Guided Study Program in System Dynamics

System Dynamics in Education Project
System Dynamics Group
MIT Sloan School of Management[1]

Solutions to Assignment #13
Tuesday, February 2, 1999

Reading Assignment:

- Beyond the Limits,[2] *by Donella H. Meadows, Dennis L Meadows, and Jorgen Randers*

Please refer to Road Maps 5: A Guide to Learning System Dynamics (D-4505-4) for an introduction to Beyond the Limits.

Exercises:

Please keep the questions for each chapter in mind as you read the chapter. They are designed to focus your reading, explore some of the ideas brought up in the reading, and relate them to ideas studied so far. Answer as many questions as you can and have time for, but we recommend that you submit an answer to at least one question from each chapter.

<u>Chapter 1: Overshoot</u>

A. Based on your experience with the CFC modeling exercise from assignment 7, discuss the behavior driving the growth of carbon dioxide concentration in the atmosphere as shown in Figure 1-3.

Much as with the CFC exercise in assignment 7, the carbon dioxide concentration discussed in the first chapter of *Beyond the Limits* appears to initially grow exponentially. If the atmospheric system exhibits the kind of delays found in the CFC model, I would expect any reduction in fossil fuel use to have a lagged effect in reduced carbon dioxide concentrations. Certainly an important lesson from assignment 7 was the notion that

[2] Meadows, Donella H., Dennis Meadows, and Jorgen Randers, 1992. *Beyond the Limits: Confronting Global Collapse, Envisioning a Sustainable Future*, Post Mills, VT: Chelsea Green Publ. Co., 300 pp.

results from changed behavior can take some time before they appear. This is consistent with the "precautionary principle" advocated by many concerned with global ecological trends, i.e., we need to act before we have irrefutable (and possibly irreversible) evidence of destruction from human activity.

Carbon dioxide grows as shown in Figure 1-3 because as the amount of pollution increases, the pollution-absorption time is also increasing: A small amount of pollution dissipates quickly, but a large amount can have a cumulative effect by interfering with the natural process of dissipation. As pollution absorption times get larger and larger, the pollution absorption rate gets smaller and smaller. At high pollution generation rates, the overloaded dissipation capacity cannot absorb the inflow rate and accumulation of generated pollution breeds unrestrained growth of the level of carbon dioxide in the atmosphere.

B. Refer to table 1-1 on page 7. Can you identify any causal relationships between any of the activities and products? Are these relationships reflected in the growth rates over the 20-year range? Which areas have grown fastest or slowest and why? What do you expect for the next 20 years?

Of course the growth in population is related to all the items in the list, but several of them grew at a faster rate than the population, and some of those are causally related to each other. Obviously, the number of registered automobiles is causally related to the number of kilometers driven. Just as the growth rate for automobiles is greater than that for the population, the number of miles driven has grown more, especially miles driven by trucks. It is interesting that the oil consumption has grown at a rate slightly less than that of the population in spite of the growth in number of automobiles. This can be attributed to the development of more fuel-efficient cars. The growth of electric generating capacity is causally related to growth in coal consumption, and the large growth in energy generation by nuclear power plants (by far the largest rate of growth in the list) has not significantly affected that relationship. Interestingly, municipal waste generation saw the smallest rate of growth--undoubtedly because of recycling efforts. Similarly, the growth in use of aluminum was smaller than the combined growth in soft drink and beer consumption. Although they are causally related, recycling mitigated the impact. While it is encouraging that the chart indicates the positive effects of conservation efforts, much more needs to be done in the next twenty years to mitigate the growth in population, to further slow the growth in consumption of non-renewable resources, and to encourage the use of bio-friendly materials.

Chapter 2: The Driving Force: Exponential Growth

A. Look at Figure 2-2 on page 16. Using the doubling-time calculation method, estimate the annual population growth fraction.

The figure shows two lines: population for less industrialized regions and populations for industrialized regions, both from 1950 to 2030. The population for more industrialized regions appears to be growing linearly in the time span that we are concerned with. Because the behavior is linear, there is no fixed growth fraction—that is, the growth fraction is continuously decreasing.
The population growth for less industrialized regions, however, looks much more like exponential growth (as the figure caption indicates). Using the doubling-time calculation method and the doubling time of 20 years given in the figure caption, the answer is approximately:

0.7/20=0.035=3.5% annual population growth fraction.

B. Using figure 2-5 and your graphical integration skills, describe the behavior of the population stocks for more and less industrialized nations from 1900 to 2100.

Figure 2-5 shows the inflow of people added to the population stock per year for industrialized and less industrialized countries. In order to estimate the stock behavior, we graphically integrate the lines in Figure 2-5.

