SUMMARY

AN APPROACH FOR SYSTEM DYNAMICS AWARENESS

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The author works, teaches and does research, in the area of water resources, urban environmental systems, using aggregate models. His audience consists of Civil Engineering and Environmental Science graduate students, undergraduate students, and continuing education groups both domestic and foreign. The professional time commitment of this audience group to system dynamics is very limited. To date, there simply has not been sufficient time to go into operational detail other than one of awareness. The basic question is whether or not one can convey useful information without "hands on" program writing and system dynamics simulation solutions.

On the other hand, the author feels that greatest value of system dynamics may well be its use to an understanding of the logic, and method of approaching problems and has pursued this as a goal. In the paper he details the audience backgrounds, time commitments, and goals; and presents an approach used to develop an awareness of system dynamics, its power "in thinking one's problems through" simulation without using a computer, but using, scenarios, flow diagrams, and "hand" simulation on aggregate models. Several examples, illustrate the approach. Building the scenario and flow

diagrams, and working then through for a feel to relative importance with reference to positive and negative feedbacks, delays and table function. Finally, followed by a hand-cranked simulation.

Lastly, he discusses the (pros and cons) as developed through participant critiques.

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Civil Engineer curricula are made up courses. Curricula also lead to degrees and most engineering curricula provide rather narrow time allocation to fundamental categories of course offering. It is usually a tight curricula, designed to be achieved in four calendar years by the good student, five by the average. It is sequestial in nature. The upper limit of course hours is usually a constraint, the addition of new course material must be at the expense of older material. The present curricula are built on science, math, chemistry physics, tools (drafting, surveying, computer programming, statistics), mechanics, dynamics, thermo and materials followed by general engineering and then the various components of civil engineering, such as hydraulics, transportation, sanitary, water resources, structures, materials, etc. This sequence presently produces a B.S. degree holder, ready to emerge on the scene at $18,000 - $30,000/year.

Engineering has been changing with more recognition of the setting being evident. So engineers are being exposed to systems, ecology, sociology, economics, etc. -- recognizing that many of the "hardware" portions of the engineering work and goals benefiting in terms of social science parameters.

To handle the new entrants, and the increased variables, rather than an in depth understanding of a limited horizon, such as structural design or soil mechanism, some engineers are now looking at the entire delivery system.

This was first noted in water resources and transportation disciplines. So new substantive materials were introduced, such as environmental impacts, systems, systems approach, computer solution, modeling, operations research, econometrics, etc.

Some school, simply added specific courses to the curricula, others add new disciplines material to existing courses. For example, 10-12 years ago the people at MIT, developed ICES (Integrated Civil Engineering Systems), computer solutions to Civil Engineering problems, programs such as STRESS, COGO, etc. While other schools introduced a course in computer solutions, as opposed to computer solutions to structural courses (STRESS, STRUDL). The new course either lengthened the curricula, threw it into the master program or deleted, or repackaged older, formerly believed to be essential offerings; at many places both were done. One look at any well balance curricula, between pure science, and applied science, engineering, and engineering specialties, with a manual of tools and humanities is seen to be difficult to tamper with. So if one were to contemplate adding a "full blown" course or possibly two in System Dynamics, it might well swallow all of the technical elective time. On the other hand the incorporation of system dynamics solution techniques, etc. into one or more courses, perhaps at a graded rate, of engineering specialties such as water resources, or transportation might be very useful. Unfortunately, one doesn't know whether or not it would reach its full potential, because this is basically reached when it is used at a policy level not a purely technical level. One might consider ones view (or paradigm) of what a civil engineer should work on, (1) socially significant model, or (2) stick to "built structures". The author personally feels that one should be concerned not only with specific detail but also with social consequence or goal, and, of course preferred choices.

Competence as a system dynamics analyst is as demanding as any other discipline, it both encompasses computer, and model building knowledge. It simply appears to be asking too much to create both in student, say a sanitary engineer and system analyst, but it does appear feasible to have one who knows engineering and modelling without detailed attention to computer programming.

