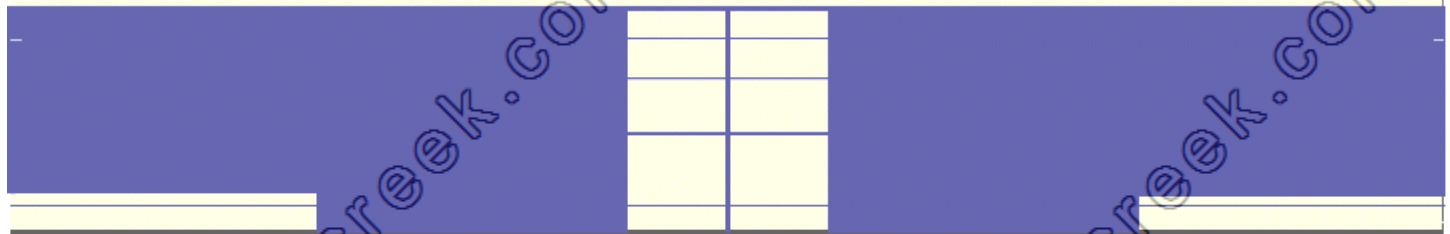


# Simulating Business Processes



**Simulation:** The imitation of some conceptual or physical collection of entities (a.k.a. a system).

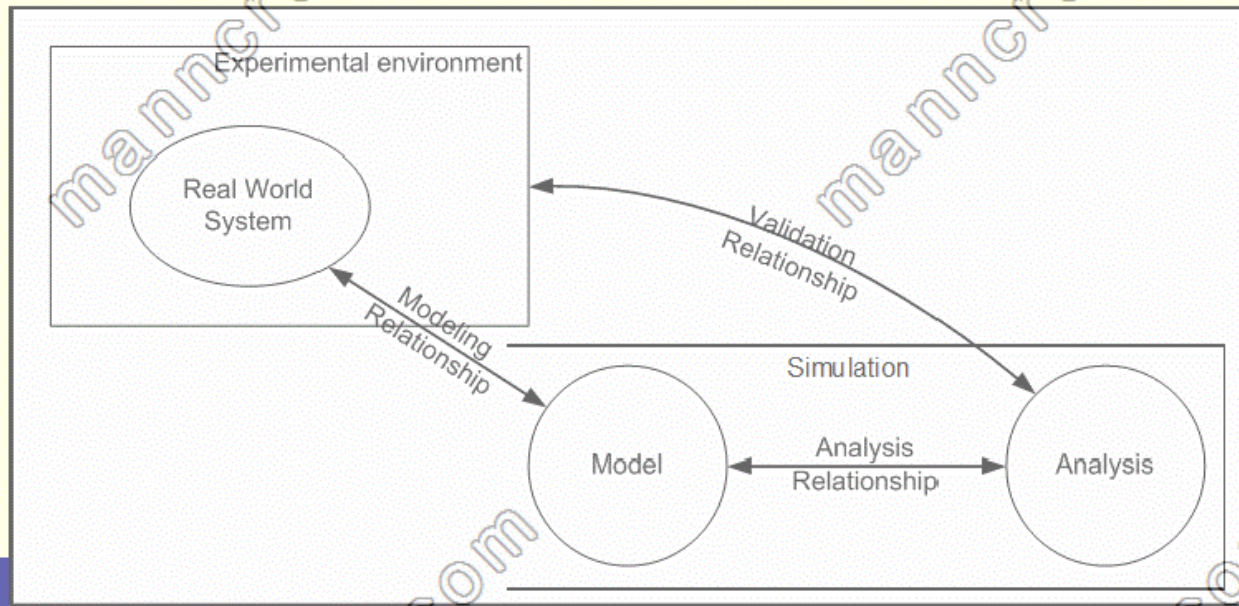
**Business Process:** An internal Business System (or set of internal Business Systems) exercised to serve customers (e.g. a purchasing process). Also, a Business System (or Systems) with workflow.

**Business System:** A collection of business entities (people, computers, telephones, ...) that work together to reach a common goal or goals. For example, a business accounting system.

## **Why Simulate?**

- Arrive at a better process understanding for complex systems; visualize system performance.
- Help identify / classify system uncertainties as aleatory or epistemic.
  - **Aleatory:** results from variability intrinsic to system behavior, e.g. machining accuracy (objective uncertainty)
  - **Epistemic:** results from gaps in knowledge, e.g. future economic conditions (subjective uncertainty)
- Provide a focal point for stakeholder / supplier communication.
- Identify hidden, emergent system behaviors.
- Verify that stakeholder requirements are satisfied.
- Test the impact of alternate system designs.

# Simulations and the Real World



**Experiment:** A process whose outcome is not known with certainty.

**Experimental Environment:** The union of the experiment and those factors surrounding the experiment that might effect the experimental outcome(s). For example, a business purchasing process affected by the availability of supplies.

**Real World System:** A collection of entities and processes that collaborate to accomplish a (real world) goal – for example a Business Manufacturing System.

