option)
 - Resource Name: **Prep A**
 - Quantity: **1** (default)
- **Delay Type:** **Triangular**
- **Units:** **Minutes**
- **Minimum:** **1**
- **Value (Most Likely):** **4**
- **Maximum:** **8**

Simulation with Arena, 3rd ed. Chapter 4 – Modeling Basic Operations and Inputs Slide 15 of 66

Prep B Process Module

- **Name:** Prep B Process
- **Action:** Seize Delay Release
- **Resources subdialog (Add button):**
 - Type: Resource (a pull-down option)
 - Resource Name: Prep B
 - Quantity: 1 (default)
- **Delay Type:** Triangular
- **Units:** Minutes
- **Minimum:** 3
- **Value (Most Likely):** 5
- **Maximum:** 10

Simulation with Arena, 3rd ed. Chapter 4 – Modeling Basic Operations and Inputs Slide 16 of 66

Sealer Process Module

- **Name:** Sealer Process
- **Action:** Seize Delay Release
- **Resources subdialog (Add button):**
 - Type: Resource (a pull-down option)
 - Resource Name: sealer
 - Quantity: 1 (default)
- **Delay Type:** Expression
- **Units:** Minutes
- **Expression:** Sealer Time

Recall – sealer Time attribute was defined upstream for both Parts A and B ... now its value is being used ... allows for different distributions for A and B.

Simulation with Arena, 3rd ed. Chapter 4 – Modeling Basic Operations and Inputs Slide 17 of 66

Sealer Inspection-Result *Decide* Module

- **Decide module provides branch points**
 - *By Condition* (entity Attributes, global Variables)
 - *By Chance* (multi-sided, possibly-biased hypercoin flip)
- **Name:** Failed Sealer Inspection
- **Type:** 2-way by Chance (default)
- **Percent True:** 9
- **Different exit points for True, False results – connect appropriately downstream**

- Note it's *percent* true, not *probability* of true ... so "9" means probability of 0.09
- We arbitrarily decided "true" meant part failed inspection ... could have reversed (but would change numerical results ... why? ... does this upset you? ... why?)
- This is a rich, deep, versatile module ... explore its Help button

Simulation with Arena, 3rd ed. Chapter 4 – Modeling Basic Operations and Inputs Slide 18 of 66

Rework Process Module

- **Name:** Rework Process
- **Action:** Seize Delay Release
- **Resources subdialog (Add button):**
 - Type: Resource (a pull-down option)
 - Resource Name: Rework
 - Quantity: 1 (default)
- **Delay Type:** Expression
- **Units:** Minutes
- **Expression:** EXPO(45)

Had to use the general Expression choice for Delay Type since what we want (EXPO) is not directly on the Delay Type pull-down list.

Simulation with Arena, 3rd ed. Chapter 4 – Modeling Basic Operations and Inputs Slide 19 of 66

Rework Inspection-Result Decide Module

- **Name:** Failed Rework Inspection
- **Type:** 2-way by Chance (default)
- **Percent True:** 20

We arbitrarily decided "true" meant part failed inspection

Simulation with Arena, 3rd ed. Chapter 4 – Modeling Basic Operations and Inputs Slide 20 of 66

Record Modules

- **Arena collects and reports many output statistics by default, but sometimes not all you want**
- **We want time in system (average, max) of parts sorted out by their exit point (Shipped, Salvaged, Scrapped)**
 - It's this sorting that Arena doesn't do by default ... it would automatically sort by Entity Type if we had Entities checked in Run > Setup > Project Parameters (which we don't)
- **Record module can be placed in the flowchart to collect and report various kinds of statistics from within the model run as entities pass through it**
- **For Tally-type output performance measures (see Chapter 3)**

Simulation with Arena, 3rd ed. Chapter 4 – Modeling Basic Operations and Inputs Slide 21 of 66

Shipped Parts *Record* Module

- **Name:** Record Shipped Parts
- **Type:** Time Interval
 - This option records the length of time that elapsed up to now (**TNOW**) from when an entity attribute was marked with a time "stamp" upstream ... Attribute Name is below ...
 - There are several other options for Type ... explore via Record module's Help button!
- **Attribute Name:** Arrive Time
 - Was defined upstream as the clock value in the Assign modules instantly after each entity was Created
- **Tally Name:** Record Shipped Parts
 - Determines the label in the reports

Other two Record modules – just like this except for Name and Tally Name.