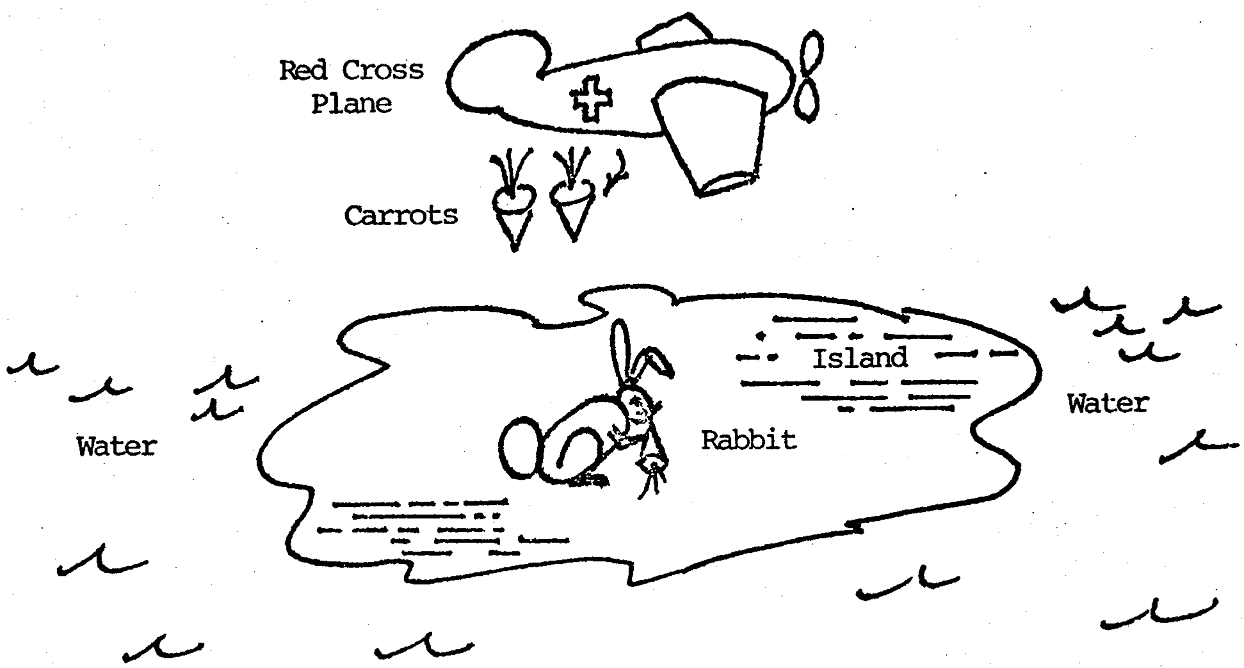
MIT, Dartmouth, and others have been taking from several types of backgrounds and producing systems analyst. After 10 years of system dynamics development I understand that in some respects they have become disenchanted, because the world has literally not come running to their door for all its solutions to its ills. This same reaction was evidence several years ago, in Pisa, Italy at the International Conference of System Dynamics where the system experts ask the question "Why doesn't the world use our technology?" My thoughts, and perhaps an over simplification, was that they talked to God and one another or they did not present the technology of linear program, dynamic program decision theory, etc. at a sufficiently attractive level to involve the technicians and professionals on the firing line. This same thesis arose, last year, at the Boston International Conference on Cybernetics and System Dynamics, "Why don't at least some of our decision makers use this powerful tool?"

I asked similar questions of the consulting civil engineers in an AVCO/ASCE study to determine what's a consulting engineer's perception of a system approach. The answers were Hardy-Cross, use of computer, etc. Perhaps most "old hands" are hard to change, perhaps the claims are outrageous, perhaps both. Behavior scientists tell us that one of our attitudinal commitments is developed through exposure at school, in this context, college, and in many it is for lifetime. It is called ones cognitive experience. So perhaps the remedy is in college. One further question, can one use system dynamics without indepth competence. This is the basic question and the answer is yes. I believe system dynamics form an excellent model for one to develop his thinking process.