<u>For the more industrialized countries</u>: From 1900 to about 1960, the flow is positive and increasing, making the stock grow faster and faster during this time period. From 1960 to 2050, the flow decreases in magnitude but is still positive, meaning that the stock is increasing but slower and slower, approaching equilibrium asymptotically. The equilibrium comes just after year 2050, when the flow becomes 0, so there is no more population growth (nor decline). The general stock behavior is S-shaped growth.

<u>For the less industrialized countries</u>: The population growth flow for less industrialized countries is not as smooth as that of the more industrialized countries. The overall flow trend, however, is growth from 1900 to 2000, and decline from 2000 to 2100. The corresponding population stock behavior is therefore S-shaped growth. Notice that the stock behavior for less industrialized countries differs from the stock behavior for more industrialized countries because here the exponential growth has a shorter doubling time, resulting in a steeper curve, and a shorter half-life for the asymptotic growth section. In year 2100, the stock has not yet reached equilibrium because the flow is still positive (though decreasing steadily). If the decreasing trend of the flow keeps up, we should expect the population to come to equilibrium at around year 2140.

C. On page 35, the authors include a feedback diagram for the stock of industrial capital. What types of behavior is the feedback system likely to generate? Why?

The causal loop diagram is a single stock structure with positive and negative feedback loops. The only types of behavior that can result are exponential, asymptotic, or equilibrium. The type of behavior that actually occurs depends on the initial value of "Industrial Capital" (which has to be positive), "investment rate," and "average lifetime of capital." If the "investment rate" is greater than the depreciation rate (which is the inverse of the "average lifetime of capital"), positive feedback will dominate, resulting in exponential growth of "Industrial Capital." If the depreciation rate is greater than the "investment rate," negative feedback will dominate, resulting in asymptotic behavior. If the two rates are equal from the start, the stock will stay in equilibrium. Notice that S-shaped growth cannot result from the structure shown page 35 because a one-stock system is incapable of shifting loop dominance unless it contains an additional feedback loop or a nonlinear lookup function.

Chapter 3: The Limits: Sources and Sinks

A. Give five examples of planetary sources and five examples of planetary sinks.

Planetary sources for materials and energy include: solar energy, water resources and energy, soil resources, mineral ores, and fossil fuels. Of these sources, solar energy, water and soil resources are renewable. Mineral ores and fossil fuels are non-renewable resources. Planetary sinks include the atmosphere, the soil of the earth's land masses, bodies of water, the ocean, and (surprisingly) outer space. We can also add vegetation, (or bacteria or microbes) as a "biological planetary sink" for certain by-products of biological processes. Balance is necessary between sources and sinks so that these sinks do not become saturated beyond their absorption rates. One of the most frightening possibilities of increasing carbon dioxide concentrations in the atmosphere is that this indicates that the atmospheric sink has been saturated and it is no longer possible for the atmosphere or other sinks (such as vegetation) to absorb excess contaminants.

Some examples of planetary sources include:

- Atmosphere (the air we breathe)
- Earth (fertile soil, provides minerals, warmth, allows food to grow)
- Sea (sea water dampens into clouds which produce rain)
- Rivers, lakes (used for freshwater, to generate electricity, irrigation)
- Forests (wood, generates oxygen from carbon dioxide)
- Solar energy (source for forest)
- Fossil fuels (oil, coal, and natural gas)
- Minerals (aluminum, iron, titanium, etc)

Some examples of planetary sinks include:

- Atmosphere (cleans polluted air, sink for carbon dioxide)
- Earth (landfills to store waste materials, soil is a sink for acid rain)
- Sea (for dumping sewage: e.g. Shell's Brent Spar debacle)
- Rivers, lakes (for dumping material)
- Forests (for dumping material)

B. World Bank economist Herman Daly explains that for a renewable resource, the sustainable rate of use can be no greater than the rate of regeneration. Provide an example of a system that uses a renewable resource at a sustainable rate. Then, thinking *back to the deforestation model from assignment 3, comment on the effect of delays on the system.*

One example of sustainable use of renewable resources would be the hunting practices of many indigenous peoples. For example, Native Americans practiced sustainable harvesting of the bison population prior to the arrival of Europeans.
One lesson learned from an earlier assignment suggests that due to system delays, once behavior is modified to accommodate a change in the relationship between inflows and outflows, the new stock equilibrium achieved will operate at a different level than the prior equilibrium. In the context of renewable resources this can have devastating consequences. If for example, fishery stocks are depleted below a critical threshold, adjusting harvesting rates to match rates of replenishment won't be sufficient to protect the stocks from catastrophic shocks that they would have previously survived.

I think the production and harvesting of Christmas trees is an example of a renewable resource that is used sustainably. Tree farms want to maximize profits over the long run so they plant enough trees every year to provide harvesting of full-grown trees in 5 or 10 years.
If, however, the consumption of Christmas trees increases, the tree farmers may harvest trees that are not yet full grown, thereby decreasing the average age of the tree population. This effect may lead to smaller Christmas trees every year.

