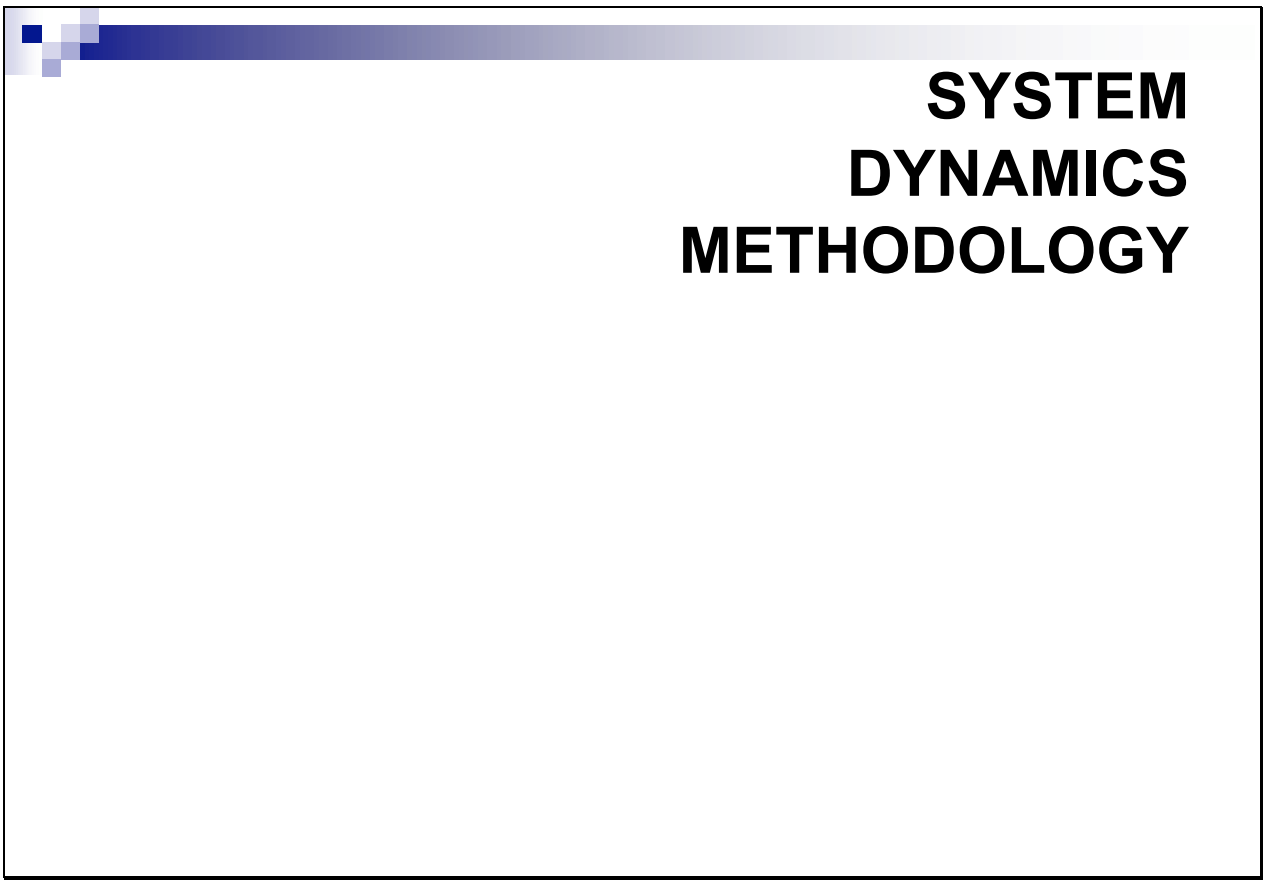

The original version of this document was prepared by Bob Williams and Bill Harris as part of a workshop organized by Glenda Eoyang, Bob Williams, Bill Harris for staff of the WK Kellogg Foundation.

Our thanks to the Foundation for allowing us to circulate this document more widely.

SYSTEM DYNAMICS

"System dynamics is a methodology for studying and managing *complex feedback systems*, such as one finds in *business and other social systems*."

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http://www.albany.edu/cpr/sds/

System dynamics is a tool to help address complex issues involving *delays*, *feedback*, and *nonlinearities*.

SD in a nutshell

All systems thinking approaches have to do with simplifying reality so we can deal with it more effectively. System dynamics offers an approach in which the model resembles reality structurally, so we can review it for usefulness and consistency. Furthermore, it offers us a way to see the ramifications of that simplification through simulation, so we can test our hypotheses.

