# Introduction to Global Simulation System

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## Background

WhatIf? Technologies was founded by myself and Bert McInnis. The company came into existence in 1990 based on the work that Bert and I had been conducting at Statistics Canada. Throughout our careers we have been interested in systems modeling. Essentially systems modeling is a way of providing insight and foresight so that the decisions that we make are better informed by an understanding of the full range of possible consequences of those decisions.

What I'm going to talk about today is a small scale model that we built originally to demonstrate the software technology that we have developed. Our objective was to design the smallest possible model that could be used to explore the concept of sustainability. As you no doubt know from reading the Brundtland Commission Report, sustainability is concerned about the capacity of our planet to sustain our species over a longer time horizon. I think the definition runs something like this: it is the responsibility of each generation to leave as much by way of resources at the end of their generation as they inherited from the previous generation.

The question before me is "why should this model be of interest to you and what lessons can be learned from it?" I guess these questions can be answered on several levels. The first level is that the model addresses a problem and a set of issues that is of common interest to everybody – the future of humankind and the ability of our planet to sustain it. At another level it says something about how one comes to understand complex systems. Complex systems can be studied and looked at analytically by sets of mathematical equations, but its very difficult to understand fully the consequences of those equations particularly if they are non-linear and there are more than two or three of them. So this is an attempt to provide you with the means of exploring or experiencing a complex system through direct exploration of that system.

## Modeling Approach

The ***Global Systems Simulation*** is based on a world view that, simply stated, our world consists of two fundamentally different kinds of processes. First, there are processes that transform materials and energy. Some of these are naturally occurring and others are purposeful insofar as they have been put in place by human beings to meet the objectives of humanity. Second, there are processes that transform information and constitute what we might call a "***mind-space***". It is the mind-space that governs the interface between the purposeful physical processes and our intentions.

What's unique about this particular approach is that the model represents only the physical transformation processes and not the mind-space. In fact it is you, the user of the model who supplies the mind-space. The mind-space is the source of novelty and what human beings are good at is novelty. Human beings are capable of learning, and learning generates new insight which reconfigures the interaction between the purposeful physical processes and the context of naturally occurring processes.

## Tension

Another thing that makes our approach unique is a concept that we call ***tension*** or disequilibrium. The idea here, which comes from control theory, is that the coordination among the different processes that humanity controls takes place in mind-space. Coordination involves communication among agents and coordination is often imperfect., therefore we want to be able to explore potential futures in which our activities are not well coordinated. In the model we do this by allowing independent manipulation of the variables that control the purposeful processes and reporting the resulting tension.

An analogy that I often refer to is driving an automobile. There are generally two levers for controlling the speed of the automobile; the brake and the accelerator. This means that the system is "over-determined", in that it has more control variables than the target variables, in this case the velocity of the vehicle. It is up to the driver of the vehicle to coordinate the use of the brake and accelerator pedals to control the speed of the vehicle. Of course if the use of the pedals is not well coordinated, for example the driver jumps on both the brake and the accelerator at the same time, the system is put into tension and the result is not easily predictable.

Tension may also be viewed as an incoherency that causes us to react and to intervene in order to resolve the tension. This is what draws the user into the model as the source of the intelligence that resolves tensions in perhaps novel ways. In the normal course of human activities we are constantly resolving tensions through coordination. Consider, for example, a system that has two processes, one that mines coal and another that makes steel. Of course these two processes have to be coordinated because making steel requires just the right amount of coal. However there are two independent entities or organizations that control the activity levels of coal mining and steel making. The coordination between these two takes place through the information flows that exist between the supplier of coal and the producer of steel.

Because many external factors can influence one or the other process the coordination has to take place in real time. This is what the user of GSS is required to mimic as he or she attempts to resolve the tensions that arise, over time, in the simulation.

The problem domain addressed by this particular model is that of an exponentially growing population of people living on a finite planet. The planet provides the resources that sustain the population. The intermediary between the needs of the population and the resource base is the know-how or understanding that transforms those resources into the things like food, shelter, energy and mental stimulation etc. that are required to sustain the population. The model is designed in such a way to illuminate the tension between the needs of a population as it might evolve over time and the ability of the natural resource base to meet those needs.

There are four tensions that we work with:

1) The first tension is between the requirements of the population for nourishment and the ability of the land base to provide adequate amounts of food.

2) The second tension relates to forestry. The population requires forest products for two purposes, namely energy and material. Wood can not only be burned to provide energy, heat and mobility but is also a material used in the construction of buildings, machines, furnishings and so on.
3) The third tension that we deal with is energy. The population requires energy for space heating, food production, transportation and industrial processes. In addition to wood, there are non-renewable sources of energy of which coal, oil and gas are represented explicitly in the simulation, and several renewable sources of energy that are treated as a single collection in the model to represent wind, hydro, solar and nuclear. Strictly speaking, nuclear is not renewable renewable but is not under the same limitations as the fossil fuels. Given the mix of resource limits and development strategies there is potentially a disequilibrium or tension between requirements for energy and the energy sources that can be exploited.
4) The fourth tension that the model represents is the tension between the availability of labour from the working age population and the amount of work that is required to drive the exploitation and transformation of natural resources into the energy, materials, and goods desired and needed.