Simulation with Arena, 3rd ed. Chapter 4 – Modeling Basic Operations and Inputs Slide 22 of 66

Dispose Modules

- **Three separate exit points for three separate part disposition (Shipped, Salvaged, Scrapped)**
- **Could have directed all three exit types to a single Dispose module**
 - But having separate ones produces animation counts of the three dispositions
- **Also, having separate Dispose modules allows for differentially checking the boxes to Record Entity Statistics**
 - Produces flow statistics separated by entity type (*if* Entities Statistics Collection is checked in *Run > Setup > Project Parameters*), *not* by final disposition of part ... so we *did* need our Record modules and Arrive Time attribute

Simulation with Arena, 3rd ed. Chapter 4 – Modeling Basic Operations and Inputs Slide 23 of 66

Run > Setup for Run Control

- **Without this, model would run forever – no defaults for termination rule**
 - That's part of modeling, and generally affects results!
- **Project Parameters tab:**
 - Fill in Project Title, Analyst Name
 - Defaults for Statistics Collection, but we cleared the check box for Entities – not needed for what we want (we installed our own Record modules), and would slow execution
- **Replication Parameters tab:**
 - Replication length: 32, accept **Hours** default for Time Units
 - Base Time Units: **minutes** for inputs without Time Units option, internal arithmetic, and units on output reports

Simulation with Arena, 3rd ed. Chapter 4 – Modeling Basic Operations and Inputs Slide 24 of 66

Different Part A, B Entity Pictures

- **Entity data module (just single-click on it in Project Bar, edit via spreadsheet only)**
- **Row for each Entity Type (Part A, Part B)**
- **Pull down Initial Picture pull-down menu, select different pictures for each Entity Type**
 - *Edit > Entity Pictures* to see, change the list of pictures that's presented here ... more later

Simulation with Arena, 3rd ed. Chapter 4 – Modeling Basic Operations and Inputs Slide 25 of 66

Running the Model

- **Check (if desired)**
 - Find button to help find errors
- **Go (will automatically pre-Check if needed)**
 - Some graphics don't show during run ... will return when you End your run ... control via *View > Layers*
 - Status Bar shows run progress – replication number, simulation time, simulation status
- **Animation speed – increase (>), decrease (<)**
- **Pause (||) or Esc key; to resume**
- **Run > Step (|) to debug**
- **Run > Fast-Forward (|||) to turn off animation**
 - *Run > Run Control > Batch Run (No Animation)* is fastest

Simulation with Arena, 3rd ed. Chapter 4 – Modeling Basic Operations and Inputs Slide 26 of 66

Viewing the Results

- **Counters during animation for modules**
 - Create, Dispose, Decide – incremented when entity leaves
 - Process – number of entities currently in the module
- **Asked at end if you want to see reports**
 - What you get depends on *Run > Setup > Project Parameters*
 - Looks like the Rework area is a bottleneck ... more later
 - Navigate through report with browsing arrows, tree at left
 - Tally, Time-Persistent, and Counter statistics
 - Avg, Min, Max, and 95% Confidence Interval half-widths
 - Confidence intervals are for steady-state expectations ... more later
 - May not be produced if run is not long enough for reliable stats
- **Generally difficult/unreliable to draw conclusions from just one run ... more later**

Simulation with Arena, 3rd ed. Chapter 4 – Modeling Basic Operations and Inputs Slide 27 of 66

Model 4-2: The Enhanced Electronic Assembly and Test System

- **A Story**
 - Original model shown to production manager
 - Pointed out that this is only the first shift of a two-shift day — on second shift there are two operators at Rework (the bottleneck station) ... 16-hour days
 - Pointed out that the Sealer fails sometimes
 - Uptimes ~ exponential, mean 2 hours
 - Repair times ~ exponential, mean 4 minutes
 - Wants to buy racks to hold rework queue
 - A rack holds 10 parts
 - How many racks should be bought?
 - Run for 10 days
- **Need: Resource Schedules, Resource States, Resource Failures**