So the scientific and professional educational time commitment of this audience to sytem dynamics is very limited. To date, there simply has not been sufficient time to go into operational detail. So the question is could one profit by incorporation of these tools, or conceptual approach, without detailed manipulation skills or the basic question is whether or not useful information can be conveyed without actual detailed competence. Let's call this an awareness level. Certainty, awareness (knowledge short of skill) is useful in other areas and many times this is all that is derived from technical elective and humanities.

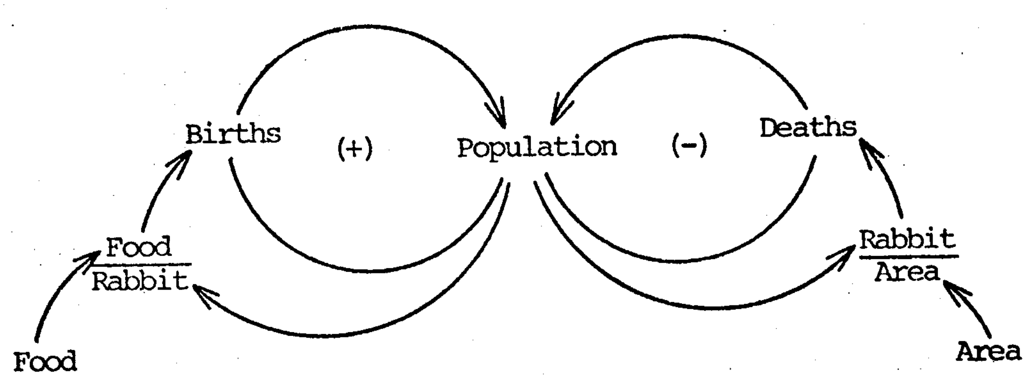
The author feels, with some justification from several years of experience that the greatest value of system dynamics may well be its use to an understanding of the logic, and methods of approaching social problems as well as engineering problems, and has been pursuing this goal with graduate students in three substantive courses, and one substantive undergraduate course. He has found it to be compatible with the audience time commitment goals. The development though more thorough at the graduate level, developed awareness not competence. System dynamics is explained but not worked on in detail, table and step function similarity. Examples are witnessed, model causal and flow diagram developed but not carried through the entire simulation process.

In this sense, one use is to think problems through without detailed computer simulation, "hand crank" as it were. Consider first, the process: the conceptual idea, next the causal diagram, then the flow net and finally the computer program. This is an orderly, beautiful teaching, learning sequence. The author has successfully used the "Rabbit Model" to demonstrate the process - study with the scenario, an island, a Red Cross plane with food, rabbits, and disease.

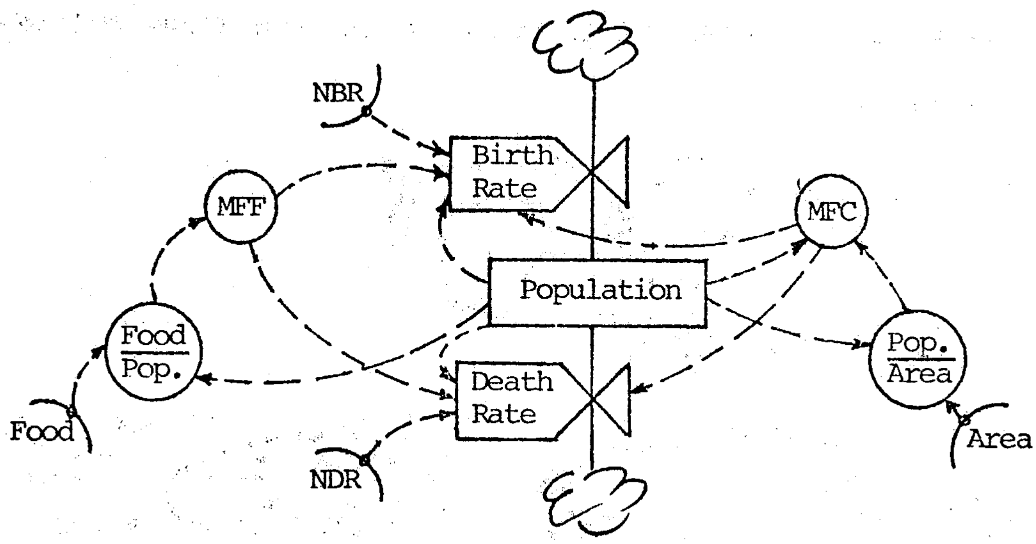


Now rabbits produce more if they have food, less if they become crowded, so the one must know rabbits vs. food, rabbits vs. crowding.