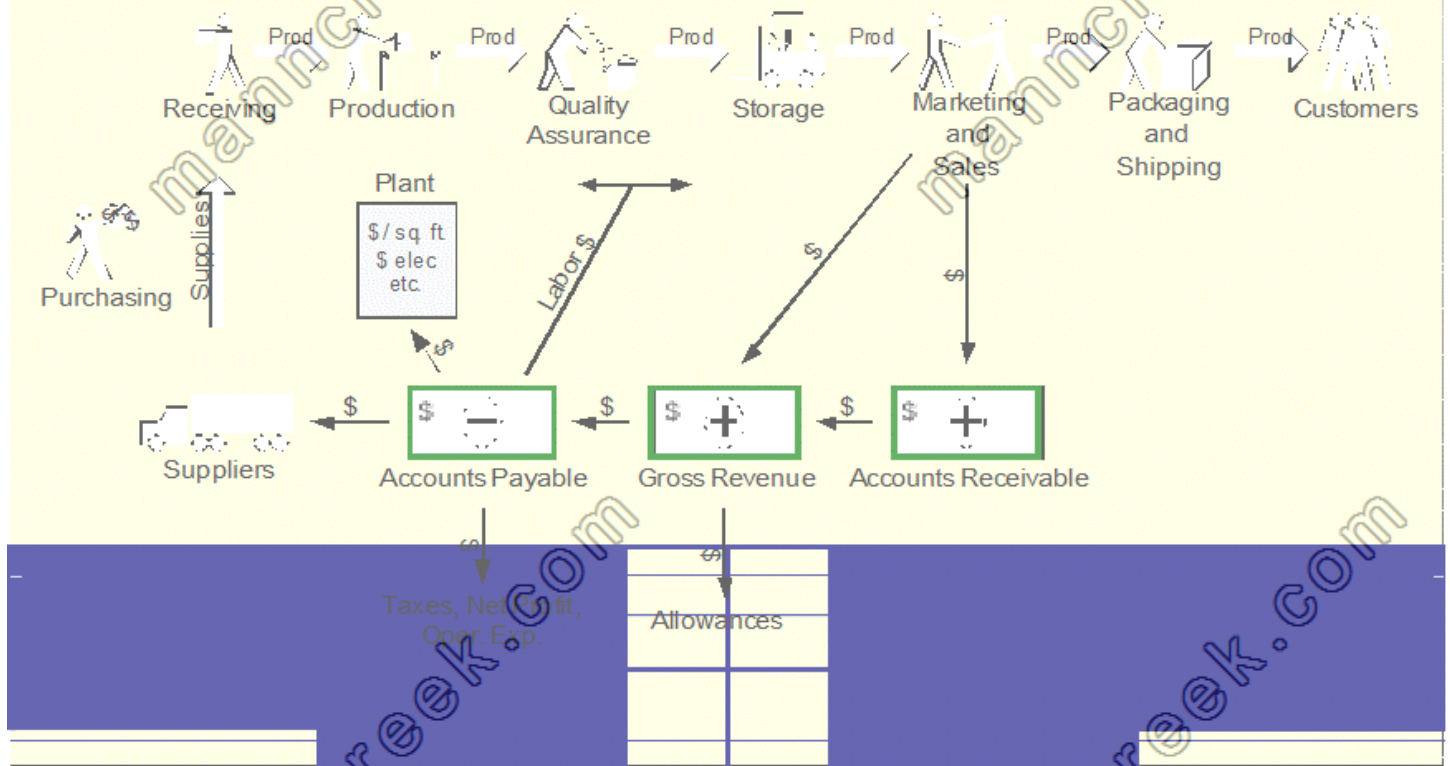
**Modeling Relationship:** The process of establishing believability (correlation) between a real-world system and a model of that system. Should include real-world domain experts and modeling experts.

**Analysis Relationship:** The process of establishing believability (correlation) between a system model and information gleaned from that model. Should include model and analysis experts.

**Validation Relationship:** The process of establishing believability (correlation) between information gleaned from a simulation analysis and information known from the experimental environment. Should include real world domain experts.

# The General Business Process

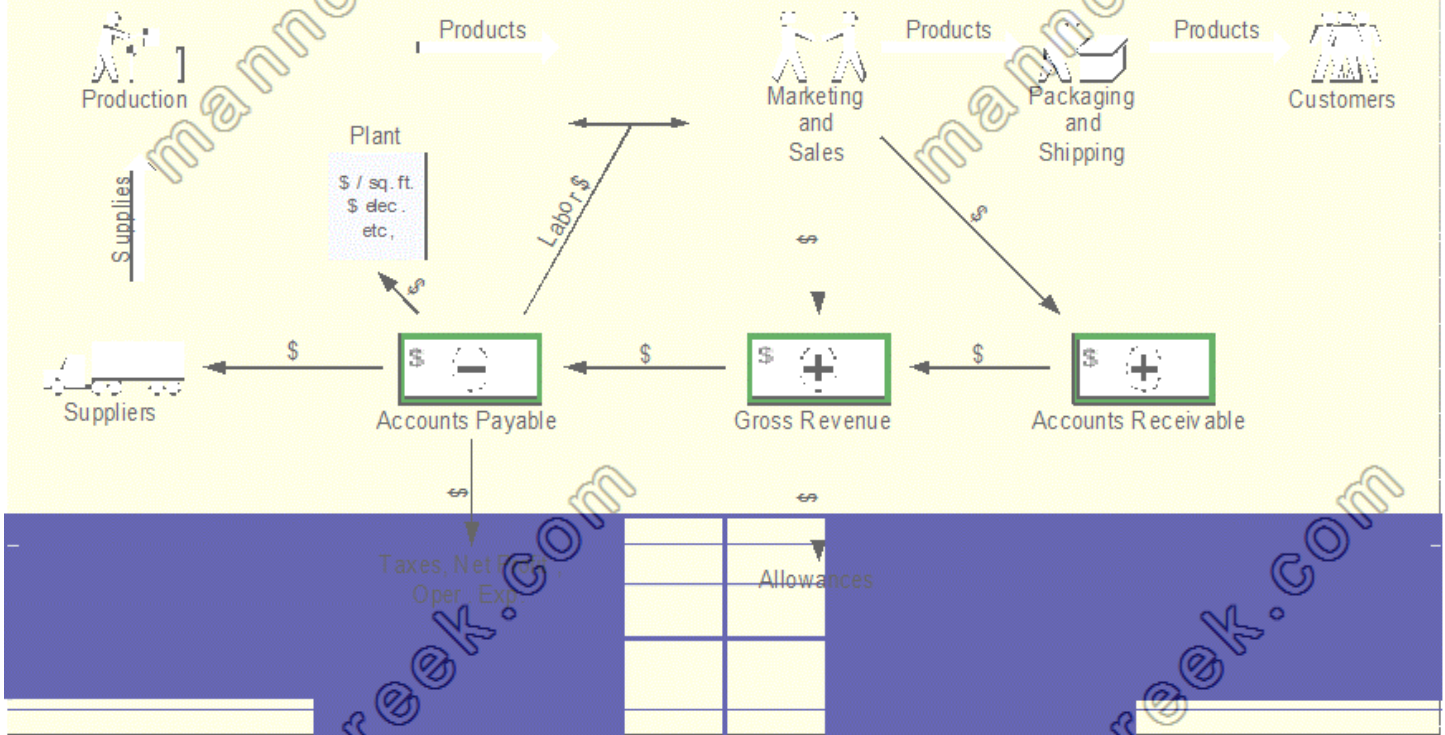
(identify the real-world system)



**(Real World) System (RWS):** A collection of entities and processes that collaborate to accomplish a (real world) goal. An **entity** is any real or abstract thing about which system information is stored / manipulated (e.g. people and products). A **process** is a time-ordered sequence of events that describe the relationships between the system entities (e.g. a manufacturing process). An **event** is an entity activity that may change the state of the system (e.g. selling a product). The system's **state** is that collection of information necessary to completely describe the system at any particular time (e.g. a company's state at the end of the month).