Some key features of systems dynamics

- You model the problem, issue, or evaluation questions, *not* the whole program or real world
- Assumes most problems have endogenous causes
- Assumes events are part of patterns, which are generated by structures
- Selection of the problem boundary is a vital step
- Extent in time and space is generally more important than detail
- It's about testing hypotheses
- You can often apply insights from other models and simulations (eg system archetypes, or the behavior of epidemics)

SD's key differentiators

- The model and the real world have related structures
- The focus is on the effect of information feedback
- Models can contain quantitative and qualitative elements
- One can simulate the model to test hypotheses

So what for evaluation?

- Clarity of mental models
- Selection of measurement points
- Testing of hypotheses regarding causality
- Answering questions regarding delays, feedback, and nonlinearities
- Communication of results
- Understanding how evaluation affects the system

System dynamic approaches

In general there are two basic approaches to system dynamics.

1. There are approaches that *map* the dynamic relationships and then use a variety of methods to understand the possible consequences of those relationships or to develop theories about them. Essentially these are very sophisticated forms of program logic or concept mapping. Examples of this form of system dynamics include the causal loop diagrams and system archetypes used by Peter Senge and Daniel Kim's, QPID (qualitative, politicized influence diagram) carried out by Geoff Coyle, John Powell, and Juani Swart at Bath, University -- estimating behavior from structure without simulation. In some cases they take delay durations and polarity of feedback into account to ascertain likely stability/oscillation issues, and oscillation frequency.
2. There are approaches that *simulate* the dynamic relationships in order to explore the consequences of different amounts of intervention, timing, delay and feedback. The models developed by Jay Forrester and John Sterman are the best known. In the evaluation world, the Centers for Disease Control and Prevention (CDC) is using this approach to system dynamics to determine the worth of particular interventions in AIDS. The important thing to remember about this approach is that the simulation isn't intended to give you the "right" answer; it's intended to be another discussant in the room, blending its unique insights with those others provide. But it does help with an area that most of us don't do well intuitively – deal with feedback and delay.

Both approaches share the following steps :-

The classic system dynamic process

- Identify a problem, puzzle, evaluation question, or issue
- Develop a dynamic hypothesis explaining the cause of the problem,
- Build a model of the system at the root of the problem
- Ensure the model reflects the behavior seen in the real world, or explore similar models that have already been tested.
- Play around with the model to see what insights it gives you about the issue, problem, evaluation question or puzzle.
- Draw conclusions from these insights.

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AN EXAMPLE OF USING SYSTEM DYNAMICS TO EVALUATE A SCHOOL BASED HEALTH PROJECT

[Important Note : This is a fictionalized version of an actual project funded by the W.K. Kellogg Foundation. It has been reproduced with the permission of the Foundation and the *real* Director of the project]

The Farm to School project links local farmers with local schools to provide healthier food for students while helping farmers create more sustainable businesses. The project provides a school based project Director who educates students on the merits of farm-fresh foods, using field trips, and direct education.

Of course, the program won't succeed without the food being available, being priced right, tasting good, fitting in with the preparation systems used by the food service personnel. Finally, there's word of mouth (WOM): the propensity (or not) of the students to persuade each other that eating this food rather than candy bars and soda pop is a good idea. A local Director working in the school provides external incentive for students to try this food; WOM and the attractiveness of the idea provides internal incentives.

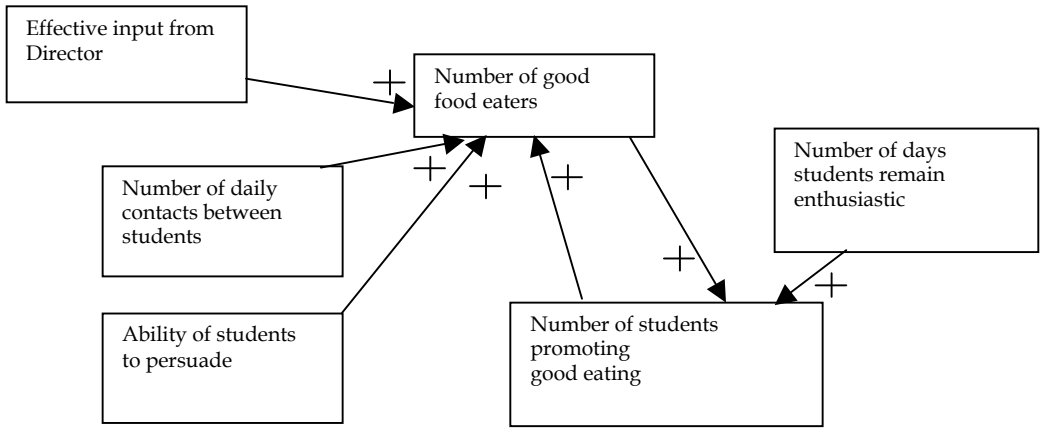
The critical evaluation question, the "puzzle" that the Kellogg Foundation might wish to know is the effectiveness of having a project Director in changing student behavior, rather than just making the food available and relying on word of mouth. In evaluation terms – what was the value or worth of the Director. How much of the Director was "enough" ? Could her time have been used in different ways without greatly affecting the impact ?