## Resolving Tensions

In reacting to tensions the user has a variety of ways of intervening in the model to resolve those tensions. The major interventions are what we might call choices of investment in infrastructure.

1) The first of these is the choice to invest in renewable versus non-renewable energy.
2) The second is the choice to invest in the capacity to recycle materials, recognizing that many materials are finite.
3) The third choice is with respect to investment in the capacity to minimize or reduce pollution, understanding that pollution has adverse effects throughout the rest of the system.
4) Fourth there is a choice regarding how much effort we devote to inventing and putting in place new technology. The model distinguishes three kinds of technological innovation, namely energy saving, labour saving and material saving which may interact with each other in fairly complicated ways.
5) There are also choices to be made with respect to fertility and mortality that determine the size of the population. There are choices with respect to the material standard of living that we wish the population to enjoy.

## Material Standard of Living

Since this model focuses on material and energy constraints it does not directly include health, education, or the aesthetic and spiritual aspects of a standard of living. The material standard of living is represented by two factors, namely the amount of ***food per capita*** and the size of the stock of what we call ***durable goods*** relative to the size of the population.

Food of course depends on agriculture, it has to be grown. However we generally don't eat directly from the field; for example wheat grown in the field must be processed to become foods like meat, bread and pasta. Thus the output of agriculture is transformed into the edible commodity called food in a ***food processing plant*** that requires both labor and energy as well as the plant itself.

The second aspect of the material standard of living represented in this model is the stock of ***durable goods***. Of course it is the actual number of durable goods per capita (the size of the stock) at any time, not the rate of production, that is relevant to the material standard of living. You can think of durable goods as the composite of houses, vehicles, office buildings, roads, etc. -- all the physical infrastructure.

To account for the diversity of material goods, in this little model we've made use of the concept of a "***brick***". You can think of a brick as something like a Lego brick. In Legoland all things can be made out of some combination of Lego bricks. In this little model our bricks are composed of a combination of wood, which is potentially renewable, and metal which comes from the mine and is non-renewable. All of the stocks in the model are made out a combination of our bricks, just like Lego bricks. This includes the stocks of durable goods that provide direct services to people, and it also includes all the plants such as those for food producing plant, energy production facilities like hydro dams, recycling plants, etc. Even the brick production plant is made out of bricks.

## Natural Resource Base

### Agriculture

In the GSS there are four components to the natural resource base that sustains our population. The first one is agriculture. The agricultural model starts with a limited stock of three quality levels of potentially arable land. The amount of land times the crop yield provides the output of agriculture that is the source of food. A number of factors influence the yield including pollution, fertilizer, seed quality and cultivation intensity.

First, the amount of untreated pollution that is released into the environment reduces crop yield. Labour and energy are applied to the land in order to produce crops. Second, fertilizer increases yield, but in a non-linear way so that yield is only increased up to a certain application of fertilizer beyond which there is no further benefit. Fertilizer itself is represented in the model as being energy. The idea behind that is that fertilizers like nitrogen fertilizers are produced from natural gas, so fertilizing is very much like a direct application of energy, at least in the way it is represented in this model.

Seed quality is represented by what we call a genetic factor which includes traditional breeding practices but could also represent genetic modification. Investing in seed improvement can increase yields, but at the cost of investing effort in the form of labour. The fourth factor that has an impact on yields is cultivation intensity which is a direct consequence of the labour we apply to agriculture. The way to think about this is to compare a market garden to a field of wheat. In a market garden a high level of labour leads to quite high yields per unit land. A field of wheat, though it is highly productive as an enterprise partly because it uses small amounts of labour per unit land, yields less crop per unit of land than a market garden does.

### Forestry

The second component of the resource base is the forestry model which is simply represented as a stock of land on which trees grow. Trees grow relatively slowly so they are simulated using a population model in which trees age, increase in volume and require more land space as a function of age. There is natural mortality so trees die as a function of their age. If left undisturbed the forest comes into a natural equilibrium age distribution. Of course as we harvest only older trees (say only those over forty) the age distribution of the forest changes more or less dramatically depending on the level of harvesting.

### Mining

The third component of the natural resource base is what we call metal mining. We use the term "metal" to encompass all non-renewable sources of material. Metal mining works with diminishing returns as mining progresses. This represents the situation where the richest ores are extracted first so that either the ore grade or the its accessibility diminishes over time so that more labour and energy must be expended to acquire the ore and extract the metal from the ore.