# Business Process Simplification

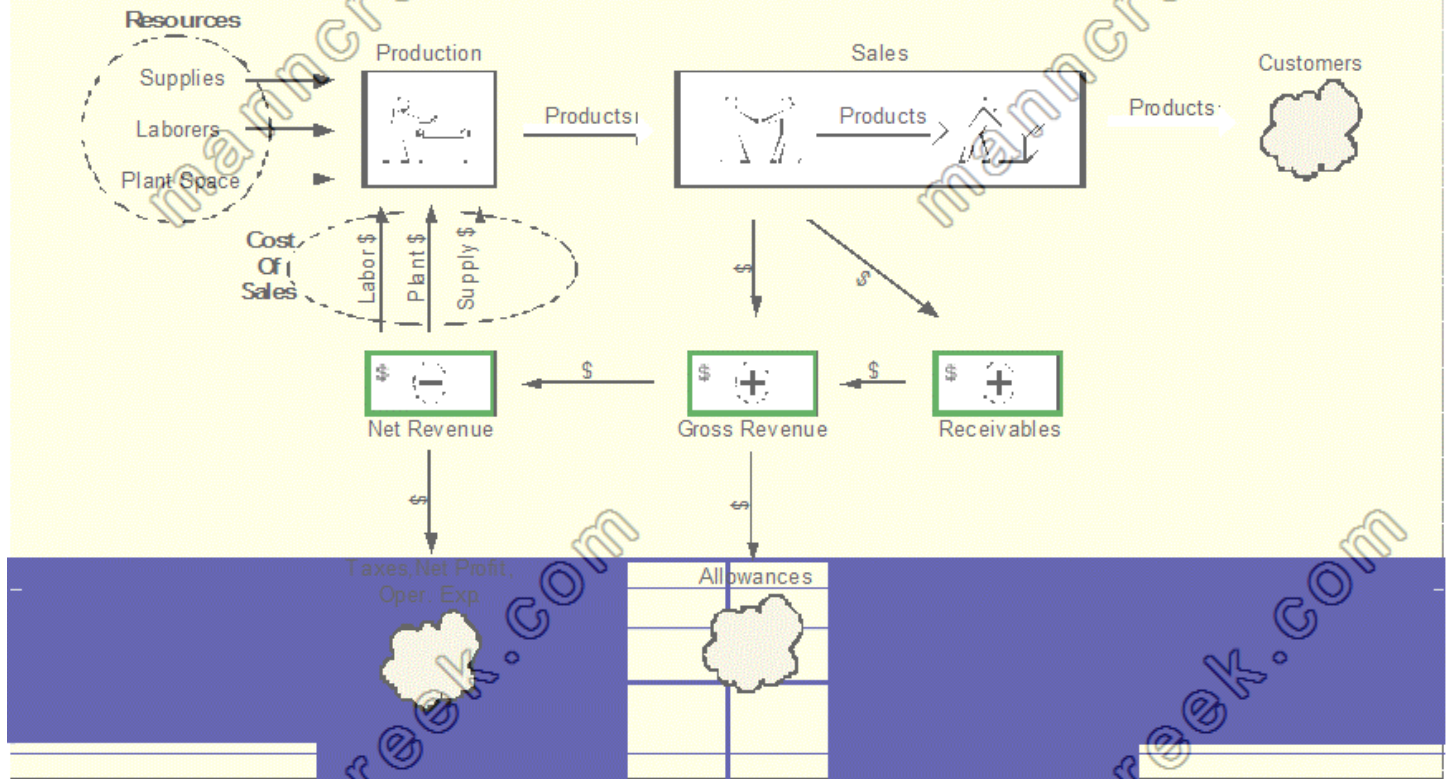
(identify what's important in the real-world - a.k.a. the experimental environment)



**Process Simplification:** An abstraction used to focus attention on the system aspects important to the type of model being built (related to the reason for creating the model). Does not “reproduce” the complete system in detail. A (simplified) model includes enough information about the RWS entities, processes, events and states to emulate system “reality” and excludes information deemed to be irrelevant

# Modeling the Simplification

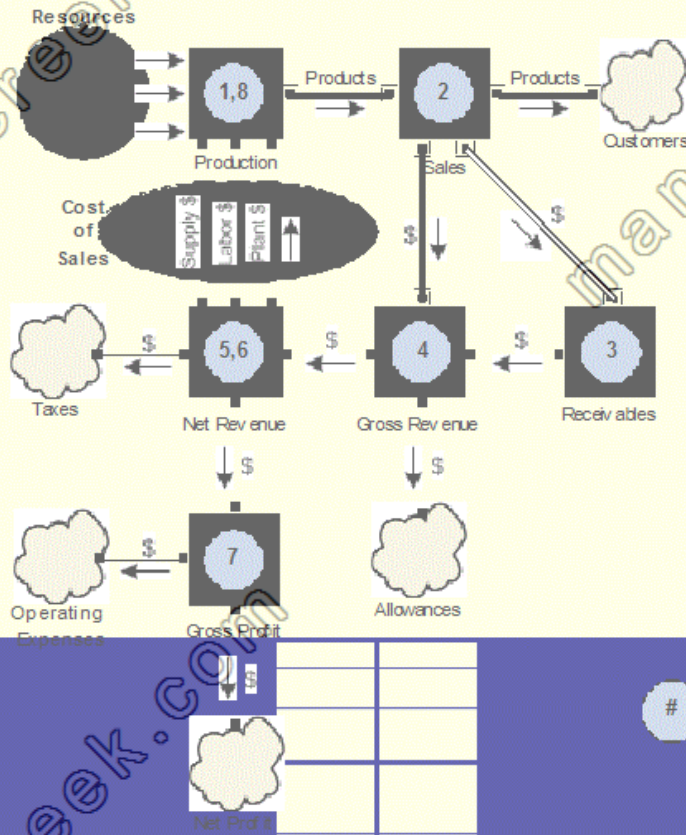
(identify the model components)



**RWS Modeling:** The activity of focusing only on the essential components of a real-world process. Requires inductive reasoning (progresses from specific experience & observation to general conclusions; the premises may predict a high probability of the conclusion, but do not ensure that the conclusion is true (see Problem of Induction)) rather than deductive reasoning (progresses from general laws, rules & widely accepted principles to a specific solution; the conclusion is *necessitated* by, or reached from, previously known facts). A model may be physical (e.g. a wind tunnel model) or conceptual (i.e. of the mind). Conceptual models might be explicit (expressible by a closed-form equation, when it exists, or by a numerical approximation – e.g. a computer simulation) or might be implicit (e.g. expressible by a diagram or text). Certain analytic models may incorporate both implicit and explicit techniques (e.g. computer-based multi-agent systems where agent actions depend on some form of (rule-based) reasoning).