Most students can see this, and it is easy to suggest.

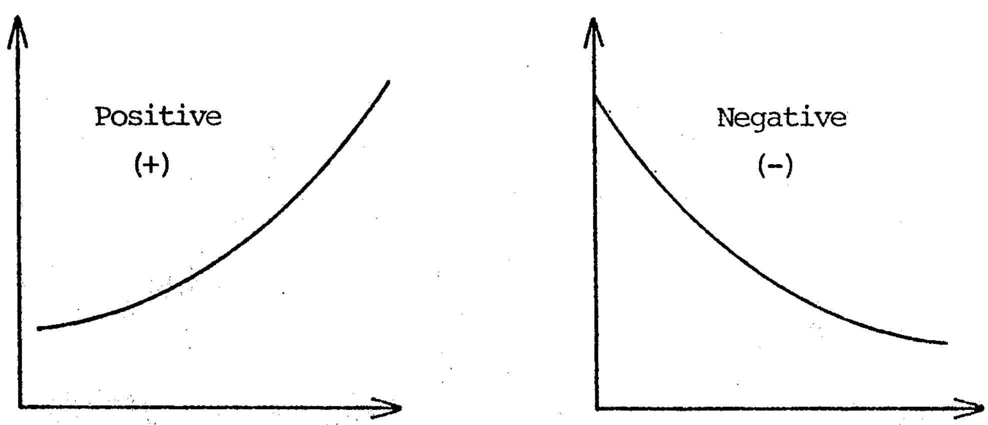


It is also useful to suggest the dual nature of the controlling concepts.



What an easy model, and what an easy transfer from scenario to causal diagram. All that follows is just refinement and quantifying. Nor is it difficult to change from rabbits to people.

Now aside from this, the concept of loops, one progressive, one regressive, is valuable.

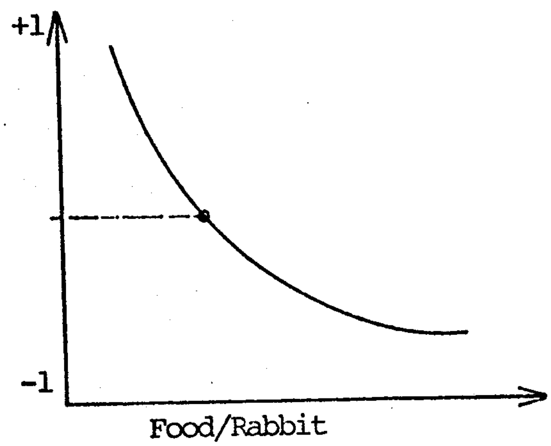


The idea of feedback is evidenced in both. Positive would be runaway, negative dampering.

Finally, one can look at an equation.