Let's assume the project has run for a year or so and we have collected the following information as part of the evaluation :

- Word of mouth does have an effect – about one in every 12 (8%) of conversations between a "converted" and non-converted students seems to result in changed behavior.
- The number of interactions between the students seem to be important in the persuasion process. Generally speaking there are around four discussions per student per day.
- There is a "stickiness issues"' the enthusiasm of students to promote the idea seems to die away five days or so after changing their behavior.
- The Director's input does seem to have a positive impact on the uptake of good food. Everyone praises her efforts and says that without her the project would have been much less successful.
- The number of students who continued to eat healthy food had leveled off around 70% of the student body after about half a term.

So based on these results most evaluations would probably conclude that the project had been a great success and because the Director has been so active in so many ways we assume that she and her resources are critical to the take up of the idea.

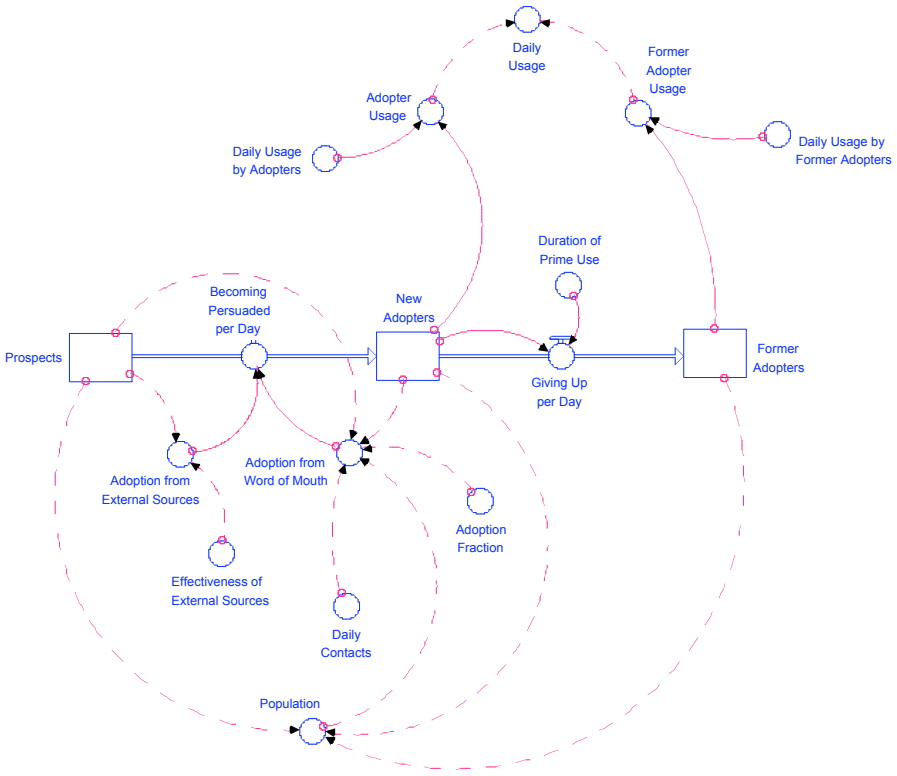
We can construct a causal loop diagram of this:



This is an example of the "static" mapping approach to system dynamics. It highlights some interesting aspects of the issue, in particular suggesting that there is a positive feedback loop operating where more students eating good food can create more interest in that eating behavior. If that was our primary evaluation interest then well and good.

However it doesn't do much to address our particular evaluation questions - what was the value or worth of the Director. How much of the Director was "enough" ? In what way was her input critical ? Could her time have been used in different ways without greatly affecting the impact ? Was she necessary at all ? In other words we have incomplete information to evaluate key aspects of *necessity* and *sufficiency*.

For this we need to turn to dynamic modeling. We can construct our own or borrow one. In this case there is an off the shelf model that we can borrow. The evaluation results and the situation we are exploring closely matches a disease epidemic. Thus we can borrow that model (the Bass Diffusion Model) and plug those parts of the situation that are relevant to our question into it.



You don't need to worry too much about this, but here is the model. You will see it is quite different in expression from the causal loop diagram, but this is because we have to turn it into concepts that can be plugged into a computer model.

An important feature of an epidemic is the "magic number", or "tipping point" Once the system parameters exceeded that magic number, the system would exhibit symptoms of an epidemic – in other words the idea of "good food" becomes contagious. In this case the magic number is :

cidS/N, where

c = the number contacts per day students may have with each other to talk about the idea of good food,
i = infectiousness or attractiveness of the idea (in this case the persuasiveness of the word of mouth),
d = duration or stickiness of the idea (ie how long a student retains excited about the idea enough to "infect" another student)
S/N = initial fraction of susceptible people (ie those who are potentially persuadable).