# The Physical Simulation Model

(translate the business model representation to a computational one with a simulation tool)



# Business activities see slide 7

**Simulation tool:** Any computational system capable of executing a simulation model to reveal its behavior. Analysts draw conclusions about a model by observing simulation results (accumulated model entity, process, event and state information), making it essential that the model be an accurate, in some sense, representation of the RWS.

# Simulating the Business Scenario

(make sure the business process is adequately represented in the computational model)

- 1 In the Production block, Supplies wait in a Production queue until Labor and Plant resources are available to produce a product. During production, Supply, Labor and Plant resources are consumed. If there's insufficient income to pay for one or two of these resources you'll be informed with a sound (click) but it's assumed the business will find the money somewhere (loan?) and the business (replication) will continue. If there's insufficient income to pay for all of the three resources, "Resource Failure" will occur in the current replication and it will terminate (you'll be informed with a "doh" sound).
- 2 In the Sales block, products wait in a Produced But Not Sold (PBNSo) queue until sold. When sold, the income is sent to either a Gross Revenue or a Receivables account (depending on percentages in the "Sales Allocation Table"). Sold products wait in a Sold But Not Shipped (SoBNSh) queue until they are packaged and shipped to customers.
- 3 Receivables are released to Gross Revenue every 20 to 40 days (a uniform distribution).
- 4 Gross Revenue is transferred every Monday morning (every five working days) to Net Revenue and Allowance accounts according to percentages in the "Gross Revenue Allocation Table".
- 5 A portion of Net Revenue is transferred to a Labor Cost of Sales account every other Monday morning (every ten working days) according to a percentage in the "Net Revenue Allocation Table".
- 6 Portions of Net Revenue are transferred to Supply and Plant Cost of Sales accounts, and to Gross Profit and Tax accounts at the end of every month (every twenty-two working days) according to percentages in the "Net Revenue Allocation Table".
- 7 Gross Profit is transparently reflected to Operating Expense and Net Profit accounts when received, according to percentages in the "Gross Profit Allocation Table".
- 8 Money in Cost of Sales accounts is converted to Supply, Labor and Plant resource "units" when received by the Production block (every twenty-two, ten, and twenty-two working days respectively).

**Business Scenario Simulation:** The simulation must accurately carry out the intent of the model (reference "verification" and "validation", slide 10 notes). Rigorous model verification and analysis validation leads to believable process understandings. Ultimately, simulations provide only estimates of RWS performance.



# Interacting with the Model

(entering your business-specific data)

**Cost of Sales:** (1) → (3)  
Enter Supply, Labor and Plant costs per product or day as noted.

**Markup Factor:** (4)  
Enter a factor that will multiply the above product cost -of-sales to result in a product selling price. Calculate an initial approximation from the formula:

**Allocation Tables:** (5) → (12)

**Gross Revenue:** Enter the percent of Gross Revenue (as a positive decimal fraction) that will be set aside for Allowances. E.g. 0.05 is equivalent to 5%. Net Revenue will be calculated as 1.0 - this value.

**Net Revenue:** Enter Supply, Labor, Plant Tax and Gross Profit percent of Net Revenue (as positive decimal fractions). E.g. 0.25 is equivalent to 25%. These five values must total to 1.0 (100%).

**Gross Profit:** Enter the percent of Gross Profit that will be allocated to Operating Expense (as a positive decimal fraction). E.g. 0.5 is equivalent to 50%. Net Profit will be calculated as 1.0 - this value.

**Sales:** Enter the percent of Sales that will be allocated to Gross Revenue and to Receivables (as positive decimal fractions). E.g. 0.9 is equivalent to 90%. These two values must total to 1.0 (100%). Other sales types in this table are non-functional in this model.

**Seeds:** (13)  
Enter an amount of money that will support the venture for the first month of operation. Calculate an expected approximation from the formula:

**Job-specific:** (14) → (15)  
Enter an expected work time per product as a fractional part of day (e.g. 0.125 is 1/8 of a work day = 1 hour) and an expected number of labor units per product (whole labor units). If the work time is 0.125 and labor units is 2, the person-hours spent to producing an individual product is expected to be 2 hrs. (0.25 day).

**Resource Limitations:** (16) → (17)  
The number of labor, Supply and/or Plant resource units available during production can be limited by entering values less than or equal to 1.0. For example, if maximum Labor units is 1, no more than 1 unit will be available at any time for product production, regardless of how much money is available.

**Approximate Minimum 22 day Seed \$ = \$(period)\*(period)\*(%)**  

$$((100 \times 22) + (133 \times 22) + (50 \times 22)) / (0.74 \times 0.95)$$

$$22 \times (100 + 133 + 50) / (0.74 \times 0.95)$$

**Expected work time per prod** (14) → Supply units per prod (1)

**Expected labor units per prod** (15) → Labor units/day (2)

**Maximum Labor units\*** (16) → Plant unit \$/day (3)

**Maximum Supply/Plant units\*** (17) → Markup factor (4)

Supply (6)  
Labor (7)  
Gross Profit (8, 9, 10)  
Plant (11)

**Labor Unit Costs:** The collection of all product-related costs coming from human entities (direct labor and management directly engaged in product production). E.g. \$35,000/year ÷ 264 working-days/year = \$132.58/day.

**Plant Unit Costs:** The collection of all product-related costs coming from environment-related entities (building space, electricity, gas, cleaning, repair, ...). E.g. 1100 ft² x \$1.00/ft²/month ÷ 22 working-days/month = \$50.00/day.

**Supply Unit Costs:** The collection of all expected non-plant and non-labor costs involved in producing a product (\$ per product, might include raw supplies, paper, ink, ...). E.g. \$10,000.00/month for all supplies ÷ 100 products/month = \$100/product.

Also, see slide 8 notes.

