Advanced Dynamic Modeling
Overview of Feedback-based Modeling Process[1]

There are a few variations to dynamic modeling process. They all share the idea of focusing on a problem, starting with a qualitative understanding of the problem, and then building a quantitative model. However they differ in how exactly they tackle the qualitative modeling part. One approach is to focus on key accumulation processes, stocks, in the problem context, and let the feedback loops emerge from assigning causal links that influence the rates. Another is to start with feedback loops that we hypothesize are related to the problem reference mode, and then incorporate the stocks and flows relevant to those loops. It is also possible to combine these two methods (See Wolstenholme, 1994). The current document gives an overview of the feedback-based modeling process which is usually very helpful in working with external clients given the structured nature of this process. You are encouraged to be aware of this process, as well as the alternatives (discussed in Wolstenholme 94 and Sterman 2000) and tailor your process based on the requirements of your project.

What is the "Feedback-based modeling process"? The feedback-based modeling process is the sequence of activities (or the process) that we use to analyze complex problems using the tools of system dynamics. Most top system dynamics practitioners follow processes that are similar to this one, even though different variations can best fit different problem contexts.

Steps in the feedback-based modeling process. The steps of the feedback-based modeling process are:
1) Problem definition
    a) List of variables
    b) Reference modes
    c) Problem statement
2) Momentum policies
3) Dynamic hypotheses (i.e. causal loops)
4) Model first loop
5) Analyze first loop
6) Model second loop
7) Analyze second loop
8) Etc.

Conclusions and insights should emerge at every step. Be sure to record these conclusions and insights when they occur.

Quick example of the feedback-based modeling process. In this example, we'll end up building a classic diffusion model. (If you *don't* know what a diffusion model is, this exercise will show you).

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[1] This process is adapted from "Standard Method" used by Professor Jim Hines. Earlier versions where created by professor Hines in February 1999. Revised February 2001. Revised February 2004. Copyright © 1999-2004 Jim Hines

1) Problem Definition

Our first meeting with the client begins with the vice president of the automated products division, and his direct reports (marketing, manufacturing, research and development). The VP provides some introductions and context.

> "Our Automated Fly Swatter is a great product. But, we need to understand the key drivers in the fly market, so I've hired these folks. Let me just turn it over to them so they can tell us what those key drivers are."

You stand up and say "We don't really don't know anything about fly swatters or even much about flies and very little about your culture, your values, the way you do business. One thing I do know, though, is if this was *my* problem, I wouldn't turn it over to anyone less than the most knowledgeable people on the planet – and that's you guys. The reason I *think* you probably really need us is not because you know too little about the technology, your own company and the market, but because you know too much. You know thousands of things and thousands of ways that they're all interconnected."

"What you probably *need*," you continue, "is some help in talking about what you know and structuring all that knowledge in a way powerful enough so that you can see what the key things are that you really ought to do. If that's what you need, then we're in good shape because what we have to offer is exactly that: A structured process for talking and thinking and for arranging what you know in a way that makes it easier to figure out what to do. Fortunately, you don't have to take my word for it. The process contains a number of steps and the first step is easier to do than to talk about. Should we start?"

a) List of Variables

We begin by simply listing important variables. A variable is something that can go up, go down, or stay the same. For example, "hatred" is a variable. "The Middle East" is not. "Revenue" is a variable. "Strategy" is not. Often when people list a word that is not a variable, they are thinking of an issue. Usually that issue can be converted into a variable. For example, although "Strategy" is not a variable, "clarity of strategy" is.

Listing variables is cheap and fast, so here is one place where you can afford to be comprehensive. Indeed one of the purposes of this step is to avoid the "lever myopia", the tendency to focus on a single cause/solution. Listing variables is an opportunity to think broadly.

When do you stop? You'll notice that at some point the quality of the variables will seem to be declining and the rate at which you're adding new variables will slow. In a group, you'll also notice that the energy fades away. When these things happen, it's time to stop. How do you get more variables? Think of areas of the system that you haven't named variables for, yet.