If S/N is very close to 1 (true at the start, assuming [for example] there are no pure carnivores in the student body who won't eat any vegetables at all and who

are thus immune to the message), then one needs (approximately) cid > 1 to reach the tipping point. While all three factors seem to have equal potential impact, the project will likely have little impact on c, the number of contacts between students each day, so the emphasis should likely be on the infectiousness of the ideas and the duration over which time students are likely to talk about the food with their peers. We will come to the vexed question of the role of the Director later.

An evaluator looking at the Farm to School project might want to understand whether there's a suitable balance between emphasis on c, i, d, and from that get some idea how important the external input (ie the Director) is in changing behaviors.

Let's step through the model to see how that might proceed.

Based on the results from the evaluation will start with setting the parameters as follows :

Number of daily contacts between students = 4
Number of days students actively promote their new changed behavior to others = 5 days
The percentages of interaction that result in a change of use (ie the power of the word of mouth) = 8%

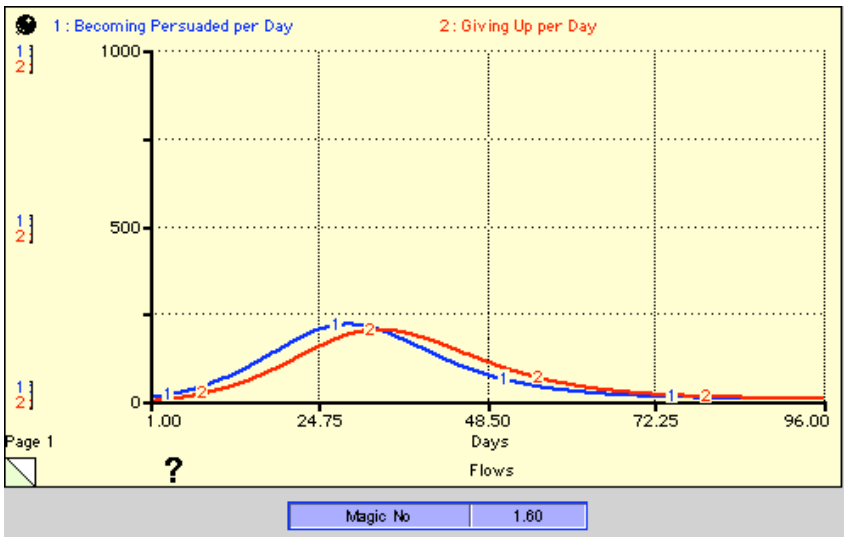
We will also add in a nominal effectiveness of the Director and her promotional budget in persuading students and her budget = 0.001

[This may seem an odd figure, but don't panic. In system dynamics we generally try to use real world figures. However at this early stage of this model where we are interested in how the systems behaves differently by changing the size of the parameters – we can get away with one or two fuzzy figures – in this case a means of expressing the impact of the Director per unit of her effort or time or budget]

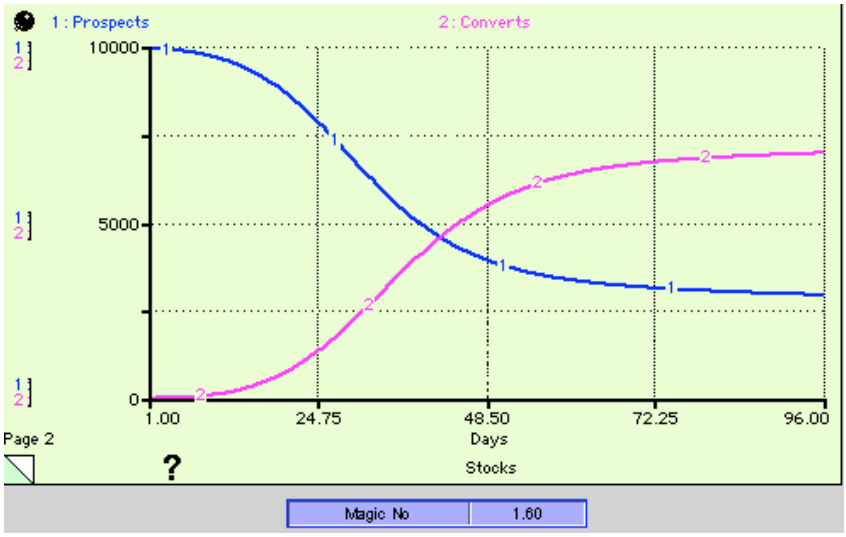
The "magic number" is 1.6, and thus you're somewhat over minimum figure (1.0) necessary to reach a tipping point.

So to recap. The evaluation showed that daily contacts between students is 4. 8% of the contacts between a recent convert to farm-fresh foods and a "normal kid" result in another convert. Each newly converted healthy food eater is excited about it for 5 days (1 week) and talks about it with others. Thereafter, she has assimilated that change and is talking about other new things. Finally, the school Director (the external influence) spends time regularly educating kids through field trips, assembly presentations, flyers, and the like.