C. Grain yields could be much higher in industrializing countries. Why do you think that they are so low? What could be done to improve them?

I think that grain yields are low in industrializing countries because of several reasons:

- in most of this countries level of industrialization is low, and agriculture is based on technology that is not highly sophisticated as in developed countries
- most of the land owners own small pieces of land, there are only few large land-owners
- because of these two reasons, economy of scale cannot be achieved, and productivity of both land and workers is low
- soil is exhausted because of poverty and hunger, lack of fertilizers, and general overuse of land

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Grain yields could be much higher in industrializing countries. Possible reasons for the low levels include: land and capital is seen as more profitably used for industry rather than agriculture, industrial use of land is contaminating the agriculture land, and land is constantly being lost to erosion, bad weather, salt buildup, and urbanization. To improve the grain yields in the industrializing countries, farmers need to be informed about sound farming techniques that are used to conserve and enhance soil and increase yield (such as terracing, contour plowing, composting etc.) However, the text also points out that if the flow of food through human society were more efficient, less wasteful, and more evenly distributed, it would not be necessary to grow more.

D. What policies can poor countries with hostile neighbors adopt to avoid reaching their water limit?

Poorer countries with hostile neighbors could protect forests, implement reforestation programs, practice soil conservation practices for crop production and conserve lands that have important water aquifers. These countries, however, have two counts against them. First, they will tend to have rapid population growth rates that will necessarily place heavy demands upon water resources. Second, they may not be able to afford expensive dam and irrigation construction programs that would help them make more effective use of their water resources.

A better approach to sustainable development in semi-arid system (regions or countries) should take into account the natural constraints of scarce water and low productivity of these areas through integrated land management, keeping population at sustainable levels, and maintaining high standards of water quality. New uses for the same water should be allowed, closing the cycle of water use in agricultural and industrial systems, and maximizing the flow of environmental, economical and social goods and services through the whole water cycle. There are also many possibilities of increasing the efficiency of water use, if traditional practices in agriculture are combined with new concepts and knowledge.

E. What are some ways a country can prevent overharvestation in other, sovereign countries? For example, how would a country like Belgium prevent overharvestation in Brazil?

A possible solution to motivating other nations to manage their resources more carefully is to rely upon material incentives. These incentives could come in a variety of forms including specific policies such as debt forgiveness, subsidies and grants for preservation efforts, and collaborative projects to develop sustainable industries such as eco-tourism. More industrialized nations are in a position to rely on their economic wealth to offer assistance in a variety of ways.

The book presents the example of the forested area in Costa Rica. Costa Rica was clearing forest land to expand cattle ranching. The new pastures proved to be unsustainable, however, so through a series of “debt-for-nature exchanges,” Costa Rica is finding the resources to put into place the infrastructure and expertise that will maintain and protect the remaining forests for scientific study and eco-tourism which will be more sustainable than the cattle-pastures. Countries like Belgium can not only get into these “debt-for-nature exchanges,” but they can also decrease demand on the exports from these countries that promote overharvestation. (Do not try to import beef from Costa Rica).

F. Discuss the differences between manufacturing redesign and end-of-pump clean-up.

Manufacturing redesign means acting before the damage has been done, to prevent such a damage or minimize it. End-of-pump clean-up means acting to repair the damage already done. So more products, effort, energy has to be invested in repairing a damage that could have been avoided in the first place by a more careful design. End-of-pump clean-up also means that traces of dirt and damage will always remain and will accumulate over time, making the cleaning more and more expensive and more and more inefficient.

End of the pipe clean up is to abate pollution at the point of emissions rather than reducing throughput at the source with manufacturing redesign. Though concentrating only on "end-of pump clean up" is commendable and is making positive progress, significant progress can be made by concentrating on manufacturing redesign. At each step of manufacturing, there is great potential to reduce pollution flow. Through manufacturing redesign, a company not only can reduce pollution, they can achieve monetary savings by using less expensive recycled material or efficiently using less material in the product design. Manufacturing redesign promotes greater material and energy efficiency which is more effective than "after the fact" clean-up.

G. Discuss the differences between a program that increases recycling and a program that increases the lifetime of products.

Recycling seems like a good way to reduce waste; however recycling in itself is a production process with all side effects of waste of energy and material. Increases in product lifetime on the other hand reduces:

- the amount of material to be recycled and the energy needed for recycling because recycling is less frequent
- the material and energy spent to produce substitute products because the product is still used and does not (yet) need to be replaced

<u>*Chapter 4: The Dynamics of Growth in a Finite World*</u>

A. Figure 4-8 on page 123 shows the four possible behavior modes of the World model and describes their structural causes. For each behavior mode, describe, in a few sentences, the simplest model that could produce such behavior. Include information about the number of stocks in each model, the relationships between the stocks (if more than one) and their flows, and the shape of possible table functions (you should justify their use). You do not need to submit any models or behavior runs, just describe the structure, and explain how and why it would produce the behavior mode.