How many variables will you end up with? The answer will depend on how many people are on your team and on how familiar you and your team are with the system (or similar systems). The more people in the room and the more familiar they are with the system, the longer the list of variables will be. A group will typically produce 50-150 variables.

Note: Do not shy away from variables that relate to emotions, e.g. anger of recording artists at being ripped off.

Slowly at first and then with increasing speed the managers call out variables while you write them on a flip chart, white board, or electronic forum. You record:

Variables List:
- Fly population
- Revenues
- Unit Sales
- Annoyance at flies
- Market saturation
- Manufacturing costs
- Price
- Cost of batteries
- Word of mouth about our product
- Product recalls
- Health problems with our products
- …etc.

Eventually, your managers run out of steam. You call a break, and ask that during the break people mark what they think are the five most important variables.

b) Reference Modes
Returning from the break, you explain that you want to graph the behavior of some of the variables. The group chooses half a dozen of them to plot over time. Why half a dozen? Usually there are only one or two patterns of behavior for a particular system, even very complex systems. So, choosing six makes it likely enough that you'll get those two patterns. Drawing more than six is even more useful, but not that much more useful.

How do you know which six variables to choose? You could probably choose any six variables, so one way of choosing would be to throw darts at the list and choose the variable where the darts land. Most people however like to feel there's a reason for choosing a particular six (and also throwing darts can be dangerous).

Here is the team process that we use for selecting variables:
Choose variables that people think are most important – but don't spend time arguing simply have everyone vote (maybe by checking off) for his favorite four or five variables. The six that get the most votes are the one's you'll plot.

How do we know which is most important? Follow these rules:

1) Given a choice between a variable that is important in and of itself and a variable that is important as a cause, choose the variable that's important in and of itself. For example, if I'm trying to build a model about losing weight, I'd pick fitness level because it's important in and of itself over time spent exercising, which is a cause.

2) Given a choice between a variable that is similar to another variable already chosen and a variable that is dissimilar from all others yet chosen, choose the dissimilar one. To some extent the reference modes are "windows" onto the system. You want windows looking out in as many directions as possible.

Note that the quality of the future analysis will be largely unaffected by which six variables we choose. Further, choosing a variable does not commit us to including it in our model, and that an un-chosen variable (in fact a variable not even on the list) might very well end up being the most central variable in our final model. Making a choice is important to this step, but that the substance of the choice itself is much less critical. Our only concern is to get variables important in themselves and to get a spread over the system.

The availability of numerical data is not a criterion for selecting variables. Choose a variable that is important over a variable for which there is lot's of data. Don't even use data availability as a "tie breaker" between two equally important variables, instead flip a coin. All that's important is that someone in the group knows about how the variable has behaved (if no one knows how the variable has behaved, then the variable isn't very important to the group).

Similarly, measurability is not a relevant criterion for selecting variables. The fact that inventory is easier to measure than morale, is not a reason to choose inventory rather than morale. The only requirement is that the variable is quantifiable, that is as long as it's meaningful to speak of the variable as increasing or decreasing, the variable is OK.

Guidelines for Drawing Reference Modes
1. Draw a pattern not data. The pattern will almost always be smooth. Think of your drawing as a cartoon of what the data would show (what chart would Bugs Bunny have hanging on his office wall?).

2. You should capture the entire pattern of interest. Do not be limited by ancillary concerns such as availability of data or the date by which the boss says the problem must be solved. If the pattern extends began in the past and extends into the future, your reference mode will begin in the past and extend into the future (this is very common).

3. Feel free to draw alternative futures. Often there will be a hope-curve and a fear-curve. (Hope and fear (or good and bad) of course is evaluated from the viewpoint of the client -- another reason that having a client is useful).