Below is the graph of students taking up the good food and those who take up and lose interest. Notice the highest number of take-ups occurs after about 25 days (5 weeks) from the start of the intervention. So already the model is telling us that the progress of the project will not be steady. There will be a delay at the start and its effectiveness will drop off as it progresses [ie the "delayed feedback" that is a common feature of system dynamics investigations]

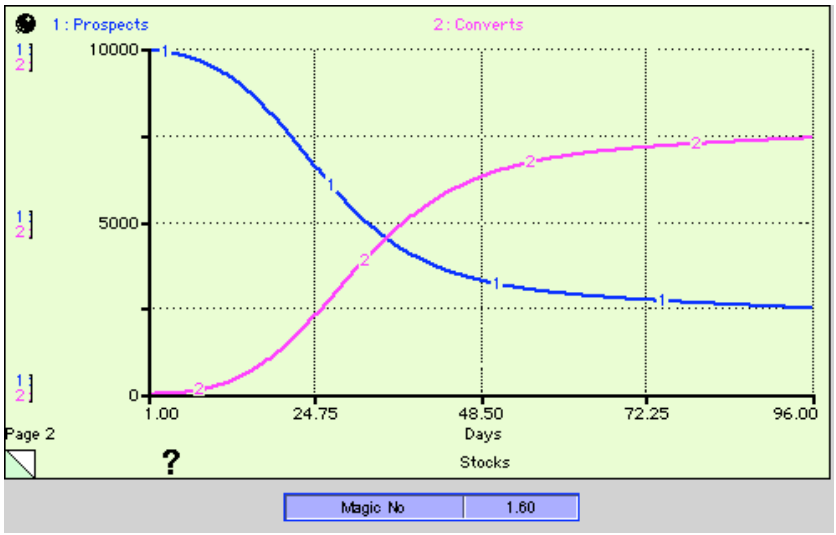


But of course we are really interested in the ultimate impact of the project. When we run the simulation we can see that just over 70% of the audience in this scenario convert to farm-fresh foods in 19 school weeks (ie 5 days per week – we'll ignore weekends for the moment), approximately half a school year.

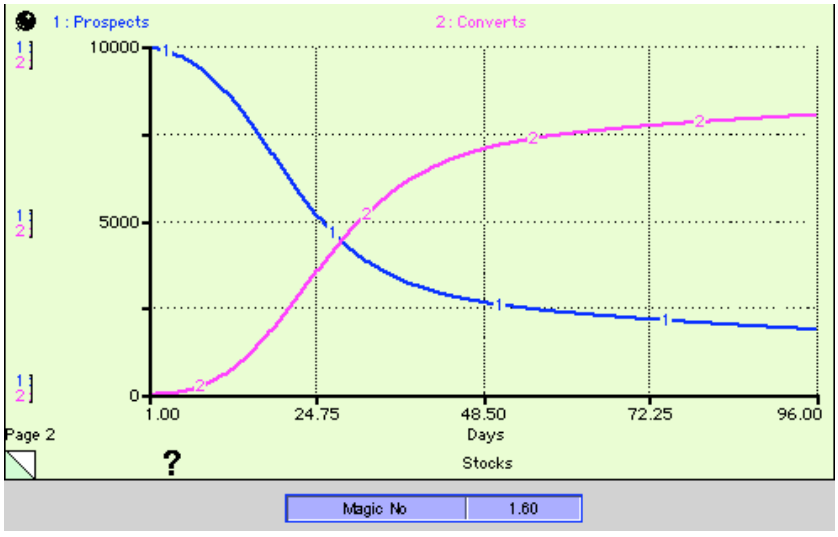


This looks pretty close to the pattern we observed in real life (see earlier), so we can begin to be confident that the assumptions underpinning our model might be reasonably reliable. Given the money poured into this project, we can now begin to ask questions whether it was possible to have had something greater than a 70% take up rate.

Perhaps we should have set the project up with a bigger budget. What might have happened if we had given the Director more resources so that her efforts could have been twice as effective (ie at .002).
What do you think ?