<u>Exponential growth:</u>

A simple model generating exponential growth contains a stock, a positive feedback loop with an inflow depending on a growth fraction and the current value of the stock, and initial value of the stock quite far from its maximum, limiting value. Initial stages of many biological processes show exponential growth, although this is a phase limited in time.

S-shaped growth:

A simple model that can produce sigmoid growth is a single-stock model with an inflow and an outflow, where 1) the inflow is a constant fraction of the stock, and 2) the stock is used as the input to a table function that yields a fraction by which the stock is multiplied to determine the outflow. The table function can be a nonlinear graph that early in the simulation run yields a fraction that is smaller than the constant inflow fraction, and that later in the simulation run yields a fraction that is equal to the constant inflow fraction. This results in exponential growth of the stock early in the simulation when the positive feedback loop of the inflow dominates, and asymptotic growth of the stock later in the simulation when the negative feedback loop of the outflow dominates.

Overshoot and oscillation:

A model showing overshoot and oscillation might have two stocks, let's say, population and resources. Population changes through births and deaths. The mortality fraction of the population stock depends on available resources, so that when resources are scarce mortality increases. Resources are renewable, that is, there is a positive feedback loop between resources and resources growth. Resources are depleted by consumption by population. The population of interest might be a predator and the stock of renewable resources might be a prey population. The predator population stock in this model would exhibit overshoot and oscillation because an increase in the predator population causes the prey population to decrease, and a lower prey stock causes the predator population to decrease (because of the effect of available resources on mortality). With a lower predator population, the prey stock may grow up again and so on. Oscillations occur due to intrinsic delays in the transmission of the state of one stock to the another one, because of the average lifetime of each stock. Longer average lifetimes would generate oscillations over greater time periods.

Many participants stated that only one stock is sufficient to produce overshoot and oscillation, while in fact, two stocks are the minimum required for oscillation. We will study this issue in more detail in later chapters or Road Maps, but here is a short explanation:
Let's assume that the stock of interest is increasing at first, so the net flow into the stock is positive. In order for the stock to start decreasing, the net flow must become negative. Hence, there must be a point in between the growth and decline of the stock at which the net flow is zero—this is the peak value of the stock. But if the model only contains one stock, then the net flow only depends on that stock (and some parameters or table functions). Hence, when the stock reaches the peak, the net flow is zero and cannot change anymore because the stock is not changing, and the system is locked in equilibrium. The net flow can become negative only if it can be changed by some other variable in the system that is still changing even though the stock of interest is momentarily not changing—that other variable can only be another stock. Therefore, the

system must contain at least two stocks so that the net flow can change from being positive to being negative.

Overshoot and collapse:

In this case, the recovery capacity of the stock acting as a resource may be affected, for example a renewable resource might behave as non-renewable, or a stabilizing mechanism to maintain certain stocks (for instance in natural processes of pollution removal) might be destroyed, if certain critical thresholds are reached.

For the same reasons as above, a structure that produces overshoot and collapse of a stock must contain at least two level variables. One of the levels is the stock that we are interested in, and the other level acts as a resource. Initially, the stock grows exponentially, but its growth causes a more rapid depletion of the resource. A lower amount of resource will cause the outflow from the stock to increase, eventually resulting in a collapse of the stock.

B. Figure 4-8 mentions that one of the structural causes of the "overshoot and oscillation" and "overshoot and collapse" behavior modes is that signals or responses are delayed. Explain how you would incorporate a delayed signal or response into the structure of a model. Explain how and why this would cause a delay.

In the deforestation modeling exercise from assignment 3, a delay is added by incorporating the maturing flow and stock into the system, which initially just included planting and harvesting.

A delay in a system is usually represented in a model by a stock-and-flow structure. Stocks, as accumulations in the system, cannot change instantaneously: they accumulate changes over time through their flows. Therefore, any signal that needs to pass through the stock will be delayed because the stock will not change immediately, and the response of the system to the signal will come too late.

C. Describe a simple example of a system (not necessarily related to any of the topics discussed in "Beyond the Limits") that could exhibit overshoot and oscillation.

When I take a shower, I am part of a system that exhibits overshoot and oscillation. If the water is too hot, I add more cold water. But it takes few seconds for the cold water to flow, and I am impatient. Therefore, after two seconds I add even more cold water. Water is O.K. for a moment because small amount of the cold water has come (from my first attempt), but after another few seconds the water becomes too cold because too much cold water flows (from my second impatient attempt). Then I decide to add more hot water, but it also takes few seconds until it comes, so I add more hot water, and the water again becomes too hot. Then I add cold water, but I learn my lesson this time and I manage to mix cold and hot water in order to be just O.K. I just realized that I repeat this almost every day. There are several reasons for that: I have very short memory for this event, I am impatient, I do not take into account delays, and I actually like to take a shower for few seconds in hot and for few seconds in cold water.