4. After you draw the curve, label the horizontal axis with approximate times (or dates). Both parts of the prior sentence are important. In reverse order: Your labels on the horizontal axis will give you a time horizon. Trying to establish a time horizon before

drawing the curve is much harder and will often generate a lot of time consuming, irrelevant discussion.

5. You do not have to put numbers on the vertical axis. Doing so isn't a problem, unless it takes you time to do it. Your time should go into drawing the curve(s).

6. If people on your team disagree about what the history looks like, no problem. If people are drawing essentially the same pattern, let the person who put forward the variable decide (and quickly). If the patterns are different (e.g. one goes up and the other goes down), make sure your teammates are talking about the same thing. If not, the person who put the variable forward defines what that variable is (see item 1). (Other people, if they insist, can draw additional variables later). If people are talking about the same thing and simply have different beliefs about what happened in the past, draw each separate belief (labeling who's curve is which).

7. If your team finds it easier to draw a variable that's slightly different from the one on your list, no problem. Draw that one instead.

For example, one of the reference modes might be
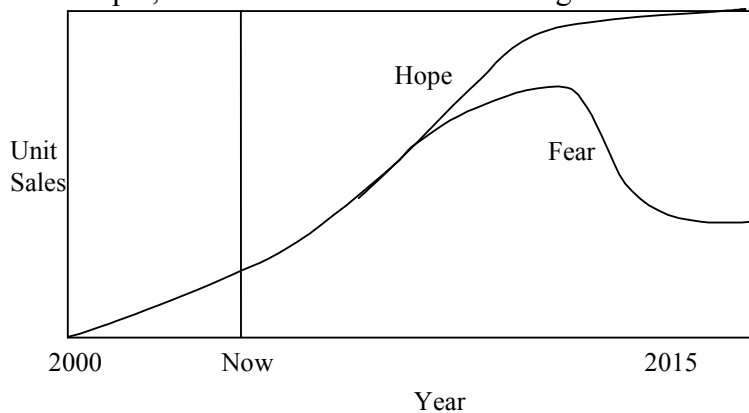
c) Problem statement
One or more of your reference modes almost certainly will contain the true concern of the clients. You phrase it to the group, but you don't write it down, after all a picture is worth a thousand words. You just point to the curve and say:

> We hope that the initial growth trend of AFS sales continues and that the product ultimately becomes a stable, high-volume seller. But we're worried that sales, after appearing to be on track, might take a nosedive leaving us with mediocre or low sales, and way too much capacity. If we are successful in our project here we will increase the likelihood of the curve labeled "hope" and decrease the likelihood of the curve labeled "fear".

2) Momentum policies. *Momentum policies* (i.e. solutions) are what the client would implement now to solve the problem, if they had no further time to collect information or

ponder. Once you have a problem focus, you are in a position to collect momentum policies.

The term "momentum solution" is meant to convey two things: First these are solutions intended to fix a problem and second these are the solutions that the current momentum of thinking would suggest. For a policy to be a momentum solution all that's required is that someone associated with the client organization (including consultants) thinks the solution would be a good idea. It's not required that everyone agree that the solution is a good one; it's not required that everyone even be aware of the possible solution. It's enough if someone believes such a solution would be helpful to the client.

Continuing with our example, you point out to your client that the system dynamics process has already added something by crystallizing the problem. You explain, though, that you would like to be able to gauge at the end of the process, whether anything beyond this additional specificity has come out of the project. Consequently you'd like to record what the client would do *now* about the problem, if decisions had to be made *immediately*.