$$\frac{d\ \text{Rabbits}}{dt} \propto (\text{food} - \text{crowding})$$

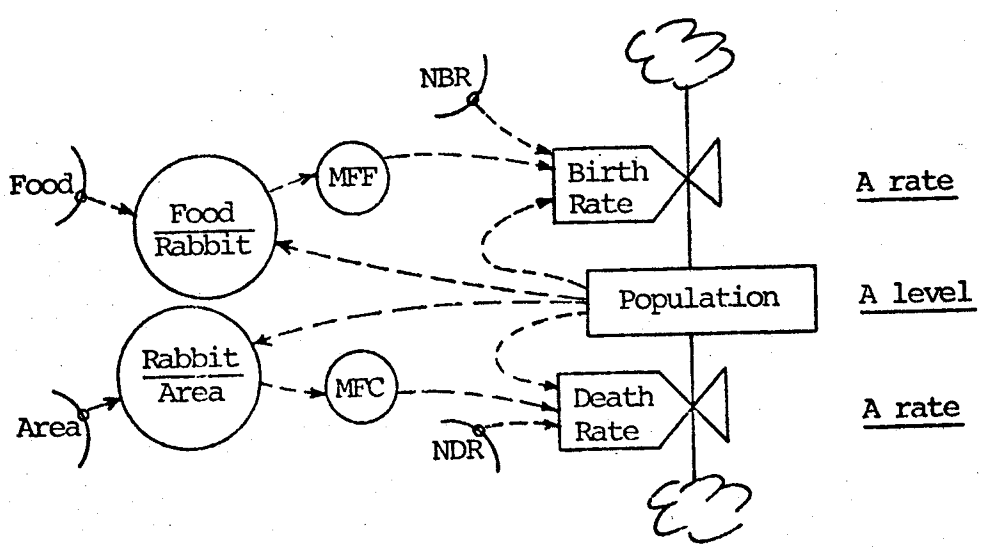
But what's easier than to construct a simple graph, or a table function.



Depending on food/rabbit, birth rate is simply increased or decreased. Similarly for crowding, again this could certainly be a model for people. This is an excellent exposure to aggregate modeling.

I believe the entire business of tracing these loops is to be non-productive but would progress to the next step, flow diagram.

Now note it gets more precise.



The student easily makes the next step. Flow systems are his "bread and butter" and this easily leads to a computer equation in Dynamo, e.g.

$POP_L = POP_K + (BR.JK - DR.JK)DT$

$BR.JK = NBR * MFF * POP_K$

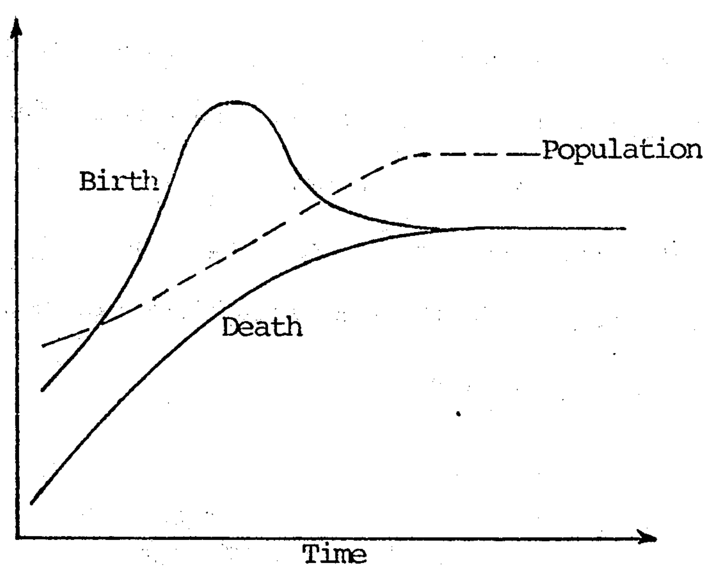
NBR = Given

MFF from a table function of MFF and Food/Rabbit

Food/Rabbit from Food $\div$ POP_K

Food = Given

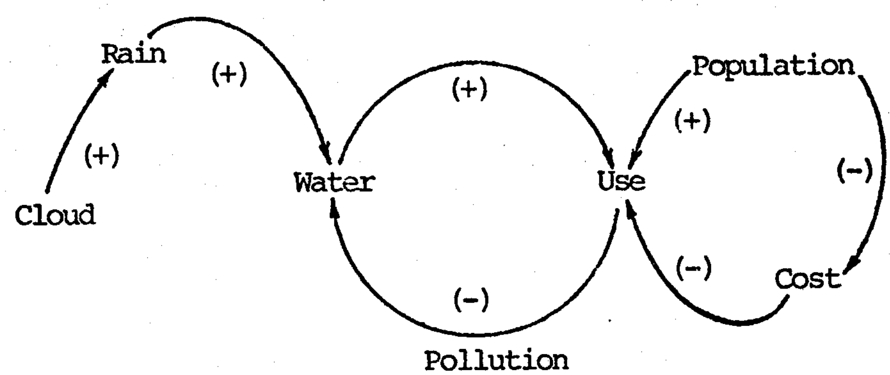
Thus, this program continued ends up in a simulation,