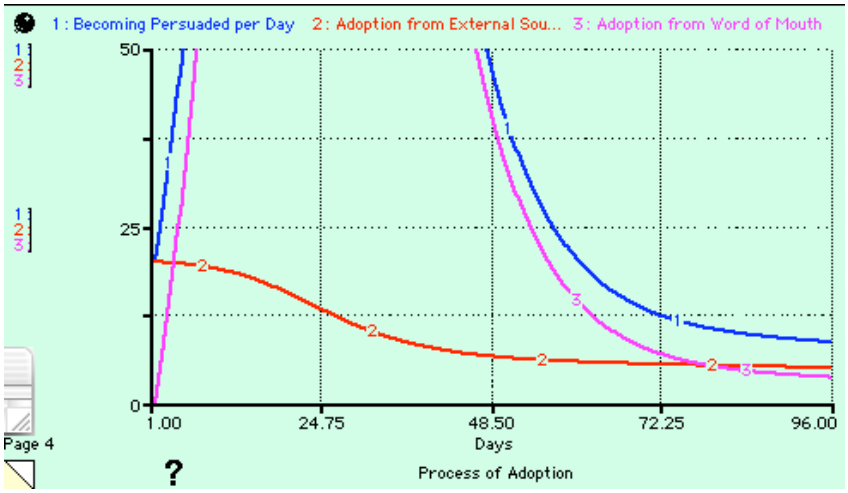


Er, not a lot - we added 5%. Four times ?



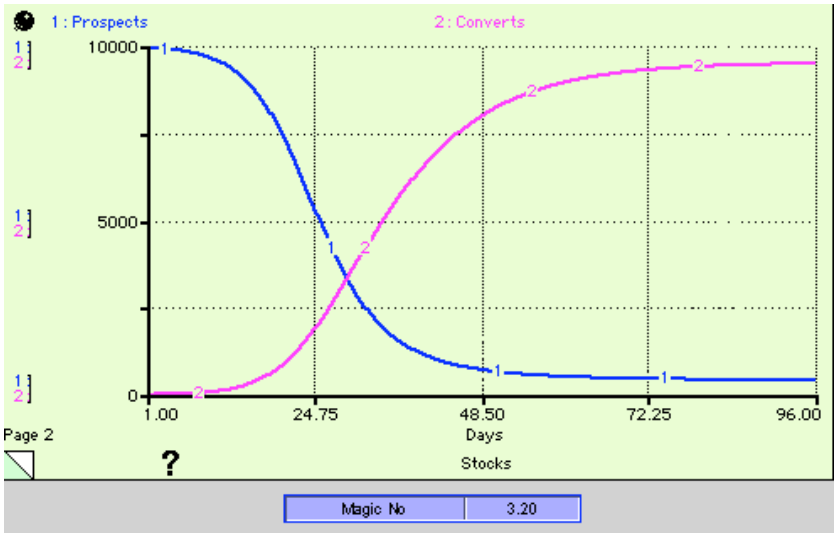
Not bad, we are now in the mid 80's. But requiring four times more impact from the Director and her budget ? Hmm.

Exploring another diagram (see below) we find that increasing the Directors impact/resources increases the *rate* at which kids adopt healthy behavior but it still bottoms out at a fairly low level (around 6 per day). We are now wondering whether the money spent on the Director (and our conclusion of her effectiveness from the raw data) is quite such a good idea after all.

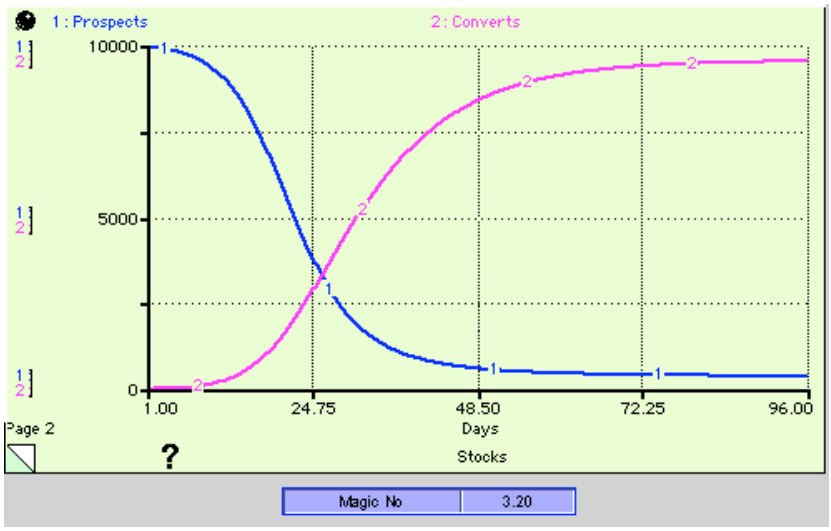


After all we could have done cheaper things. Like made the food more attractive so people stayed enthused longer ? Say for 10 days and not 5.

What do you think might happen? Draw a graph of key variables.
Let's try that out.