D. Describe a simple example of a system (not necessarily related to any of the topics discussed in "Beyond the Limits") that could exhibit overshoot and collapse.

A classic example of the "overshoot and collapse" behavior mode is the "predator-prey" model frequently encountered in ecology. Destruction of a predator population is likely to result in a population explosion of the prey population. Because no finite environment can support unlimited growth of a population, eventually natural constraints will check the prey population explosion. This natural check (most likely a depleted food source) could potentially have the consequence of generating collapse in the prey population.

Chapter 5: Back from Beyond the Limits: The Ozone Story

A. Think back to the model of CFC releases from assignment 7. How would you expand that model to study the actual effects of CFCs on the destruction of ozone? You may choose whether you would like to submit a model or provide a verbal description; in either case, make sure to explain your reasoning.

The original CFC model we built could be expanded with a stock-and-flow structure that represents the amount of ozone, generation of ozone, and destruction of ozone in the stratosphere by CFCs. This model should be able to show the decline of ozone level in the stratosphere. There should be a stock for the amount of ozone in the stratosphere, an inflow to this stock that represents ozone generation under the influence of sunlight, and an outflow from the ozone stock that represents deterioration of the ozone layer as a result of CFCs in the stratosphere. The outflow (ozone deterioration) is directly linked to the stock CFCs in stratosphere.

B. On page 152, the authors state that "NASA scientists found that their computers had been programmed to reject very low ozone readings on the assumption that such low readings must indicate instrument error." Can you think of any examples of similar attempts to ignore the actual behavior of a system?

At the Chemical Reprocessing Plant where I used to work, several sets of samples taken from the system at a critical monitoring point were showing a contaminant at very high levels. The operators refused to believe the readings because in their words 'there is no way for the contaminant to be there'. Further investigation discovered a leaking valve in a long forgotten vessel that was leaking the contaminant into the process. What should have been a several hour inconvenience turned into a near catastrophe.

An example of such a system purposely designed to ignore the actual behavior of the system was a torpedo defense system that I worked on. The system was labeled as "too sensitive" and would be shut off if it had a high false alarm rate. So even though if an actual torpedo was in the water (and you would want immediate notification), the first few pulses were ignored before the system indicated the presence of a torpedo.

In 1941 on a December 7th morning at a remote northern portion of an island in the Pacific Ocean, a new technology was being calibrated to detect objects in the sky. When the technician reported hundreds of blips on his screen and transmitted the result to his superiors, he was told to ignore them. He did. We now celebrate that day every year. How differently would the system have responded and history have been changed if the system was allowed to respond as programmed.

Chapter 6: Technology, Markets, and Overshoot

A. Chapter 6 essentially shows that technology and current "efficient" market systems cannot be relied upon to solve the problem of the limits to growth. A section in an undergraduate microeconomics textbook by Robert S. Pindyck and Daniel L. Rubinfeld,[3] however, says:

> *"The early 1970's was a period of public concern about the earth's natural resources. Groups like the Club of Rome predicted that our energy and mineral resources would soon be depleted, so that prices would skyrocket and bring an end to economic growth. But these predictions ignored basic microeconomics. The earth does indeed have only a finite amount of minerals, such as copper, iron and coal. Yet, during the past century, the prices of these and most other minerals have declined or remained roughly constant. [For example, our annual steel consumption is about twenty times greater than it was in 1880. The price of steel, however, has remained almost constant over that time period]."*

Discuss some of the reasons why the price of steel may not have increased over the past century.

The earth has very large iron reserves, so steel supply is much greater than the demand, and the price has not increased. Besides, prices of many commodities often do not depend on demand and supply equilibrium, but the relative bargaining powers of the buyers and sellers. Powerful buyers could keep the price of a product low, even if the supply is decreasing.

Improving technology has helped reduce the cost of mining iron and manufacturing steel. Thus, even if costs should have increased due to decreasing supply, increasing efficiency in production has compensated by making steel production cheaper, thereby keeping prices stable. This reasoning is especially true for other resources that are not as abundant as iron. Better technology has also allowed us to find and gain access to new raw material resources, such as deep-sea oil fields. The expectation (and hope)

[3] Pindyck, Robert S. and Daniel L. Rubinfeld, 1992. *Microeconomics*. New York, NY: Macmillan Publishing Company, 720 pp.

that new resources will be found as current ones decrease also encourages producers to keep prices low.