# Analyzing the Data (1)

(mean expected values and confidence intervals)

1. Simulations rely on multiple runs that use random numbers. Each of these runs is commonly called a "replication".
2. A "failure" occurs when there are zero Labor, Plant, and Supply resources available to the model, at the same time.
3. A "warm-up" period occurs at the start of each replication. This allows the model to achieve a steady-state condition before output statistics are compiled.
4. Each model replication runs for 330 days, which is the warm-up period (88 days) plus one work year (264 days).
5. In this model, the supply interarrival rate is keyed to the rate of product sales (automatically calculated).
6. The mean work time per product incurred by Labor resources (a Normal distribution, compare to 14).
7. The mean number of Labor resources devoted to producing each product (a Normal distribution, compare to 15).
8. The mean number of Supply units available for product production (95% confidence interval).
9. The mean number of Labor units available for product production (95% confidence interval).
10. The mean number of Plant units available for product production (95% confidence interval).
11. The mean Supply unit utilization ( $\leq 1.0$ , 95% confidence interval).  $1.1 \times 8 =$  approx. single Supply unit utilization.
12. The mean Labor unit utilization ( $\leq 1.0$ , 95% confidence interval).  $1.2 \times 9 =$  approx. single Labor unit utilization.
13. The mean Plant unit utilization ( $\leq 1.0$ , 95% confidence interval).  $1.3 \times 10 =$  approx. single Plant unit utilization.
14. The mean number of Supply units waiting for Labor or Plant resources (95% confidence interval).
15. The mean number of Products produced in one year (95% confidence interval).
16. The mean number of Labor resources waiting for Supply or Plant resources (95% confidence interval).
17. The mean Gross Revenue, over a one year period (95% confidence interval).
18. The mean Allowance allocation, over a one year period (95% confidence interval).
19. The mean Tax allocation, over a one year period (95% confidence interval).
20. The mean allocation to pay for Supplies, one year period (95% confidence interval).
21. The mean allocation to pay for Labor, one year period (95% confidence interval).
22. The mean allocation to pay for Plant, one year period (95% confidence interval).
23. The mean Operating Exp. allocation, one year period (95% confidence interval).
24. The mean Net Profit allocation, one year period (95% confidence interval).
25. Button to expose previously created Queue-related plots.
26. Button to expose previously created Resource Utilization plots.
27. Button to expose previously created Available Resources plots.

OUTPUT STATISTICS			
	Mean	(LC)	(UC)
# Replications	4		
# Resource failures	0		
Warm-up period (days)	88		
Run time (days)	330		
Supply interarrival (days)	0.54		
WORKTIME PERIOD			
Mean	0.299		
Labor units/prod	1.021		
RESOURCE UNITS AVAILABLE/95%			
Supply	2.133	1.921	2.345
Labor	2.28	2.094	2.467
Plant	2.133	1.921	2.345
RESOURCE/JOB STATS/95%			
Supply Resource Utilization	0.2315	0.2243	0.2388
Labor Resource Utilization	0.2216	0.214	0.2293
Plant Resource Utilization	0.2315	0.2243	0.2388
Production Jobs Waiting	1.1972	-2.13	4.5239
Production Jobs Completed	629.25	582.85	675.65
Labor Resources Waiting	1.7751	1.6392	1.911
REVENUE ACCOUNTS/95%			
Gross Revenue \$	29952.33	275541.37	323503.28
Allowance \$	14976.116	13777.069	16175.164
Tax \$	56193.13	50790.89	61595.371
Supply \$	69571.996	62907.1	78236.892
Labor \$	97979.973	89533.405	106426.54
Plant \$	34798.916	31439.034	38158.798
Oper. Exp. \$	6692.1189	6053.4139	7330.8238
Net Profit \$	6692.1189	6053.4139	7330.8238

SHOW OUTPUT PLOTS

- Queue-related
- Resource Utilization
- Available Resources

After your model runs, you'll need to analyze the output data. Explicit data items are defined above and terms are defined below. Also see slide 15 for notes and suggestions.

**Analysis:** The process of breaking down (complex) collections of information into simpler collections for better understanding. May employ statistics and/or probability. Should include both model verification and analysis validation.

**Statistics:** A broad mathematical discipline which studies ways to collect, summarize and draw conclusions from data; a mathematical quantification of uncertainty (Mean, Std. Dev., Variance, ...).

**Probability:** A number in the interval from 0 to 1 assigned to "events" whose occurrence or failure to occur is random. Uses information from set theory and statistics to compute the likelihood of events.

**95% Confidence Interval:** This means "I am 95% confident that the actual mean value will lie between the lower confidence interval and the upper confidence interval. The 'best guess' (expected value) is the value given as the mean." Conversely, this also means "There is a 5% chance that the actual mean value does not lie between the lower and upper confidence intervals."

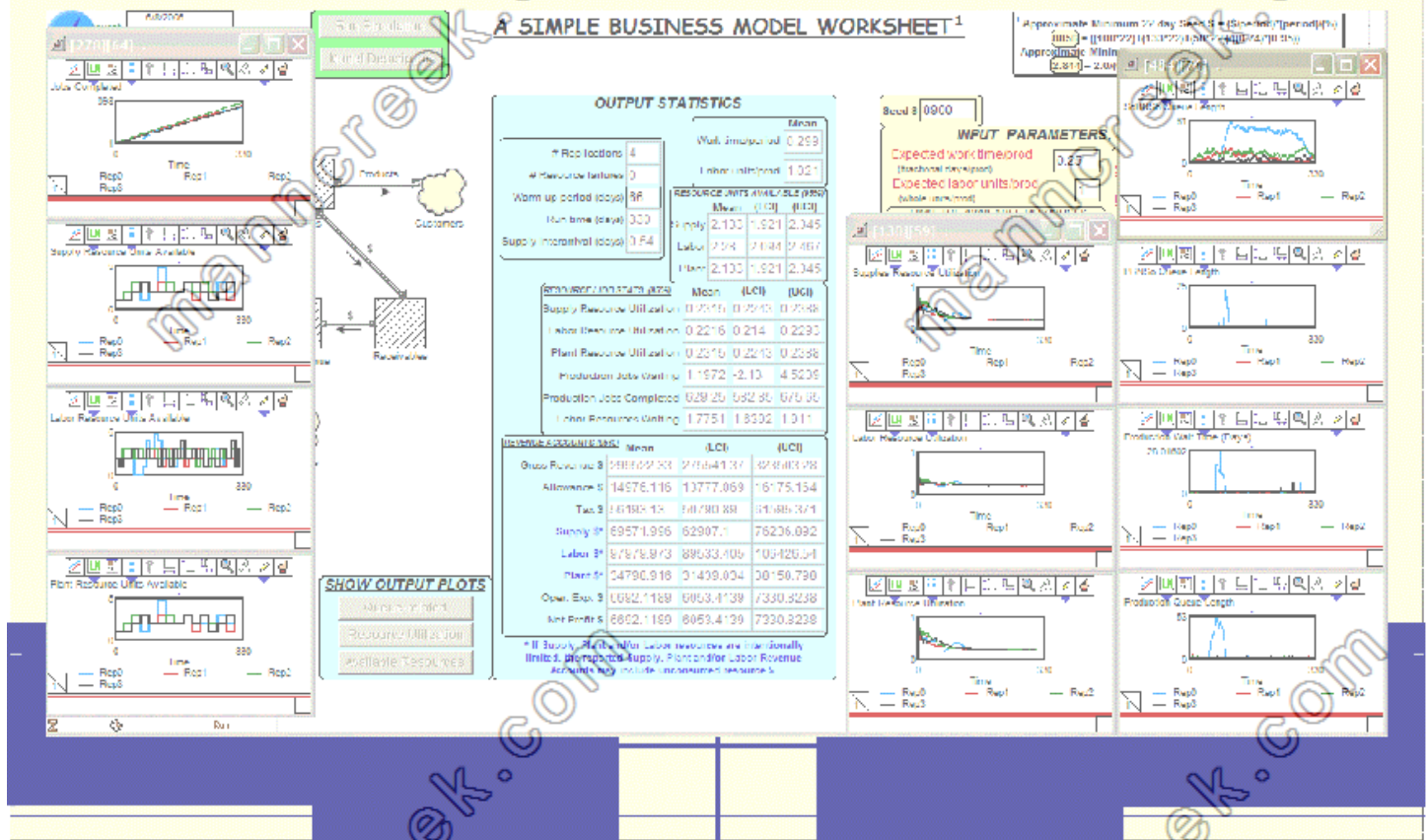
**Model Verification:** Ensuring that the problem is being solved correctly.

