NGI101x - 4.3B - System Dynamics II

So, what do System Dynamics (SD) models look like? Let's have a look at the technique. This might be a difficult part but if you get confused, just have a look at the additional resources we included in this MOOC.

Two types of diagrams are often used in SD. The first type, Stock-Flow diagrams, are mainly used to build simulation models.

Stock-Flow diagrams focus, as suggested by the name, on stocks and flows, which are two types of variables.

Stock variables are accumulations of all inflows minus all outflows over time. And te net flow actually determines the behavior of the stock over time. Or, mathematically speaking, stock-flow structures are differential or integral equations.

Apart from stocks and flows, constants and parameters are also included in these models.

And auxiliary variables are included to build models that closely correspond to the real world system.

Auxiliary and flow variables often contain very specific functions, such as non-linear graphical functions or delay functions.

Direct causal relationships between these variables are indicated with (blue) causal links. Note that the flows are causal links too.

And also note that variables need to have real-world meaning and that all units need to be consistent.

Then, if a model is fully specified, it can simulate behavior over time.

This type of representation is good for building models and for communicating stock-flow structures, but it is not really appropriate for thinking in terms of feedback loops or communicating important feedback effects.

For this purpose, System Dynamicists use Causal Loop Diagrams.

These show causal links between the main variables, the polarity of these causal links, the feedback loops, and the polarity of these feedback loops.

A positive causal link from A to B either means that A adds to B (if B is a stock variable), or that a change in A causes a change in B in the same direction.

And for a negative causal link from A to B, one says that either A subtracts from B if B is a stock variable, or that a change in A causes a change in B in the opposite direction.

A feedback loop consists of two or more causal links between elements that are connected in such a way that if one follows the causality starting at any element in the loop, one eventually returns

to the first element.

There are actually two types of loops.

A feedback loop is called a balancing loop if an initial increase in variable A leads after some time to a decrease in A, but also if an initial decrease in A leads to an increase in A.

In isolation, such feedback loops generate balancing or goal-seeking behavior.

A feedback loop is called a reinforcing loop if an initial increase in variable A leads after some time to an additional increase in A and so on. And if an initial decrease in A leads to an additional decrease in A and so on.

In isolation, such feedback loops generate reinforcing behavior. Exponential behavior for instance.

But feedback loops hardly ever exist in isolation. Feedback loops are often strongly connected, and their relative strength changes over time.

Complex system behaviors often arise due to such shifts in dominance between different feedback loops in the same system.

When dealing with feedback loop systems consisting of multiple loops, it is hard to derive the behavior of the system without simulation.

So, let's gradually transform the previous Stock-Flow Diagram into a Causal-Loop Diagram.

The first step would be to turn the flows into causal links: an inflow into a stock is a positive causal link from the flow variable to the stock variable.

But an outflow out of a stock is a negative causal link from the outflow variable to the stock variable: the higher the outflow is, the lower the stock variable will become.

If we further transform the Stock-Flow Diagram into a Causal-Loop Diagram, we need to add the link polarities, identify the feedback loops, and derive their loop polarities.

In this case we would end up with a reinforcing loop with a delay and a balancing loop.

Depending on which loop is dominant and whether dominance shifts, this feedback loop system could generate several modes of behavior, for example exponential growth if the reinforcing loop remains dominant or S-shaped growth if the balancing loop takes over after some time.

So, what's so specific about System Dynamics?

1) SD models are largely endogenous theories, that is: model boundaries are chosen such that all important feedback loops are within these boundaries

2) SD models are rather aggregated: stock variables are often used to group rather homogenous individuals or items.

This also means that we need to be sure the aggregation assumption holds in order to be able to use SD modeling.

If the aggregation assumption holds, then SD has an advantage over less aggregated methods.

SD is therefore most useful for studying the long term big picture.

As already mentioned: SD models are integrated numerically to generate the behavior over time.

System Dynamicists assess and interpret the resulting trajectories over time in terms as general mode of behavior. For example, oscillatory behavior or S-shaped growth, or overshoot and collapse.

In case of undesirable modes of behavior, system dynamicists actually analyze which structures need to be changed or added to change the undesirable modes of behavior, for example exponential growth, into more desirable modes of behavior, for instance an S-shape curve.

So, outcomes are not interpreted as precise predictions; outcomes are general foresights at most.

System Dynamicists are far more interested in improving our understanding and changing faulty mental models, and generating general policy insights than generating predictions.

As such, SD models are essentially tools for thought. More, reflection beyond the model is also hugely important in SD.

Let me give you two examples now: a very simple example first and then a more advanced.

Let's make a very simple model about the electrification of the European car fleet between the year 2000 and the year 2100.

Say, at the start, there are nearly 100 million conventional vehicles and only 2000 electric vehicles.

Owners of electric vehicles stick to their electric vehicles. At the end of the average lifetime of a conventional vehicle of, say, 10 years, conventional vehicle owners may consider buying a conventional vehicle or an electric vehicle.

Suppose that the electrification process depends on some sort of incentive. Say, this incentive makes electric vehicles 5 times more attractive than without this incentive between 2005-2015.

Simulating this vey simplistic model, we obtain the S-shaped growth of electric vehicles.

The second example relates to material scarcity, mining and recycling infrastructure.

The model displayed here is a bit bigger than the previous model. It consists of a demand sub model, a supply sub model, an extraction infrastructure sub model and a recycling infrastructure sub model.

All sub models are linked although this does not show in this picture.

The model was made with mineral/metal scarcity experts and used to develop scarcity scenarios.

The model generates very interesting dynamics.

The blue lines on the left and the right give an indication of mineral/metal scarcity: abundance and scarcity.

In this simulation, there are first some temporary periods of scarcity, after that scarcity becomes chronic beyond 2030.

Changing a few assumptions, leads to even more interesting dynamics.

These and other scenarios can then be used to design and test policies and strategies for different stakeholders.

So, System Dynamics is useful for modeling complex social-technical systems and simulating behavior over time. Without SD or other simulation techniques, this is almost impossible.

Here, we briefly looked at the basics of SD. From here on we recommend you to work through various e-books, books, online resources, do supervised projects, and take some advanced courses.

After that, you are ready to make and use your own SD models and combine SD with other methods.

And then the fun really starts. Enjoy!