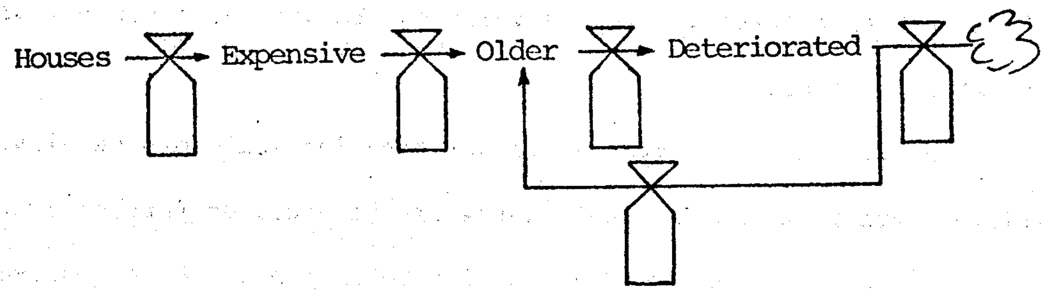
The basic idea is across. Now it opens itself to later refinement. So if not all rabbits are old enough or too old to produce, so a delay is used. It can be pointed out that a delay can be used as a control or so can a table function.

Finally any of the parameters, or the time scale can be altered, additional variables can be added, norms can be used, or further extended into a more elaborate system. Levels of information can be expounded in that context even professional conflicts.

This model is used with undergraduates after they have looked at population forecasts by trend, and morphological method - linear, incremental, logistic moving average, goal seeking, and cohort analysis. It has proven quite illuminating. Next in the undergraduate program it is used in a water resource model.

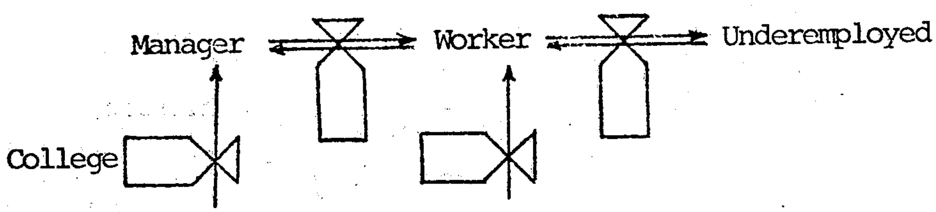


In the urban environmental system course (graduate/senior level course), the Forrester Urban Model has with it 9 inventories, 27 valves and three major pathways. Everything short of the actual running of computer simulation by students, simulation by Forrester is examined. This also leads to disaggregate concepts.



Houses decay, become of less value, finally either renovated or removed from the stock.

Similarly, we go from underemployed, to workers, to managers, with managers occupying the expensive house, workers the older, etc., and so it



goes. Everyone of the rates can be explored in depth, and their relationship to each trace. The model allows speculation on counter-intuitive concepts. Would creation of slums cause poor people to come to a city as would expensive homes cause managers, and research and development to move in. This leads to concepts of Supply and Demand models.

The world model, the energy models etc., are used in the graduate resources and forecasting courses, here in detailed, population, capital, resources and pollution inventories are tied together.

One of the principle thrusts of the forecasting course rests with the idea that all activities are interrelated. System Dynamics illustrates that concept. And points out the possible validation through sensitivity analyses.

The author has for 7 to 8 years now used as part of three courses, system analysis. Each year it is critized, and the critiques are favorable, mostly conceptually, students still do not have a feel for actual data, except for that from the population model.

In conclusion, it appears, as a concept, and as awareness tool, it is very valuable. As a device to identify what's under the hood it is good, but at present as a number generating tool or quantitative policy tool, it is not, except for population. One of the reasons for this, is that to develop a model requires many assumptions about many discrete disciplines and in an absolute sense violates all of them.

So, as a recommended exercise yes, but not as a usable numerical output device.

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