**Analysis Validation:** Ensuring that the correct problem is being solved.

**Sensitivity Analysis:** Determining the sensitivity of the model results (as a whole or of a specific result) to changes in one or more model input parameters.

# Analyzing the Data (2)

(charts and graphs)



As the simulation runs, the Output Statistics change and several plots are displayed (zoomed in slide 12). The four plots on the right track the main queues in the process. From the bottom up:

- (1) Production queue length
- (2) Product Supplies wait time
- (3) Produced But Not Sold (PBNSo) queue length
- (4) Sold But Not Shipped (SoBNSh) queue length

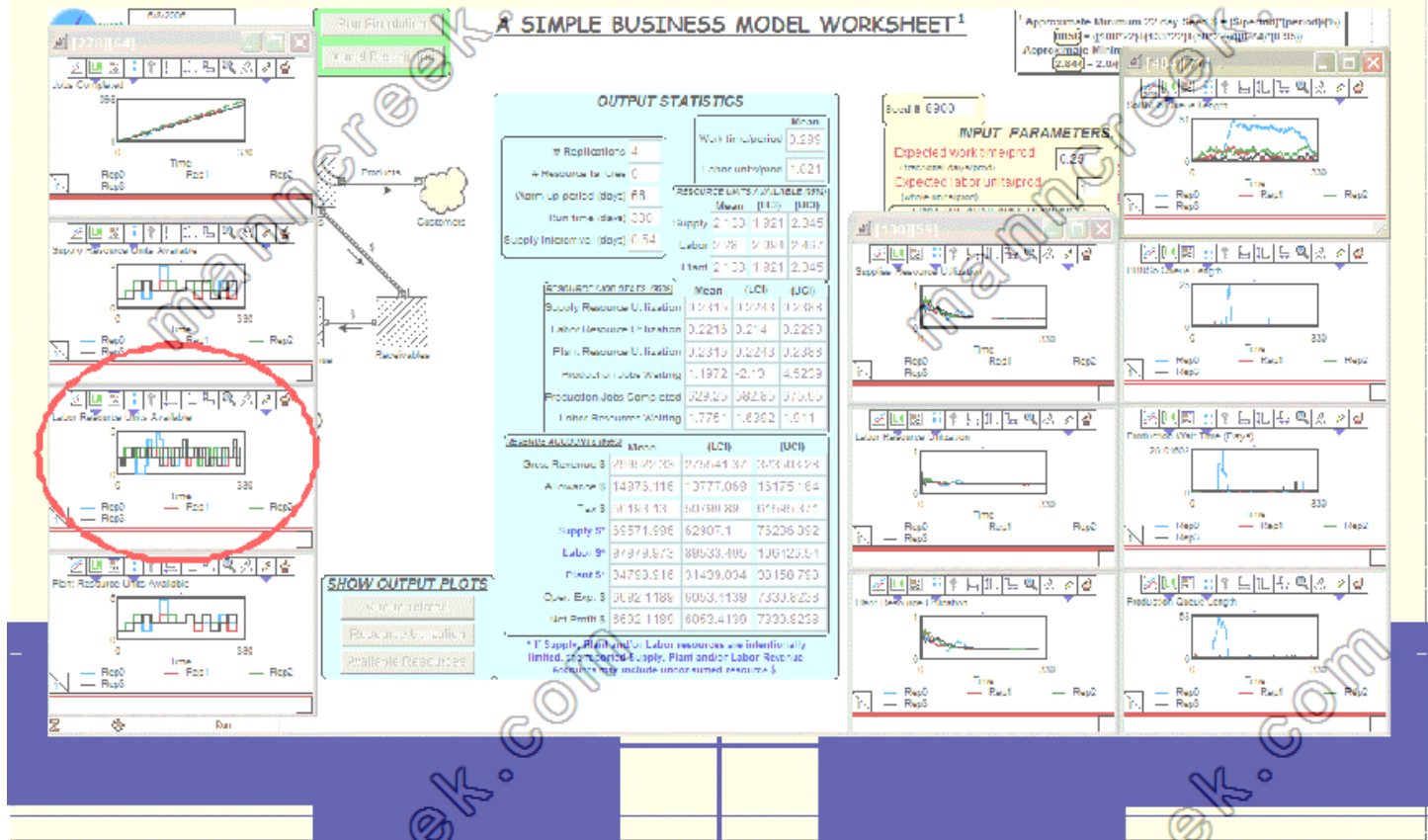
The next three plots to the left indicate the relative convergence of the resource utilizations to a steady state.

The four plots on the left show, from the bottom up:

- (1) Available Plant resources (a 22 working day cycle)
- (2) Available Labor resources (a 10 working day cycle)
- (3) Available Supply resources (a 22 working day cycle)
- (4) Number of products (jobs) produced

# Analyzing the Data (2)

(charts and graphs)



Clicking on a plot's "maximize window" icon will expand the plot to full-screen size (see slide 13).