You record ideas like:
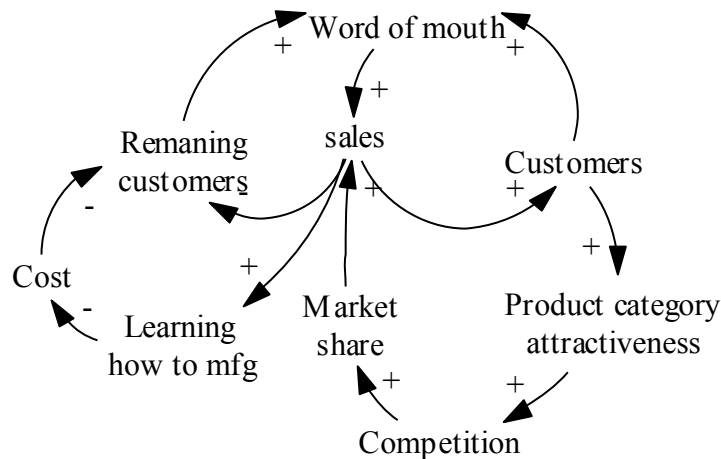> "We need to do a market study"
> "We should start a competitor intelligence unit"
> "We need to get data on the drivers of the market"
> "We've got to get better forecasts from the Economics Group".

Note that these policies are not all well thought out, and some are not even policies. No problem, simply record them. You might want to use them to suggest tests or directions of inquiry, but at least (and in most cases at most) you will pull them out ten weeks from now to say, "look how far we've come".

3) Causal loop diagram. With variables, reference modes, and a problem-focus, you will be in position to start coming up with dynamic hypotheses; that is, loops that describe feedback processes capable of generating the patterns in your reference modes. Coming up with a diagram will take several weeks, and will likely result in a number of insights and good ideas.
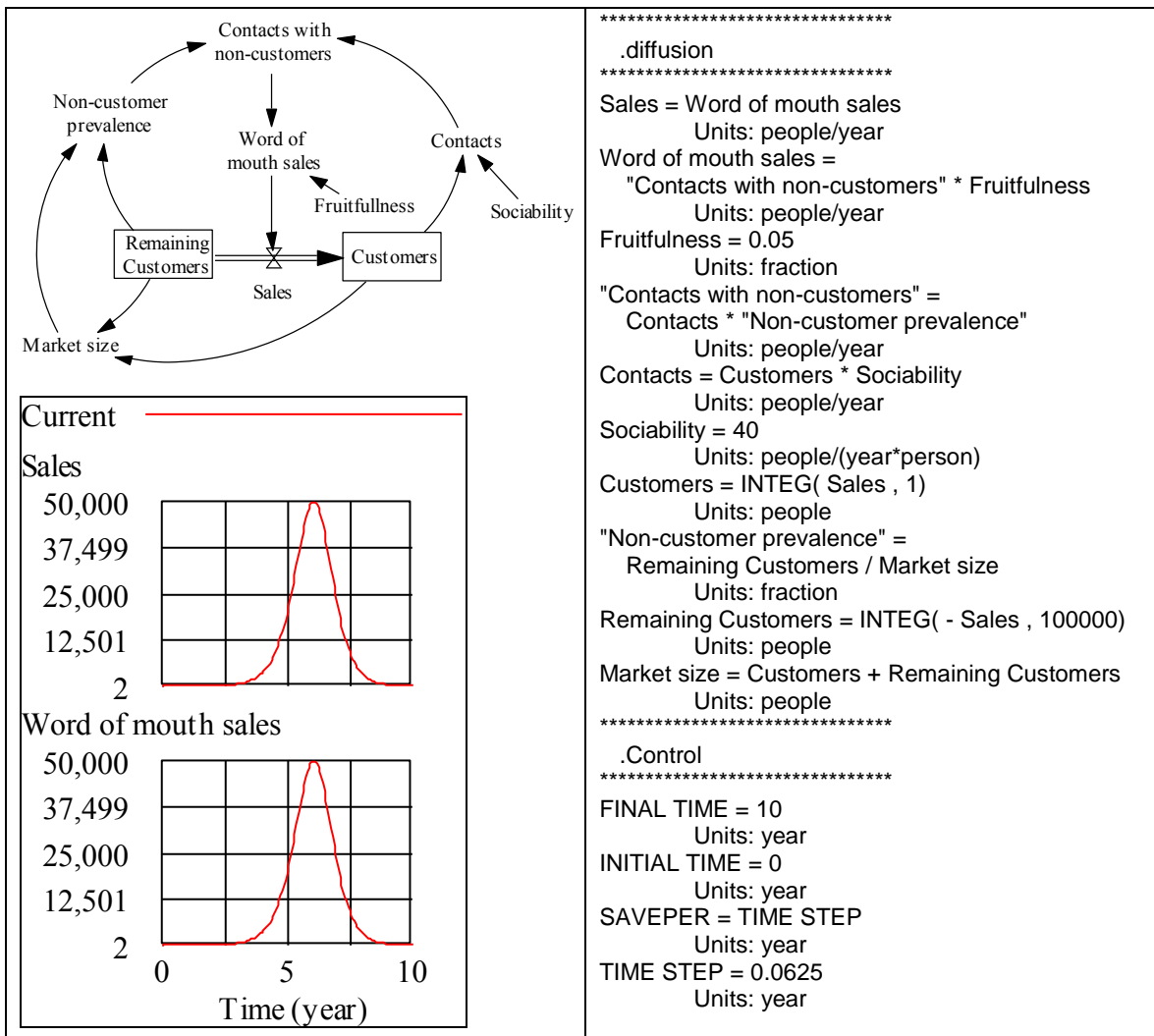
Word of mouth