Simulation with Arena, 3rd ed. Chapter 4 – Modeling Basic Operations and Inputs Slide 28 of 66

Change Run Conditions

- **Redefine a “day” to be 16 hours – Run > Setup > Replication Parameters**
- **Change Replication Length to 10 (of these) days**

Simulation with Arena, 3rd ed. Chapter 4 – Modeling Basic Operations and Inputs Slide 29 of 66

Schedules

- **Vary Capacity (number of units) of a resource over time**
- **In Resource Data module (spreadsheet view)**
 - For Rework Resource, change Type from **Fixed Capacity** to **Based on Schedule**
 - Two new columns – Schedule Name and Schedule Rule
 - Type in a schedule name (**Rework schedule**)
 - Select a Schedule Rule – details of capacity decrease if the Resource is allocated to an entity
 - *Ignore* – Capacity goes down immediately for stat collection, but work goes on until finished ... “break” could be shorter or gone
 - *Wait* – Capacity decrease waits until entity releases Resource, and “break” will be full but maybe start/end late
 - *Preempt* – Processing is interrupted, resumed at end of “break”

Simulation with Arena, 3rd ed. Chapter 4 – Modeling Basic Operations and Inputs Slide 30 of 66

Schedules (cont'd.)

- **Define the actual Schedule the Resource will follow – Schedule data module (spreadsheet)**
 - Row already there since we defined **Resource** schedule
 - Format Type is Duration for entries based on time past simulation beginning
 - Type is Capacity, for Resource schedule (more later on Arrival Type)
 - Click in Durations column, get Graphical Schedule Editor
 - X-axis is time, Y-axis is Resource Capacity
 - Click and drag to define the graph
 - Options button to control axis scaling, time slots in editor, whether schedule loops or stays at a final level forever
 - Can use Graphical Schedule Editor only if time durations are integers, and there are no Variables or Expressions involved

Simulation with Arena, 3rd ed. Chapter 4 – Modeling Basic Operations and Inputs Slide 31 of 66

Schedules (cont'd.)

- Alternatively, right-click in the row, select Edit via Dialog
 - Enter schedule Name
 - Enter pairs for Capacity, Duration ... as many pairs as needed
 - If all durations are specified, schedule repeats forever
 - If any duration is empty, it defaults to infinity
 - Can involve Variables, Expressions
- Another alternative – right-click in the row, select Edit via Spreadsheet
 - Enter capacity Value, Duration pairs

Simulation with Arena, 3rd ed. Chapter 4 – Modeling Basic Operations and Inputs Slide 32 of 66

Resource Failures

- **Usually used to model unplanned, random downtimes**
- **Can start definition in Resource or Failure module (Advanced Process panel) ... we'll start in Failure**
- **Attach Advanced Process panel if needed, single-click on Failure, get spreadsheet view**
- **To create new Failure, double-click – add new row**
- **Name the Failure**
- **Type – Time-based, Count-based (we'll do Time)**
- **Specify Up, Down Time, with Units**

Simulation with Arena, 3rd ed. Chapter 4 – Modeling Basic Operations and Inputs Slide 33 of 66

Resource Failures (cont'd.)