# Analyzing the Data (3)

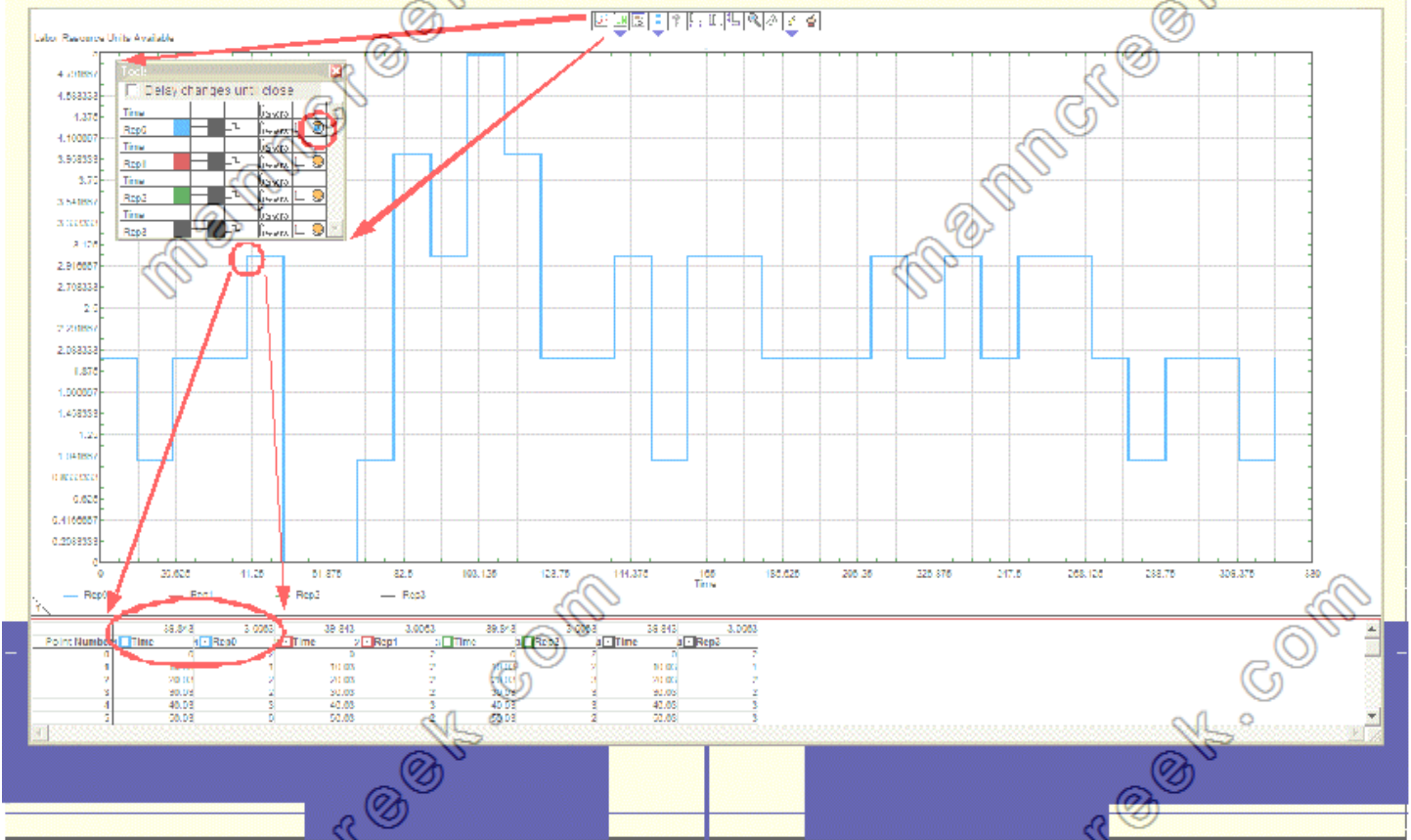
(charts and graphs)



The data from each replication is presented in a different color. The table at the bottom of the plot shows the numerical data that created the plot. Clicking on the "trace properties" icon (circled above) opens a dialog box that allows showing only one set of data at a time. See slide 14.

# Analyzing the Data (4)

(charts and graphs)



As you move the cursor across the face of the plot, its position is dynamically reported near the bottom of the plot just above the data table (see ellipse above).

# Notes and Suggestions (1)

- Resource Failures (slide 10, item 2) may negatively influence the Output Statistics. Remove these failures by increasing the Markup Factor (slide 9, item 4 -- the quick, broad-brush approach) or by decreasing individual Cost Of Sales amounts (slide 9, items 1, 2 or 3 -- the slower, tinkering approach).
- Resource Utilization plots (slide 12) should show a convergence, by all replications, to a steady-state utilization after the Warm-up Period (slide 10, item 3). If there isn't a convergence, the model is unstable and the Output Statistics should not be trusted.
- The meaning of a 95% confidence interval is "I am 95% confident that the actual mean value will lie between the lower confidence interval and the upper confidence interval. The 'best guess' (expected value) is the value given as the mean. Conversely, this also means "There is a 5% chance that the actual mean value does not lie between the lower and upper confidence intervals."
- Lower and upper confidence intervals (slide 10, items 8 thru 24) should closely bracket their mean value. One or more broad confidence intervals could be an indication of Resource Failures (see bullet 1, above) or of other model instabilities. Broad confidence intervals are, generally, a red flag -- an indication of low output believability (see, for example, sheet 10 item 14; "Production Jobs Waiting" shows a high variability). Confidence interval width is inversely proportional to the square root of the number of replications, and increasing the number of replications will narrow the intervals accordingly (but if the original intervals are broad, the narrowing will be slow).
- With respect to the plots of slide 12, replication 0 (blue lines) shows a period of zero Labor resources available from time 50 to 70 days. This is better seen on slide 14. The event was not registered as a "resource failure" because Supply and Plant resource levels were greater than zero during that time (resource failure is defined on slide 10, item 2). Because of the zero Labor resources, there are production queue and product wait time spikes (slide 12). After the production queue size reduces, the "Produced But Not Sold" (PBNSo) queue spikes, then subsides. As the PBNSo queue subsides, the "Sold But Not Shipped" (SoBNSh) queue spikes and gradually decreases as the shipping department catches up. This is all apparent from the plots (blue lines) of slide 12.
- Limiting the Available Resources (slide 9, items 16 and 17) gives the modeler/analyst the ability to constrain available resources, thereby increasing resource utilization factor(s). (When considering sick leave, vacations, meetings, breaks, education and maintenance, the amount of time that Labor has available for "production" work may be as low as 50%.) Limiting available resources normally results in decreasing the number of products produced. As noted on slide 10 in a footnote, intentionally limiting Supply, Plant and/or Labor resources may result in unused monies being included in the Supply, Plant and/or Labor Revenue Accounts.
- If, for example, when running the model with "unlimited" resources (limited only by the available \$), the mean number of Labor resources available (slide 10 item 9 mean) is 2.28 and the mean Labor resource utilization (slide 10 item 12 mean) is 0.2216, then an approximate equivalent single Labor resource utilization (i.e., limiting the number of Labor resources to 1, see the previous bullet) would be  $2.28 \times 0.2216 = 0.505$ . You could check this out by running the model in the "Limiting the Available Resources" mode with slide 9 item 16 set to 1. The Output Statistics should then report 1 (or possibly slightly less than 1) in the item 9 output mean and close to 0.505 in the item 12 output mean. I use the words "approximate", "possibly slightly less" and "close" because the random input to these two runs would be slightly different. A more rigorous comparison would use values' means and confidence intervals.