+   +

+

Remaning
customers   sales   Customers

−   +

+

Cost   +

Product category
attractiveness

−   Learning   Market
how to mfg   share

+   +   +

+

Competition

Again remember to record insights as they come up. For example: "The learning loop counteracts the running-out-of customers loop" and "We can strengthen the word-of-mouth loop with a sign-up-a-friend promotion".

4) Modeling
Finally, after having extracted a set of dynamic hypotheses, you will be ready to model. By this time, your clients realize that the model is not the actual objective, rather the process is. The modeling is simply the next step in the process, it may help people refine some of the insights you've already recorded, it will probably result in additional insights, but it probably won't contradict any of the insights you've already had.

Here's what you'll do: You will choose a loop, model it, simulate, analyze, and work with your client to develop insights and ideas. Then you'll choose another loop, add it to your growing model, simulate, analyze again, and work on further developing new or existing ideas.

You will probably only have time to model two or three loops. As always you'll record insights and conclusions as you go along. For example, "Strengthening the positive word-of-mouth loop creates a faster rise and a deeper collapse." and "Replacement sales may lesson the severity of the down-turn in sales".

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*******************************
  .diffusion
*******************************
Sales = Word of mouth sales
         Units: people/year
Word of mouth sales =
   "Contacts with non-customers" * Fruitfulness
         Units: people/year
Fruitfulness = 0.05
         Units: fraction
"Contacts with non-customers" =
      Contacts * "Non-customer prevalence"
         Units: people/year
Contacts = Customers * Sociability
         Units: people/year
Sociability = 40
         Units: people/(year*person)
Customers = INTEG( Sales , 1)
         Units: people
"Non-customer prevalence" =
      Remaining Customers / Market size
         Units: fraction
Remaining Customers = INTEG( - Sales , 100000)
         Units: people
Market size = Customers + Remaining Customers
         Units: people
*******************************
  .Control
*******************************
FINAL TIME = 10
         Units: year
INITIAL TIME = 0
         Units: year
SAVEPER = TIME STEP
         Units: year
TIME STEP = 0.0625
         Units: year
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You may find that the modeling leads to the best insights. Or you may find in retrospect that the causal loops, or even the reference modes, was the source of the most important insights and conclusions. You may find that some people involved in the process liked the modeling best and others liked causal looping or something else best. The important lesson from this is that the model is *not* the goal of the engagement. The goal is to use the entire process to help the client. Modeling is just one piece – in any particular situation it might provide the brightest illumination, but in another situation a different part of the process might turn out to be the real source of light, and in yet another situation, the entire process may shine with a uniform brilliance.

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