- **Attach this Failure to the correct Resource**
 - Resource module, Failures column, Sealer row – click
 - Get pop-up Failures window, pick Failure Name **sealer Failure** from pull-down list
 - Choose Failure Rule from **wait, Ignore, Preempt** (as in Schedules)
- **Can have multiple Failures (separate names)**
- **Can re-use defined Failures for multiple Resources (operate independently)**

Simulation with Arena, 3rd ed. Chapter 4 – Modeling Basic Operations and Inputs Slide 34 of 66

Frequencies

- **Record time-persistent occurrence frequency of variable, expression, or resource state**
 - Use here to record % of time rework queue is of length 0, (0, 10], (10, 20], ... to give info on number of racks needed
- **Statistic data module (Advanced Process panel)**
 - Five Types of statistics, of which Frequencies is one
 - Specify Name (**Rework Queue Stats**), Frequency Type (**Value**)
 - Specify Expression to track and categorize
 - Right-click in field to get to Expression Builder
 - Report Label (**Rework Queue Stats**)
 - Pop-up secondary spreadsheet for Categories (browse file)

Simulation with Arena, 3rd ed. Chapter 4 – Modeling Basic Operations and Inputs Slide 35 of 66

Frequencies (cont'd.)

- **Add another Frequency (in Statistic module) to give a finer description of the Sealer states**
 - Will produce statistics on proportion of time Sealer is in each of its *three* possible states – Busy, Idle, and Failed
- **Frequencies are not part of default Category Overview report – open Frequencies report from Project Bar (get a separate window for them)**

Simulation with Arena, 3rd ed. Chapter 4 – Modeling Basic Operations and Inputs Slide 36 of 66

Results of Model 4-2

- **Differ from those of Model 4-1 since this is a longer run, modeling assumptions are different**
 - All of which causes underlying random-number stream to be used differently (Chapter 12)
- **Prep A/B didn't change (other than run length and random variation) ... need statistical analysis of simulation output (Chapters 6, 7, 12)**
- **Sealer is more congested (it now fails)**
- **Rework is less congested (50% higher staffing)**
- **Frequencies report suggests one rack suffices about 95% of the time, two racks all the time**
 - See text for discussion of Standard, Restricted Percents

Simulation with Arena, 3rd ed. Chapter 4 – Modeling Basic Operations and Inputs Slide 37 of 66

Utilizations – Some Fine Points

- **Two utilizations reported for each Resource**
 - *Instantaneous Utilization* is the time-average of the ratio of the number of units that are busy to the number of units that are scheduled
 - By definition, counts periods when zero units are scheduled as zero-utilization periods
 - *Scheduled Utilization* is the average number busy divided by the average number available
 - No division-by-zero problem, assuming there were ever any units of the Resource scheduled at all (if not, it shouldn't be in the model)
- **Identical for fixed-capacity Resource**
- **Can differ for Resources on a variable Schedule**
 - If Resource capacity varies among several different positive values, it's better to use Scheduled Utilization
 - See text for discussion of issues and even finer points

Simulation with Arena, 3rd ed. Chapter 4 – Modeling Basic Operations and Inputs Slide 38 of 66

Model 4-3: Enhancing the Animation

- **Get "Spartan" generic default animation for some things (queues, connector-animation movement)**
 - Usually sufficient for verification, validation
- **Often want to customize, enhance it a bit**
 - More realism, impact
- **Can pull animation away from model logic in model window**
 - Useful for big models, complex animation
 - Set up Named Views for model logic, animation, or close-ups of parts of animation
- **Animation objects are connected to model logic**
 - Identifiers, physical location (Shift-drag to decouple)

Simulation with Arena, 3rd ed. Chapter 4 – Modeling Basic Operations and Inputs Slide 39 of 66

Changing Animation Queues

- **Lengthen (click, drag, maybe hold shift) to “hold” more entities**
 - Simulation logic, results still OK even if animated queue overflows
- **Rotate to re-orient for realism**
- **Change the “form” of the queue from *Line* (the default) to *Point* — fixed places for entities**
 - Double-click on the queue
 - Select Type to be Point
 - Click Points... button
 - Successively click Add for points, then OK
 - Drag them around on screen
 - *Check Rotate box to show entities turning*


Simulation with Arena, 3rd ed. Chapter 4 – Modeling Basic Operations and Inputs Slide 40 of 66