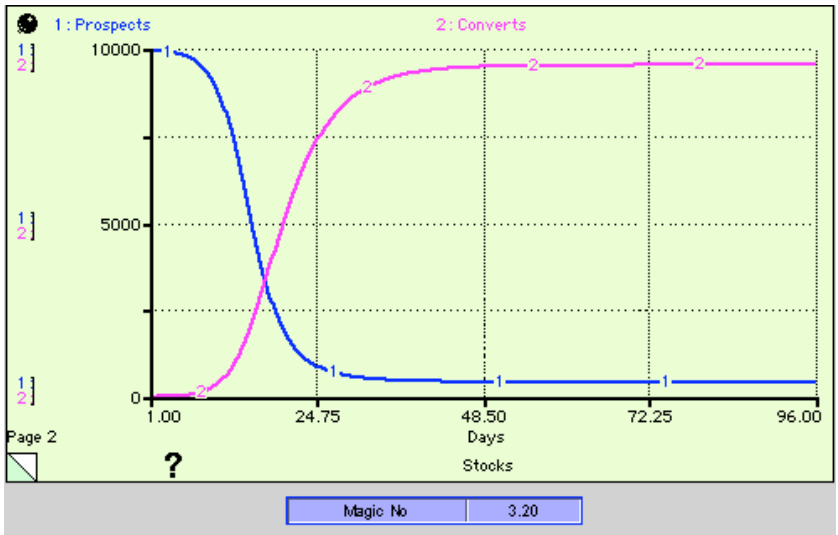
Wow 96%. Now *this time* let's see if we could have hit the jackpot by doubling the Director's impact by increasing her resources.



Oh that's disappointing. Not a scrap of difference.

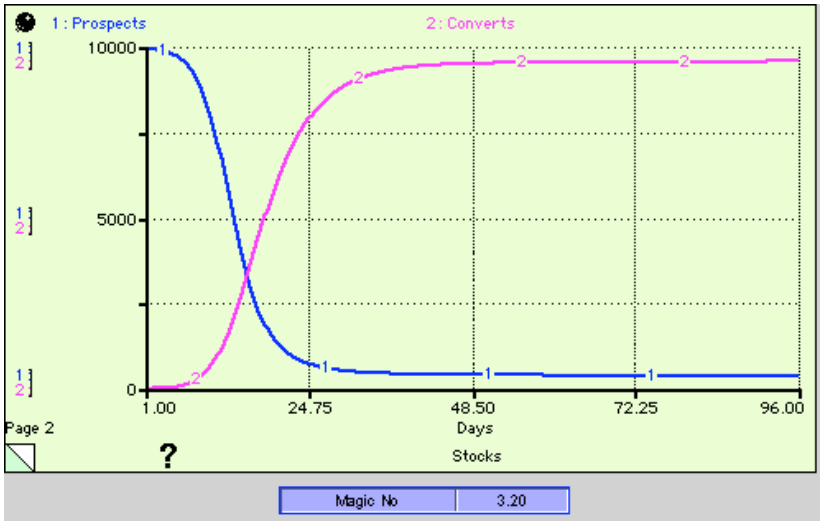
But making the food more attractive is also expensive. Maybe it would have been cheaper to make the word of mouth more effective, say by giving the kids communication training. Let's double their effectiveness to 16%.

What do you think might happen ?



My goodness we get the same effect as improving the food, but we got to the 96% in half the time.

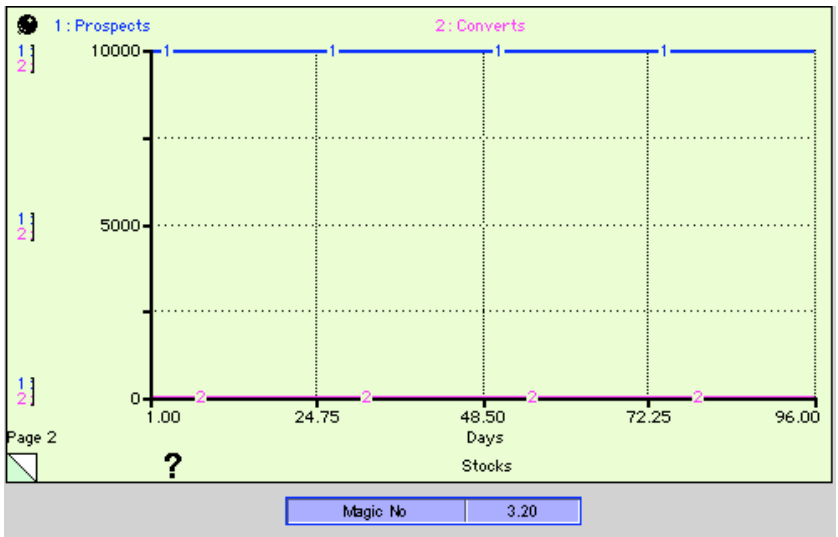
Maybe we can get to 100% this time by doubling the Director's impact.



Nope no difference at all.

