Week 1 – System Dynamics

Simulation is an approximate imitation of reality, and its applications are:

* Investigate the behaviors of a system w/o building it
* Identify unexpected phenomenon
* Validate hypothesis and test different scenarios
* Make better decisions and improve system’s performances
  1. System Dynamics

Model the nonlinear behavior of complex systems over time using stocks, flows, internal feedback loops, table functions and time delays.

(Use Excel, InsightMaker, Vensim, AnyLogic, Stella)

* 1. Discrete Event Simulation

Simulate the operation of a system as a discrete sequence of events in time. Each event occurs at a particular instant in time and marks a change of state in the system.

(Use Excel, VBA, JaammSim, Jackson, Simio, SimuLink)

* 1. Agent-based Simulation

Model the behaviors of a system by simulating the behavior of each individual agent within it.

(Use HTML5, JavaScript, D3, AnyLogic)

System Dynamics (SD)

Generally used to make long term/strategic decisions. Thinking of the system as a whole as oppose to its parts. SD seeks to understand system behavior by analyzing the interactions between the different elements of the same system structure, thereby providing insights on how alternative policies may affect the growth, stability, fluctuation, and changing behaviors in a system.

**Predator-Prey Dynamics**

Biological phenomenon: predator and prey populations oscillate.

**Lotka-Volterra Model**

N(t) denote the prey population at time t

P(t) denote the predator population at time t

r is fractional birth rate of the prey population

q is the fractional death rate of the predator population

s is the hunting efficiency of the predator

f is the rate of conversion of food to predator offspring

Approximation with difference equation (Euler’s Method)

Using a fixed time step duration :

System Dynamics (SD) Modeling

1. Start with an influence diagram
2. Make it more specific with stock and flows diagrams
3. Convert into mathematical equations
4. Implement in software
5. Simulate with chosen parameters

* 𝑃𝑟𝑒𝑦𝐵𝑖𝑟𝑡ℎ𝑠(𝑡) = 𝑃𝑟𝑒𝑦𝐵𝑖𝑟𝑡ℎ𝑅𝑎𝑡𝑒 ∗ 𝑃𝑟𝑒𝑦(𝑡)
* 𝑃𝑟𝑒𝑑𝑎𝑡𝑜𝑟𝐷𝑒𝑎𝑡ℎ𝑠(𝑡) = 𝑃𝑟𝑒𝑑𝑎𝑡𝑜𝑟𝐷𝑒𝑎𝑡ℎ𝑅𝑎𝑡𝑒 ∗ 𝑃𝑟𝑒𝑑𝑎𝑡𝑜𝑟(𝑡)
* 𝐴𝑡𝑡𝑎𝑐𝑘𝑂𝑝𝑝𝑜𝑟𝑡𝑢𝑛𝑖𝑡𝑖𝑒𝑠(𝑡) = 𝑃𝑟𝑒𝑦(𝑡) ∗ 𝑃𝑟𝑒𝑑𝑎𝑡𝑜𝑟(𝑡)
* 𝑃𝑟𝑒𝑦 𝐷𝑒𝑎𝑡ℎ𝑠(𝑡) = 𝑆𝑒𝑎𝑟𝑐ℎ𝐸𝑓𝑓𝑖𝑐𝑖𝑒𝑛𝑐𝑦 \* AttackO𝑝𝑝𝑜𝑟𝑡𝑢𝑛𝑖𝑡𝑖𝑒𝑠(𝑡)
* 𝑃𝑟𝑒𝑑𝑎𝑡𝑜𝑟𝐵𝑖𝑟𝑡ℎ𝑠(𝑡) = 𝐹𝑜𝑜𝑑𝐶𝑜𝑛𝑣𝑒𝑟𝑠𝑖𝑜𝑛𝑅𝑎𝑡𝑒 ∗ 𝑆𝑒𝑎𝑟𝑐ℎ𝐸𝑓𝑓𝑖𝑐𝑖𝑒𝑛𝑐𝑦 \* 𝐴𝑡𝑡𝑎𝑐𝑘𝑂𝑝𝑝𝑜𝑟𝑡𝑢𝑛𝑖𝑡𝑖𝑒𝑠(𝑡)
* 𝑃𝑟𝑒y(𝑡+1) = 𝑃𝑟𝑒y(𝑡) + 𝑃𝑟𝑒𝑦 𝐵𝑖𝑟𝑡ℎ𝑠(𝑡) − 𝑃𝑟𝑒𝑦𝐷𝑒𝑎𝑡ℎ𝑠(𝑡)
* 𝑃𝑟𝑒𝑑𝑎𝑡𝑜𝑟 (𝑡 + 1) = 𝑃𝑟𝑒𝑑𝑎𝑡𝑜𝑟(𝑡) + 𝑃𝑟𝑒𝑑𝑎𝑡𝑜𝑟𝐵𝑖𝑟𝑡ℎ𝑠(𝑡) − 𝑃𝑟𝑒𝑑𝑎𝑡𝑜𝑟𝐷𝑒𝑎𝑡ℎ𝑠(t)
* Assignment statements that change the state of the system (e.g. Q=Q+1) are associated with events only (not with delays or conditions) – state of the system only changes in the events!;