Changing the Entity Pictures

- **Earlier – used Entity data module to assign different Initial Pictures to different Entity Types**
- **Now – customize the list, or alter the pictures in it**
 - *Edit > Entity Pictures*
 - Left column – names, pictures currently on the list
 - Right column – picture libraries (.plb filename extension)
 - Add a hand-drawn picture – Add button on left, name it in Value field at top, double-click on blank depressed button, then artwork (or paste in a copied graphics image)
 - New name won't appear in Entity data module until you type it there
 - Edit an existing picture – double-click, artwork
 - Copy a picture over from picture library


Simulation with Arena, 3rd ed. Chapter 4 – Modeling Basic Operations and Inputs Slide 41 of 66

Adding Resource Pictures

- **Animate a Resource – Resource button  in animate toolbar – get Resource Picture Placement window**
- **Left column – default pictures for different Resource states**
 - Attach logically to a Resource by Identifier pull-down list
 - Double-click to edit the artwork by hand, or paste in previously copied graphics images
 - Seize area – where seizing entity will “reside”
 - Multiple seize areas for multi-capacity Resources
- **Right column – picture libraries (.plb files) – can copy over to selected (depressed) state pictures**
- **Accept window, cross hairs, click to place**
 - Resize, reposition later

Simulation with Arena, 3rd ed. Chapter 4 – Modeling Basic Operations and Inputs Slide 42 of 66

Adding Variables and Plots

- **Variable animation – just show a value of something as a number, watch it change**
 - Variable object  from Animate toolbar
 - Double-click, specify Expression to be shown (Expression Builder), and cosmetics
 - Resize, reposition later
- **Dynamic animated plots – discussed in Chapter 3**
- **Other animation objects from Animate toolbar**
 - Clock (TNOW), variety of formats
 - Level (thermometer) animation
 - Others discussed later


Simulation with Arena, 3rd ed. Chapter 4 – Modeling Basic Operations and Inputs Slide 43 of 66

Model 4-4: The Electronic Assembly and Test System with Part Transfers

- **Generalize Model 4-3**
- **All part transfers now take 2 minutes (not instant) ... want to model and animate**
 - Includes:
 - Arriving parts to prep areas
 - Departing parts to appropriate exit
 - All internal part transfers
 - Regardless of distance ... will fix this (unrealistic) assumption in Chapter 8

Simulation with Arena, 3rd ed. Chapter 4 – Modeling Basic Operations and Inputs Slide 44 of 66

New Arena Constructs

- **Station – location where some process occurs**
 - Arrivals, manufacturing cells, departures
 - Each Station given a unique name
 - Can serve as an entry point for a section of model logic
 - *Station marker*  represents a logical station in the flowchart/animation
- **Station Transfer – entities move between Stations without direct connection**
 - Several different types – we'll use *Routes* here, which allow for positive transfer time, but no other delays like "room" on the transitway or transporters
 - *Route paths* represent Routes in the flowchart/animation

Simulation with Arena, 3rd ed. Chapter 4 – Modeling Basic Operations and Inputs Slide 45 of 66

Adding the Route Logic – From Arrival

- Stations and Station Transfers affect both the model logic and the animation
- Start with Model 4-3 ... change to Model 4-4
- For incoming parts (A and B) delete connection from Assign modules to “Prep” Process modules
 - Replace with Station/Route module pairs
 - Station module (Advanced Transfer panel) – define entity’s current location
Module Name vs. Station Name
 - Route module (Advanced Transfer panel) – send entity out
Route Time, Destination Station
 - No direct connections exiting from the Route modules – Route module’s Destination Station Name defines that

Simulation with Arena, 3rd ed. Chapter 4 – Modeling Basic Operations and Inputs Slide 46 of 66

Adding the Remaining Route Logic

- Add Station modules for entry to each Prep area
 - Station names are **Prep A Station**, **Prep B Station**, and are the destination stations for Routes after arrivals
- Process modules for Prep A, Prep B unchanged
- After prep, entities connected to Route module to send to next station (sealer)
 - Don’t need a separate Station module for outgoing side
- Similar changes for rest of model
 - Station modules for incoming parts into sealer, rework, each of three Record modules (entity exit points)
 - Route modules for outgoing parts out of sealer inspection, rework inspection (two for each Decide module – pass/fail)
- Could run model now, get correct results ... but no animation of transfers ...