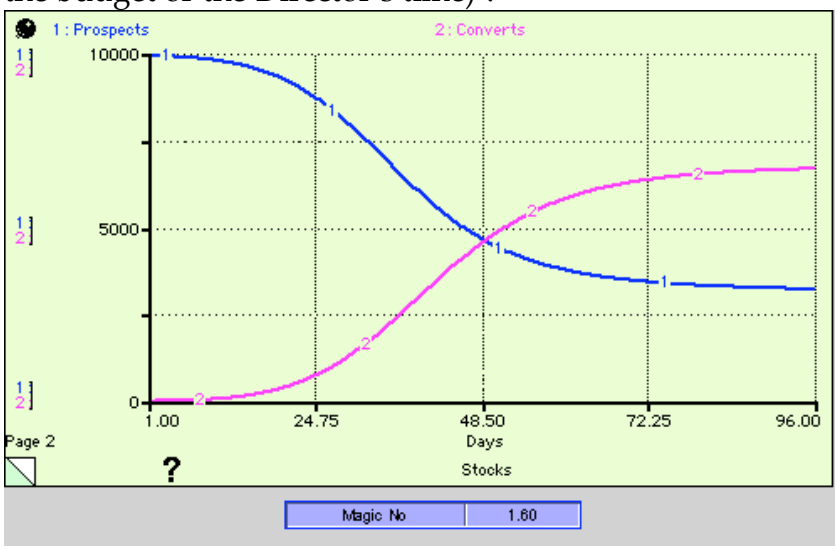
This is all bad news for the Director and her expensive advertising budget, trips and resources kits.

In fact, perhaps we didn't need a Director and her resources at all ? What do you think would happen if the project relied completely on word of mouth, and the availability of good food ?



Ahh. So it is true that nothing would have happened without her, she was worth something after all. But now we are wondering just what's going on here. What would have happened say if she had half the impact, (say perhaps by reducing

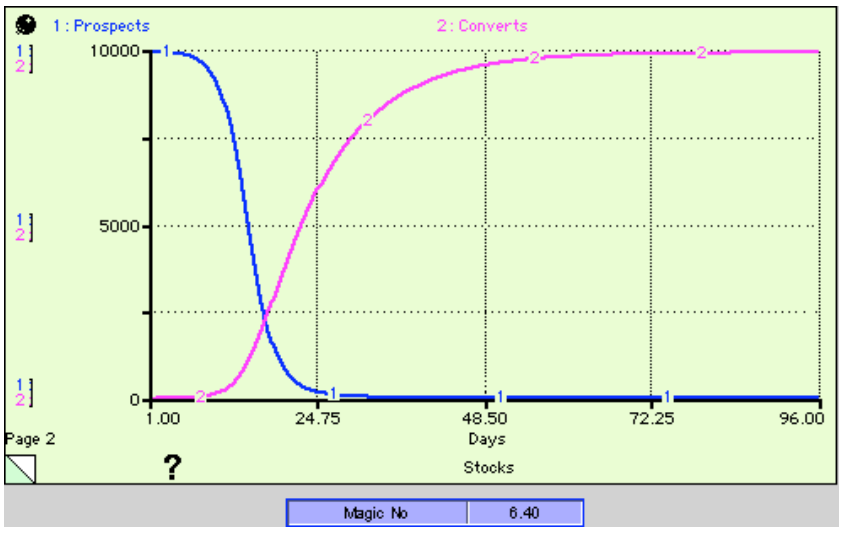
the budget or the Director's time) ?



Oh not a lot of difference. Things proceed a bit more slowly, but we get there in the end.

So it looks like we may have overspent on the Director and her resources. On the other hand the Foundation was willing to put this money into the project. So what could have been the best way of this cash ?

What if we had used had half as an effective Director (fewer time, less trips smaller budget) and put the money into getting better food, and communication training for kids ?



Bingo. We finally hit the jackpot. Not only did we get all the school converted but we did so in two thirds the time.

So, we have a situation where by normal evaluation methods, and perhaps the causal loop diagrams, we would have regarded the project a "success". However, actually it looks like it was only a moderate success, indeed a missed opportunity. We could have been even more effective by diverting the Director's resources and activities into other things. If evaluation is about program improvement *this* is program improvement.

What lessons can you draw from this? Start with your own experiences. What have you learned by working through the model? How did your predictions match what the model suggested? What conclusions do you draw from this exercise?

Lessons learned

Strengths of system dynamics: when would I use it?

Weaknesses of system dynamics: why might I not use it?

Possible uses of system dynamics in evaluation

Things to try when I return home

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At Any Rate™, a column on system dynamics modeling, with an included model

http://facilitatedsystems.com/expmgmnt.pdf

Another introduction into the language of system dynamics, done while describing the solution to a real problem

http://www.uni-klu.ac.at/~gossimit/linklist.php

The SD Mega Link List, a pointer to all things related to system dynamics

http://facilitatedsystems.com/links.html

Find Dietrich Dörner and Harald Schaub's "Errors in Planning and Decision Making and the Nature of Human Information Processing" under the section on System Dynamics

http://facilitatedsystems.com/pubs.html

You can find any of my articles on the subject in the Systems Thinking section