• Conditions are expressed as a statement that returns either true or false; Use the construct "=if(condition, true, false)" where condition is an expression that evaluates to a logical value;

• There are no “yes/no” branches in this language. You will need two condition nodes to model a branching process (one for the “yes” and one for the “no”) – see next slide

• Delays are expressed as a statement that returns a positive value; Use the construct "=expression" when describing the delay.

• Events can be triggered only by other events, through condition nodes and delay nodes – there should be no two events connected!

• No statements in the arcs. The statements are all in the nodes.

Diagram

Description automatically generated

Diagram

Description automatically generatedA a tray arrives at random intervals, uniformly distributed between 10.5 and 17 minutes (13.75 minutes on average). If there are 10 trays already waiting to go into the oven, then this tray simply disappears. If there are 9 or fewer trays in the queue, then the tray joins the queue. If the oven is empty, then a tray entering the queue will trigger the start of an oven cycle. When an oven cycle starts, up to 2 trays are removed from the queue and placed into the oven. The oven cycle lasts exactly 25 minutes.

Diagram

Description automatically generatedA tray arrives at random intervals, uniformly distributed between 10.5 and 17 minutes (13.75 minutes on average). If the oven is off and it is cold (that is, SimCurrentTime less the time of the last oven completion is greater than or equal to 5 minutes), then the oven is turned on for a pre-heating cycle of duration exactly 6 minutes. When the pre-heating cycle completes, the oven cycle starts. Assume the oven is off and cold at the time of the arrival of the first tray of cookies and must be pre-heated. Equivalently, assume the time of the last oven completion was less than negative 5 minutes. On the other hand, if the oven is off when a tray arrives and if the oven is hot (SimCurrentTime less the time of the last oven completion is less than 5 minutes), then the oven cycle starts immediately.

Diagram

Description automatically generatedIf the oven is clean and empty, then the oven cycle is started. On the other hand, if when an arrival occurs the oven is being cleaned or is in a bake cycle, then nothing happens. When an oven cycle starts, up to 2 trays are removed from the queue and placed into the oven. The oven cycle lasts exactly 20 minutes. When the oven cycle finishes, the trays are removed from the oven and we keep track of the number of trays completed since the last cleaning. If this count equals or exceeds 10 trays then we start a cleaning cycle. The cleaning cycle lasts exactly 6 minutes. When the cleaning cycle finishes and when the oven cycle finishes and cleaning is not required, we check to see if there are any trays of cookies in queue. If there are trays in the queue, then the oven cycle starts again. We remember to reset the number of trays completed since the last cleaning every time we start the cleaning cycle.

Diagram

Description automatically generatedDiagram

Description automatically generatedA tray arrives at random intervals, which are uniformly distributed between 10.5 and 17 minutes (13.75 minutes on average) unless the queue size gets large. If there are 10 or more trays waiting to go into the oven just after the current arrival, then the next arrival will be delayed by an additional 5 minutes. That is, the next interarrival time will be 5 minutes plus a uniformly distributed delay between 10.5 and 17 minutes. If the oven is empty, then a tray entering the queue will trigger the start of an oven cycle. When an oven cycle starts, up to 2 trays are removed from the queue and placed into the oven. The oven cycle lasts exactly 25 minutes if 2 trays have been placed in the oven and it is exactly 20 minutes if only 1 tray has been placed in the oven. When the oven cycle finishes, if there are trays in the queue then it starts again.

A picture containing text, document, screenshot

Description automatically generated 