Simulation with Arena, 3rd ed. Chapter 4 – Modeling Basic Operations and Inputs Slide 47 of 66

Why Not Just Add Delays?

- Simpler approach than the above to getting the two-minute transfer times:
 - Insert a Process module with Action = Delay for 2 minutes on each relevant connection
 - Alternatively, use Delay module from Advanced Process panel
- Actually this *would* work fine from modeling, numerical-output viewpoints
- But it would not allow animation of part transfers, so we’ll proceed with the Stations and Routes

Simulation with Arena, 3rd ed. Chapter 4 – Modeling Basic Operations and Inputs Slide 48 of 66

Altering the Animation – Station Markers, Routes

- **Add animation for Stations and Routes**
- **Station button , Animate Transfer toolbar**
 - Attach Identifier to it from pull-down list of station names
 - Get cross hairs, place (click) marker in animation
 - Can place several station markers for the same logical station (to represent incoming, outgoing sides)
 - Can drag station markers around later
- **Route button  from Animate Transfer toolbar**
 - Options for appearance of entities as they travel the route
 - Get cross hairs; click in origin, destination Station Markers
 - Intermediate clicks for corners along the route
 - Can drag around endpoints, corners later

Simulation with Arena, 3rd ed. Chapter 4 – Modeling Basic Operations and Inputs Slide 49 of 66

Altering the Animation – Entity Pictures

- **Part B arrivals are in batches of four parts/batch**
 - But constant travel time to Prep B implies they travel “on top of each other” so it looks like just one part B
 - Try – change Route time from 2 to **EXPO(2)**, see separation along the route
- **Create illusion to animate the batch**
 - Assign module just after **Part B Arrive**
 - Add assignment of Entity Picture to **Picture.Batch B**
 - **Edit > Entity Pictures** to draw the new picture
 - Copy **Picture.Part B** and rename it **Picture.Batch B**
 - Double-click on picture, use Picture Editor to get four circles
 - When batch arrives to Prep B, change to single circle
 - Add Assign module after **Prep B Arrival Station**

Simulation with Arena, 3rd ed. Chapter 4 – Modeling Basic Operations and Inputs Slide 50 of 66

Input Analysis: Specifying Model Parameters, Distributions

- **Structural modeling: what we’ve done so far**
 - Logical aspects — entities, resources, paths, etc.
- **Quantitative modeling**
 - Numerical, distributional specifications
 - Like structural modeling, need to observe system’s operation, take data if possible

Simulation with Arena, 3rd ed. Chapter 4 – Modeling Basic Operations and Inputs Slide 51 of 66

Deterministic vs. Random Inputs

- **Deterministic: nonrandom, fixed values**
 - Number of units of a resource
 - Entity transfer time (?)
 - Interarrival, processing times (?)
- **Random (a.k.a. stochastic): model as a distribution, “draw” or “generate” values from to drive simulation**
 - Transfer, Interarrival, Processing times
 - What distribution? What distributional parameters?
 - Causes simulation output to be random, too
- **Don’t just assume randomness away — validity**

Simulation with Arena, 3rd ed. Chapter 4 – Modeling Basic Operations and Inputs Slide 52 of 66

Collecting Data

- **Generally hard, expensive, frustrating, boring**
 - System might not exist
 - Data available on the wrong things — might have to change model according to what’s available
 - Incomplete, “dirty” data
 - Too much data (!)
- **Sensitivity of outputs to uncertainty in inputs**
- **Match model detail to quality of data**
- **Cost — should be budgeted in project**
- **Capture variability in data — model validity**
- **Garbage In, Garbage Out (GIGO)**

Simulation with Arena, 3rd ed. Chapter 4 – Modeling Basic Operations and Inputs Slide 53 of 66

Using Data: Alternatives and Issues

- **Use data “directly” in simulation**
 - Read actual observed values to drive the model inputs (interarrivals, service times, part types, ...)
 - Arena ReadWrite module ... see Model 10-2
 - All values will be “legal” and realistic
 - But can never go outside your observed data
 - May not have enough data for long or many runs
 - Computationally slow (reading disk files)
- **Or, fit probability distribution to data**
 - “Draw” or “generate” synthetic observations from this distribution to drive the model inputs
 - We’ve done it this way so far
 - Can go beyond observed data (good and bad)
 - May not get a good “fit” to data — validity?