B. The microeconomics textbook continues two paragraphs later:

> *"This is not to say that the prices of copper, iron and coal will decline or remain constant forever—these resources are finite. But as their prices begin to rise, consumption will likely shift at least in part to substitute materials."*

Rising prices will certainly increase the pressure to find substitute resources. What are some potential problems in waiting for prices to give the signal to develop and implement the substitutes? Think about the current state of corporate competition and market attitudes.

As mentioned above, all markets do not always satisfy perfect markets assumptions, that is, everyone always has access to all information, and more importantly, no single players, or groups of players have large market power. There are many instances in which one or both of these assumptions do not hold. Very often, no one knows the right information—for example, no one knows the exact size of the world oil reserves at this moment. Thus, when the fundamental assumptions on which our theories are based are not fulfilled, a lot of our decisions are based entirely on guesses and estimates.

Even if we did have all the information and perfect markets and so on, we have to consider the inertia of our current processes. Developing and implementing reliable new technologies and substitutes takes a long time. The intense competition in even a perfect market place may keep prices artificially low till too late, and then it could be a difficult task to make the required changes within the time available, without producing undesirable side effects, including the possibility of complete failure to do so.

C. It would be better for society as a whole if individuals realized the need to find renewable substitutes before prices started rising. What are the incentives for a person or organization to develop such substitutes much before they are urgently required? Consider various price, material quality and ease of substitution effects.

Incentives might be useful for encouraging use of substitute materials. Such incentives might include artificially high prices (e.g. taxes) on the original resource, or subsidies (tax credits) to lower the cost of new alternative or unfamiliar resources. In some cases public awareness programs can provide the needed impetus for change in consumer behavior which, in turn, will force commercial organizations to change their use of materials. Increased funding of research into the improved use of alternate materials can also greatly speed the process of adoption of new materials and processes.

Chapter 7: Transitions to a Sustainable System

A. The simulation runs of the World3 model demonstrate that as long as we do not change the fundamental way in which we use resources, we are not removing the limits, but simply delaying their effects. The more we use technology today to push back the limits to growth, the worse the effects will be in the future. Refer back to the systems notes in the appendix of Systems 1, An Introduction to Systems Thinking by Draper L. Kauffman. Which systems notes best describe the lessons gathered from the World3 model? Can you think of any examples of similar systems from your personal experience?

There is no "away". We cannot throw anything away—if we do not see garbage, it does not mean that it does not exist. Nothing grows forever. For example, if human population continues to grow at present speed, after 100, 200 or 500 years every human being will suffer from hunger and lack of medical care. In the extreme case, there is just not enough space on the Earth to sustain population growth. But, we should not be boiled frogs, and sit and wait what is going to happen. We should take actions in order to assure a bright future. However, we should take into account several principles when we take any action. First, don't fight positive feedback; support negative feedback instead. Do not order companies to improve lifetime of their products, make it more profitable for them to do it instead. Second, good intentions are not enough. Implementing substitutes for CFCs can create more problems if we did not test them in order to evaluate their influence on the environment. This also tells us that every solution creates new problems. Finally, we have to remember that there are no simple solutions and no final answer, but that foresight always wins in the long run because if we look ahead and anticipate the problem we have more time to react and more alternatives to solve the problem.

A company I had experience with faced a limits to growth problem centered around the need to produce more goods. The demand for goods was growing exponentially (population driven), regulations and legal procedures were changing, and technology (just-in-time systems) was changing the flow rate and methods of production. There were a series of interlocking constraints that perplexed management. Among them were the demands of markets and the governing bodies to increase quality (the ability of the items to be "perfect"), maintain or reduce the price of the goods, increase production by an order of magnitude to meet increased demands, and not increase the number of employees because of salary, physical constraint (office space), and limited supply of people in the world that currently have the aptitude and training to produce these items. The managerial approaches to the stresses on the system touched just about every System note—all incorrectly. I will describe a few of them:

1. Solution: Remove the physical constraint by removing employees from spacious, individual rooms with doors, walls and windows and build a large building with "Dilbert"-like cubicles of half the original square footage per employee. Incorporate centralized, shared copiers, secretaries, phones, fax machines and meeting rooms.

Result: Item production was greatly reduced because employees were unable to concentrate because the confusion, noise levels and constant interruptions increased. The time to make photocopies increased, driving individuals to walk from floor to floor even to other buildings looking for the shortest copier line. Secretary assignment that use to be coordinated by familiarity with a small cluster of known employees and their routine requirements were replaced with uncoordinated, unprioritized, start-stop work flows resulting in miscommunication, multiple rework, mistakes, missed deadlines, increased frustration and overtime. This is an "Obvious Solution" gone wrong.