### Energy

And finally we come to energy; both the renewable and nonrenewable components to energy. The nonrenewable component comprises coal, oil and gas. In this model there is a finite stated amount of resource in the ground that can potentially be exploited. The production of these three resources is also rate limited; you can't produce it all at once. The rate of production follows a rather nice curve that shows an increase in production from the available pool up to a peak, and then declining production after that peak. This curve is sometimes referred to in discussions concerning fossil fuel resources as "peak oil". Thus for these three nonrenewable resources the model has captured both the idea of a finite absolute amount of a recoverable material and the rate limitation. Furthermore coal, oil and gas can only be produced from those stocks that have been discovered. Exploration for fossil fuel sources is represented in the model by a labour investment.

On the renewable side of energy three different types of sources are represented in the model: wood, hydro-electricity, and other renewables. Energy can be obtained from wood by combustion. or by extracting a hydro-carbon fuel such as ethanol. Wood is available as it grows, but the other two types of renewable sources of energy are only available if you invest in building the appropriate plants.

Hydropower is only available if dams are built. In this model, there is a finite stated amount of hydropower sites available, and it is the decision of the user to determine how much investment in hydro is put in place for any given scenario. The quality of hydro sites diminishes as the number of good sites are used up, with the consequence that there is a diminishing return to investment in hydro facilities.

The third type of renewable energy is a composite that we regrettably have called solar-nuclear. This source of energy has the property that if you invest in a plant, for example a solar collector, you get a stream of energy out of that plant for the life of the plant. The life of the plant is finite, so plants are represented with another population model based on a life-tables of 30-40 years. For simplicity, nuclear has been treated in an analogous way, that is, the model does not represent the finite source of nuclear fuel or uranium.

## Recycling and Pollution Control

Its necessary in a model like this to introduce the concept of recycling; otherwise one would run out of the nonrenewable materials in rather short order. The way we have represented recycling is that all stocks, including durables and the different kinds of plants, are governed by life tables. As the stocks age and wear out a number of bricks are considered to be waste but the rest are available for recycling. Since the model keeps track of the number of bricks that were invested in each stock it can calculate how many bricks are released at any time. If the user has put in place the capacity to recycle then a percentage of the metal that was embodied in each brick can be extracted for reuse. This recycled metal can be sent to the brick factory so that the factory needs less metal sourced from the mine. Note that there is potentially a tradeoff between the energy it takes to recover metal through recycling and the amount of energy it takes to extract the same amount of metal from the mine. This is not a simple tradeoff because the amount of energy that is required by the mine to produce a unit of metal goes up as a function of the accumulated production of the mine. Hence there is an interesting crossover when it becomes beneficial to switch from the mined source to the recycled source.

The model also represents pollution and pollution control. A number of processes generate pollution as a function of their level of activity. It is up to the user of the model to determine how much capacity to treat pollution is put in place. To the extent that pollution is untreated it has two impacts that feed back into other processes. As already mentioned, agricultural yields are a function of the amount of pollution that is released in each year. To also incorporate a cumulative effect the natural mortality of trees has been made a function of the cumulated amount of pollution that is in the atmosphere. Hence, all other things being equal, the decision not to treat pollution will have an adverse an impact on the productivity of renewable resources.

## Technological Change

Many models treat technological change as if were an exogenous factor, something that simply happens as time goes by. In this model the choice to invest time and effort into new technology has been made explicit. If new technology is generated, it gets embedded in the processes that transform materials and energy. For example if the user chooses to invest in energy saving technology, then all those processes that require energy for each unit of output will work with greater efficiency. However, investment doesn't have instantaneous results. The new technology penetrates only when new durables, plants or capacity are put in place. For example, when a new durable is put in place, its efficiency with respect to energy, labour and materials is determined for its entire lifespan by the technology investment that has accumulated up to that point. The accumulation of technology is not entirely simple either, technology has to be used or it is lost. That is, the model also represents the decay of knowledge if there is not enough investment in technology research. Essentially, the notion of forgetting has been built into this model.

## Understanding, not Prediction

We chose a time horizon of a hundred years into the future for the purposes of this simulation because it is concerned with sustainability. A hundred years seems like a long time horizon, and one can wonder whether a model can say anything useful that far about anything that far in the future. The reason we made this choice is that we wanted all the stocks in the model to turn over at least once or twice. Some of the living "stocks", like people or trees have long lives relative to a hundred years, and many of the durable stocks have "lives" of 30 or 40 years. If one were to work with a much shorter time horizon one would be stuck with the stocks that are already in place and it would be difficult to see a transition to a new state that could be described as being sustainable or persistent.

Are the results of the model realistic? This is a complicated question but I'll try to answer it by saying first of all that it is not the intention of the model to predict what will happen. The intention of a model like this is to bring together concepts so that you can begin to understand how the various concepts and components interact with one other and thus present a dynamic picture that enables you to generate an understanding of the system as a whole.

We have calibrated the model using data from United Nations sources, but of course given it is a global model many details are lost through working with global averages. We know the population and natural resource information is quite reasonable. And curiously enough, when we compare some of the results with other models in this class, this model performs better that many of the more detailed ones. The tensions that show up in this model 20 or 30 years in the future do correspond with a number of analyses that have been done independently.