Simulation with Arena, 3rd ed. Chapter 4 – Modeling Basic Operations and Inputs Slide 54 of 66

Fitting Distributions to Data with the Arena Input Analyzer

- **Assume:**
 - Have sample data: Independent and Identically Distributed (IID) list of observed values from the actual physical system
 - Want to select or fit a probability distribution for use in generating inputs for the simulation model
- **Arena Input Analyzer**
 - Separate application, also accessible via Tools menu in Arena
 - Fits distributions, gives valid Arena expression for generation to paste directly into simulation model



Simulation with Arena, 3rd ed. Chapter 4 – Modeling Basic Operations and Inputs Slide 55 of 66

Fitting Distributions to Data with the Arena Input Analyzer (cont'd.)

- **Fitting = deciding on distribution form (exponential, gamma, empirical, etc.) and estimating its parameters**
 - Several different methods (Maximum likelihood, moment matching, least squares, ...)
 - Assess goodness of fit via hypothesis tests
 - H_0 : fitted distribution adequately represents the data
 - Get p value for test (small = poor fit)
- **Fitted “theoretical” vs. empirical distribution**
- **Continuous vs. discrete data, distribution**
- **“Best” fit from among several distributions**

Simulation with Arena, 3rd ed. Chapter 4 – Modeling Basic Operations and Inputs Slide 56 of 66

Data Files for the Input Analyzer

- **Create the data file (editor, word processor, spreadsheet, ...)**
 - Must be plain ASCII text (save as text or export)
 - Data values separated by white space (blanks, tabs, linefeeds)
 - Otherwise free format
- **Open data file from within Input Analyzer**
 - File > New or 
 - File > Data File > Use Existing or 
 - Get histogram, basic summary of data
 - To see data file: Window > Input Data
- **Can generate “fake” data file to play around**
 - File > Data File > Generate New



Simulation with Arena, 3rd ed. Chapter 4 – Modeling Basic Operations and Inputs Slide 57 of 66

The Fit Menu

- Fits distributions, does goodness-of-fit tests
- Fit a specific distribution form
 - Plots density over histogram for visual “test”
 - Gives exact expression to Copy and Paste (Ctrl+C, Ctrl+V) over into simulation model
 - May include “offset” depending on distribution
 - Gives results of goodness-of-fit tests
 - Chi square, Kolmogorov-Smirnov tests
 - Most important part: *p-value*, always between 0 and 1:
Probability of getting a data set that’s more inconsistent with the fitted distribution than the data set you actually have, if the the fitted distribution is truly “the truth”
“Small” p (< 0.05 or so): poor fit (try again or give up)

Simulation with Arena, 3rd ed. Chapter 4 – Modeling Basic Operations and Inputs Slide 58 of 66

The Fit Menu (cont'd.)

- Fit all of Arena’s (theoretical) distributions at once
 - *Fit > Fit All* or 
 - Returns the *minimum square-error* distribution
 - Square error = sum of squared discrepancies between histogram frequencies and fitted-distribution frequencies
 - Can depend on histogram intervals chosen: different intervals can lead to different “best” distribution
 - Could still be a poor fit, though (check *p* value)
 - To see all distributions, ranked: *Window > Fit All Summary* or 

Simulation with Arena, 3rd ed. Chapter 4 – Modeling Basic Operations and Inputs Slide 59 of 66

The Fit Menu (cont'd.)