2. Solution: Limit salary growth by permitting employee attrition with no replacement, thus "saving money."

Result: Worked fine in year 1. However, with no replacement of the individuals leaving, there is a gradual loss of corporate knowledge about the methodology and experience gained through decades of producing these items. An indication of quality degradation began to appear by year 2. During this time, fewer and fewer people had the skill and experience to fill the gap. Eventually some of these skilled individuals began to show signs that a "threshold" was being reached. People started quitting, transferring out of high stress areas, retiring early, and refusing to work additional overtime. This put more strain on the few workers who had to take up the additional slack. Year 2 saw further reduction in salary expenses due to the accelerating reduction in the number of employees. By year 3, management was beginning to see disturbing signs that had the potential to lead to a cascading breakdown of the system. The best people, the ones who would always get the job done in a pinch were failing to meet both quality and quantity of item production.

3. Solution: Use technology to increase production of workers. This was to be accomplished by reorganizing into work teams, thus leveraging off of the individual expertise and facilitating coordination. At the same time move to complex information capabilities of the web/LAN-based communications and new software that supports item production.

Result: The individuals who were already stressed out trying to increase production had to find the time to simultaneously remove well-established patterns of work flow and develop new ones on the fly. The older tools (computers, copiers, software etc.) they used and were familiar with were replaced with unproven new technologies. The new systems were still working out bugs and identifying system incongruities and interface flaws even as the workers' "old" computers were being physically removed from their desks and carried down the corridor. Areas of production came to a complete halt even as the inventory levels reached historic lows, and workers were leaving. Demand had increased by an order of magnitude. It was not a pretty scene.

B. The authors recommend steps that must be taken in order to transition to a sustainable system. The first two recommendations are to improve the signals and speed up response times. How would those recommendations be implemented in the real *world? For example, which people, governmental agencies, or private organizations would be equipped to carry out these tasks?*

In order to "improve the signals" monitoring of signal sources needs to be improved. This is difficult given that many of the "signals" are not known! Clearly the establishment of watchers for specific signals (special task forces or agencies) would be helpful, but are not the only answer. Thus, constant monitoring of "everything" is necessary. This can only be achieved if sufficient financial and social resources are committed to all types of investigation about the earth and the systems that use it. Nevertheless, efforts can emphasize studies of the sources and sinks of the earth. Increased emphasis on product life cycles can help to ensure that new products are fully monitored in terms of their resource needs and effects on sinks. While international agencies can assist in these processes, it is individuals who will make the initial discoveries that will be taken up by these agencies. Maintenance of educational and supportive social and political systems to prepare and assist those individuals is the key here.

In order to "speed up response times" functioning national and international agencies are essential. These must be supported by a knowledgeable populace who will be asked to implement new approaches. Again, supportive social and educational systems and functioning governments are essential.

It seems that such support will become harder and harder to ensure as increasing populations make the supply of education and stable socio-political systems more difficult. In the USA, for example, support for international family planning programs (and for international agencies in general) is near an all time low because of religious and political beliefs. It appears that factors such as religion, nationalism, and race are still more important than the need for sustainability, in many people's minds.

C. How do the value and incentive systems in our current social systems need to change to make the solutions in the book viable?

Value systems in the US would need to move away from "the one with the most stuff" wins. If this value could really shift, it may be the only one needed to shift. Even for those of us aware of and struggling with these issues, this value is difficult to contain. Since I am older and have more income now than in the past, I find myself wanting to replace less good stuff with better stuff. When the question I should be asking is, "Do I need the stuff at all?"

I also can relate to younger Americans who see so much available and hear constantly that consumers drive the economy. Most now believe that two incomes are necessary—when really they are only necessary to have more "stuff". It is so easy to fall into this trap—"things" are so easily attainable and it is easy to justify—"keeping other Americans working"! However, this is a recent value shift for the US. The depression generation certainly does not have it—so it is us baby boomers and our children who seem to be driving this one.

Incentive systems in the US are also materially based. Yes, I get satisfaction from achieving lots of esoteric things in my work (helping others, personal growth) but I work for money. Since I have met many of my financial needs, I find myself working more and more on volunteer efforts—essentially doing the same consulting work for social and educational institutions but I can not escape the fact that without the sound economic base, I would not be able to do these.

So, how do we change incentive systems, given that (I assume) most people are very much like me—they work for a base of support? I do not think that incentive systems would need to change in the US IF we could deal with our consumerism value. Many people—not all—would begin to devote time to efforts other than making money, they would insist on time from employers to devote to other pursuits and would look for ways to simplify their lives and their living.

D. The authors say that poverty, and unemployment must be eliminated before we can reach a sustainable equilibrium. Keeping in mind Professor Forrester's paper Counterintuitive Behavior of Social Systems*, suggest some ways of dealing with these problems in the short and long-term.*

Forrester points out that social systems are inherently complex and that our ability to make predictions about their behavior is very limited. He uses this argument to support the need for system dynamics modeling approaches to study social systems. In the long term, continued studies of that sort are needed to assist society in making decisions about social problems.