# Notes and Suggestions (2)

**Gross Revenue Verification:** Compare sheet 10 item 17 with the following calculation based on slide 9 and slide 10 input/output data:

$$\begin{aligned} \text{Expected gross revenue} &= ((\text{MeanSupplyUnits/Product} \times \$/\text{SupUnit}) + \\ &\quad (\text{MeanLaborUnits/Product} \times \text{MeanLaborActivityTime} \times \$/\text{Day/LabUnit}) + \\ &\quad (\text{MeanPlantUnits/Product} \times \text{MeanPlantActivityTime} \times \$/\text{Day/PlaUnit})) \\ &\quad \times \text{Markup} \times \text{NumProductsProduced} \\ &= (1 \times 100 + 1.021 \times 0.299 \times 133 + 1 \times 0.299 \times 50) \times 3 \times 629 \quad [ \$/P \times F \times P = \$] \\ &= \$293,527 \end{aligned}$$

Sheet 10 item 17 = \$299,522 (~2% diff and, within confidence interval)

Also:

$$\sum (\text{Revenue/Accounts}) = 14976 + 56193 + 69572 + 97980 + 34799 + 6692 + 6692 = \$286,904 \quad (\sim 4\% \text{ diff, in CI}) \quad [ \$]$$

**Labor, Plant and Supply Accounts Verification:**

$$\text{Labor Account} = \$/\text{Day/LabUnit} \times \text{RunTime} \times \text{MeanLabUnitAvail} = 133 \times 330 \times 2.28 = \$100,069 \quad (\sim 2\% \text{ diff in CI})$$

$$\text{Plant Account} = \$/\text{Day/PlaUnit} \times \text{RunTime} \times \text{MeanPlaUnitAvail} = 50 \times 330 \times 2.133 = \$35,195 \quad (\sim 1\% \text{ diff, in CI})$$

$$\text{Supply Account} = \$/\text{Prod} \times \text{Prod/SupUnit} \times \text{RunTime} \times \text{MeanSupUnitAvail} = 100 \times 1 \times 330 \times 2.133 = \$70,390 \quad (\sim 1\% \text{ diff in CI})$$

**Sensitivity Analysis:**

A basic and underlying assumption for all simulations is that (possibly extreme, but reasonable) variations in the input parameters will yield reasonable and stable variations in the simulation results. If this is not true, the model is classified as "brittle" or "questionable". All good simulation tools (slide 6 footnote) will have the ability to conduct sensitivity analyses by incrementally altering specific input parameters and recording / comparing simulation results for those different parameters. For instance in the model at hand, it may be a good idea to vary the input Labor unit \$/day through the range \$100, \$125, \$150, \$175 and observe how the number of Resource Failures and the number of Production Jobs Completed behave.

**Product Sales Price Verification:**

$$\text{Product Sales Price} = (\text{manufacturing cost} + \text{sales cost} + \text{shipping cost}) \times \text{markup}$$

$$\begin{aligned} \text{manufacturing cost} &= (\text{product supplies } \$/\text{product}) + ((\text{manufacturing labor units}/\text{product}) \times (\text{labor } \$/\text{hr}) \times (\text{manufacturing hrs}/\text{product})) \\ &\quad + ((\text{manufacturing plant units}/\text{product}) \times (\text{plant } \$/\text{hr}) \times (\text{plant hrs}/\text{product})) \end{aligned}$$

$$\text{sales cost} = ((\text{sales labor units}/\text{product}) \times (\text{labor } \$/\text{hr}) \times (\text{sales hrs}/\text{product})) + ((\text{sales plant units}/\text{product}) \times (\text{plant } \$/\text{hr}) \times (\text{sales plant hrs}/\text{product}))$$

$$\text{shipping cost} = (\text{shipping cost rate}) \times (\text{manufacturing cost})$$

**Resource Cost of Sales Verification:**

$$\text{Total Product Supplies Cash Account} = (\text{product supply unit cost}/\text{month}) \times (\# \text{ months}) \times (\# \text{ supply units})$$

$$\text{Total Labor Cash Account} = (\text{labor unit cost}/\text{month}) \times (\# \text{ months}) \times (\# \text{ labor units})$$

$$\text{Total Plant Cash Account} = (\text{plant unit cost}/\text{month}) \times (\# \text{ months}) \times (\# \text{ plant units})$$

## EXPLICIT EVENTS

Executed at specified times , after simulation start



○ (0) Initialize Supply, Labor and Plant environments

■ (5.01 to 5.02, repeat every 5 working days) Transfer\$ from Gross Revenue to Net Revenue

▲ (10.005 to 10.006, repeat every 10 working days) Subtract spent Labor\$ from Labor account

(10.007 to 10.008, repeat every 10 working days) For restricted Labor units add excess Labor\$ to Gross Profit

(10.01 to 10.02, repeat every 10 working days) Add \$ from Net Revenue to Labor account

(10.03, repeat every 10 working days) Create new Labor units from\$ available in Labor account

◆ (22.005 to 22.006, repeat every 22 working days) Subtract spent Supply or Plant\$ from Supply or Plant accounts

(22.007 to 22.008, repeat every 10 working days) For restricted Supply or Plant units add excess Supply or Plant\$ to Gross Profit

(22.01 to 22.02, repeat every 22 working days) Add \$ from Net Revenue to Supplies Plant, Taxes and Gross Profit accounts

(22.03, repeat every 22 working days) Create new Supply or Plant units from\$ available in Supply or Plant accounts

## RESOURCE COSTS BREAKDOWN