- “Fit” Empirical distribution (continuous or discrete): *Fit > Empirical*
 - Can interpret results as a Discrete or Continuous distribution
 - Discrete: get pairs (*Cumulative Probability*, *Value*)
 - Continuous: Arena will linearly interpolate *within* the data range according to these pairs (so you can never generate values outside the range, which might be good or bad)
 - Empirical distribution can be used when “theoretical” distributions fit poorly, or intentionally

Simulation with Arena, 3rd ed. Chapter 4 – Modeling Basic Operations and Inputs Slide 60 of 66

Some Issues in Fitting Input Distributions

- **Not an exact science — no “right” answer**
- **Consider theoretical vs. empirical**
- **Consider range of distribution**
 - Infinite both ways (e.g., normal)
 - Positive (e.g., exponential, gamma)
 - Bounded (e.g., beta, uniform)
- **Consider ease of parameter manipulation to affect means, variances**
- **Simulation model sensitivity analysis**
- **Outliers, multimodal data**
 - Maybe split data set (see textbook for details)

Simulation with Arena, 3rd ed. Chapter 4 – Modeling Basic Operations and Inputs Slide 61 of 66

No Data?

- **Happens more often than you’d like**
- **No good solution; some (bad) options:**
 - Interview “experts”
 - Min, Max: Uniform
 - Avg., % error or absolute error: Uniform
 - Min, Mode, Max: Triangular
 - Mode can be different from Mean — allows asymmetry
 - Interarrivals — independent, stationary
 - Exponential— still need some value for mean
 - Number of “random” events in an interval: Poisson
 - Sum of independent “pieces”: normal
 - Product of independent “pieces”: lognormal

Simulation with Arena, 3rd ed. Chapter 4 – Modeling Basic Operations and Inputs Slide 62 of 66

Cautions on Using Normal Distributions

- **Probably most familiar distribution – normal “bell curve” used widely in statistical inference**
- **But it has infinite tails in both directions ... in particular, has an infinite left tail so can always (theoretically) generate negative values**
 - Many simulation input quantities (e.g., time durations) must be positive to make sense – Arena truncates negatives to 0
- **If mean μ is big relative to standard deviation σ , then P(negative) value is small ... one in a million**
- **But in simulation, one in a million can happen**
- **Moral – avoid normal distribution as input model**

Simulation with Arena, 3rd ed. Chapter 4 – Modeling Basic Operations and Inputs Slide 63 of 66

Nonstationary Arrival Processes

- **External events (often arrivals) whose rate varies over time**
 - Lunchtime at fast-food restaurants
 - Rush-hour traffic in cities
 - Telephone call centers
 - Seasonal demands for a manufactured product
- **It can be critical to model this nonstationarity for model validity**
 - Ignoring peaks, valleys can mask important behavior
 - Can miss rush hours, etc.
- **Good model: *Nonstationary Poisson process***

Simulation with Arena, 3rd ed. Chapter 4 – Modeling Basic Operations and Inputs Slide 64 of 66

Nonstationary Arrival Processes (cont'd.)

- **Two issues:**
 - How to specify/estimate the *rate function*
 - How to generate from it properly during the simulation
- **Several ways to estimate rate function — we'll just do the *piecewise-constant* method**
 - Divide time frame of simulation into subintervals of time over which you think rate is fairly flat
 - Compute observed rate within each subinterval
 - In Arena, must convert to expected number of arrivals *per hour* on subintervals of time that need not be of one-hour length
 - Want expected 45 arrivals in a half hour; specify rate = 90 *per hour*
- **Example: Model 5-2 in Chapter 5**

Simulation with Arena, 3rd ed. Chapter 4 – Modeling Basic Operations and Inputs Slide 65 of 66

Multivariate and Correlated Input Data

- **Usually we assume that all generated random observations across a simulation are independent (though from possibly different distributions)**
- **Sometimes this isn't true:**
 - A "difficult" part requires long processing in both the Prep and Sealer operations
 - This is positive correlation
- **Ignoring such relations can invalidate model**
- **See textbook for ideas, references**

Simulation with Arena, 3rd ed. Chapter 4 – Modeling Basic Operations and Inputs Slide 66 of 66

Homework

- Text, pg. 168, problem 4-2
- Due Wed. April 20. Mail to cmo

Simulation with Arena, 3rd ed. Chapter 4 – Modeling Basic Operations and Inputs Slide 67 of 66