Based on past finding of such studies it would seem that we are in need of walking the fine line between having a healthy, functioning economy and having an economy that is stable in terms of resource use. That is, the healthy economy is needed to provide jobs and goods and services, but at the same time it must be the type of economy that emphasizes recycling, renewal and energy efficiency.

Thus policy should emphasize and encourage economic development (providing jobs, services and goods) in sectors that emphasize sustainable use of resources, and should discourage those areas that emphasize excessive and wasteful use of resources.

Professor Forrester points out that social systems exhibit a conflict between short-term and long-term consequences of policy change. Much of this conflict occurs when the improvement programs are centered in one area only, and not surrounding areas. This makes it attractive for people to move to the area where the improvement program is being offered, thus causing the improvement program to be overstressed and acting to further depress the system. So the improvement programs to solve the poverty and unemployment program should be equitably distributed and not concentrated in certain pockets. In current society, this idea is fiscally limited. As was pointed out in the book, major shifts in thinking will be required if the problems of poverty and unemployment are to be eliminated. Through these major shifts, people will stop trying to acquire huge amounts of wealth and learn to "share," which will then provide resources required for the wide-spread improvement programs.

Chapter 8: Overshoot but not Collapse

A. Chapter 8 discusses the agricultural and industrial revolutions. What do you think of the so-called technological revolution? How does it fit into this discussion?

The general consensus is that the technological revolution is an extension of the industrial revolution in that it is a result of the need for ever-increasing efficiency. The technological revolution has changed the way things are done, but not what is done. The technological revolution can be seen as a stepping stone to the next revolution by making available the information that is always the vital key to transformation.

B. Discuss the quote by Ralph Waldo Emerson on page 225. To what extent is it still relevant today?

I think Emerson's quote is still quite relevant today. Structures created by human societies are independent from ideologies and world visions. Societies transform the world according to their ideas and mental models, so the reverse should also be true: it is necessary to change ideas and mental models in order to change structures. Education is important because it changes ideas and mental models, which in turn alter socioeconomic systems and the way the environmental system is managed. But the opposite is also true to some degree: structures and institutions are sometimes designed to promote and maintain the type of ideas and mental models under which structures were developed. As a result, considerable inertia exists of synergistic effect between mental models and the structures they have created. To introduce changes, it is necessary to generate new ideas and mental models capable of creating new structures.

C. The authors list on page 225 many components of their vision for a sustainable society. Which aspects of the vision are immediately realizable? Which aspects will be the most difficult to realize?

Like the authors of the book, I am convinced the technological aspects of sustainability are easily and already within reach. We now have the technical ability and the productive capacity to achieve the material achievements sought in the sustainability vision (e.g., "Material sufficiency and security for all," "Efficient, renewable energy systems," "regenerative agriculture."). The greatest challenges to a sustainable path for humanity lie in the political and psychological realms (an observation the authors make in the preface.) Applying the limitless power of human creativity turns out to be a far easier task when the focus is on the world around us than it is when the focus of our creative energies is on human institutions, ideological constructs, and cultural paradigms. "Work that dignifies people," "An economy that is a means," Decentralization of power," Balanced political structures," and "Non-material reasons for living and thinking well of oneself," all strike me as examples of the more challenging tasks that lie ahead. These are not insurmountable tasks, for every social institution and every paradigmatic construct is the product of human ingenuity and imagination. They simply represent the greatest obstacles to a better way of life for all of humanity. How ironic that the greatest obstacles we face are the ones we constructed.

D. In the preface to Beyond the Limits*, the authors revised the summary conclusions from* Limits to Growth*. Do you agree with these revisions? Why or why not? What are some of the factors that have may led to these revisions?*

I believe the conclusions in the preface are right on. I also believe that these will be hard to reach. In number one, it is stated that many resources have already surpassed sustainable rates. The salmon resource in the Pacific Northwest is at a critical point. Many of our waterways are polluted beyond their carrying capacity. Our forests are disappearing at an alarming rate.

Number two says we need policies to reduce material growth and population growth. It seems fairly clear the earth's resources are finite and without some kind of policy they will be gone in the future. It is also clear that the earth cannot support the kind of population growth we presently have.

Number three is the problem one. It requires that we change our ideas and habits to one of quality rather than quantity. Most of us have grown up with the idea that growth equals success, equilibrium equals stagnation, and downsizing is bad. How we transition to "maturity, compassion, and wisdom" to change our habits is not going to be easy.

As I stated earlier, I find it hard to believe everyone on earth will change their lifestyles, habits, cultures, and religions, when presented with the future under present growth patterns. I think it will eventually take official policies to force us to preserve ourselves.