BWeb Notes for Chapter 9:
Information Feedback and Causal Loop Diagrams

(two notes)

1st Note, page 110: variety of mathematical methods on loop dominance

System dynamics models are comprised of a combination of feedback loops that control the dynamic behavior. Many readers have come to expect that certain loops will dominate the behavior of system dynamics models during different phases of the simulation. (These readers would be comfortable with an image like the scales in Fig. 9.20).

Although practitioners may have shared expectations, we are not necessarily well equipped to identify the key loops in a rigorous manner. Richardson (1986, 1996) describes the search for "dominant structure" as one of the top research challenges for the field. David Ford (1999) describes a behavioral approach to identify dominant feedback loops based on the concepts of atomic behavior patterns. Other researchers have reported on automated analysis tools that rely on eigenvalues to characterize the modes of behavior:

- Nathan Forrester (1983) describes a formal link between the strength of a feedback loop and the system eigenvalues using the ***eigenvalue elasticity***. The elasticity represents the relative change in the eigenvalue that results from a relative change in the gain around the loop. The elasticity of the real part of the eigenvalue impacts the rate of decay or growth of the state variable. The elasticity of the complex part of the eigenvalue impacts the oscillatory behavior. For example, if the complex part is positive, an increase in the loop gain leads to an increase in the frequency of the oscillations.

- These ideas are explored by Kampmann (2004) in a working paper which applies loop elasticity analysis to a model of the economic long-wave. Kampmann states that eigenvalue elasticity analysis yields insights beyond "old-fashioned intuition."

- Goncalves (2005) also addresses the causes of oscillatory behavior. He shows eigenvalue evolution plots in a case study of capacity utilization at a semiconductor manufacturer. He states that eigenvalue analysis yields pragmatic insights especially when the plots show "sharp transitions from real to complex eigenvalues."

- Guneralp (2006) presents a ten-step approach for analysis of loop dominance which uses a combination of software programs (Vensim, C language and MATLAB). Guneralp illustrates the approach by showing the evolution of loop dominance in a model of predator-prey cycles and in a model of the economic long wave.

More recent papers on EEA (eigenvalue elasticity analysis) are available here for downloading:

- The review of EEA methods by Kampmann and Oliva (2008),

- A demonstration of EEA for better understanding of behavior modes by Goncalves (2009), and

- A demonstration of EEA as a policy intervention tool by Saleh (2010).

A different method for loop analysis was created by Mojtahedzadeh (2004) and implemented in Digest, a software which accepts the list of equations generated by one of the standard system dynamics software packages (i.e., Stella, Vensim, and Powersim). "Once a text version of the model equations has been edited and accepted by *Digest*, the software leads the modeler through a series of step-by-step procedures that use the PPM calculation to first detect and then display model structure." PPM stands for the ***pathway participation metric***, "a mathematical calculation that can help to identify the linkages between the structure and behavior of a dynamic system." Mojtahedzadeh argues that "pathways, links of causal structure between two system stocks" may be envisioned as the primary building blocks of influential structure. Mojtahedzadeh (2008) provides a comparison the PPM and eigenvalue elasticity methods using four case studies. He concludes that, despite the diversity of methods for model analysis, "recent studies indicate a considerable convergence in the results they produce."

A third approach is ***statistical screening***, the method described by Ford and Flynn (2005) and described in Appendix D of the book. Statistical methods are used to identify the model parameters that are most strongly correlated with model outputs at different times in the simulation. The 2005 paper explains the method in detail with illustrative results from the sales model in chapter 7 and the World3 model from The Limits to Growth. The 2005 paper also shows illustrative results for a small model of industrial growth to permit a comparison with the PPM approach by Mojahedzadeh (2004). The statistical approach relies on efficient sampling methods (i.e., Latin Hypercube Sampling) to learn the behavioral tendencies in a limited number of simulations (ie, 50 or 100 runs). The simulations are then exported to a spreadsheet to learn the most important inputs to the model.

Those interested in the dominant loops would then use their judgment to make the correspondence between key inputs and key loops. Tim Taylor describes how this may be done by following a six-step process for screening and interpretation. He then illustrates the process for a model of diffusion of innovation. The process is further illustrated in a screening analysis of a project management model which shows tipping points due to overwhelming rework backlogs. Taylor (2010, 85) concludes that

statistical screening offers an easy and objective method to efficiently identify high leverage model parameters. With good judgment, these high-leverage parameters can be connected with key model structure, leading to improved understanding of the existing model as well as productive avenues for model improvement.

The 2nd Note is on page 111: warning about confusion over an "influence diagram"

An ***influence diagram*** is sometimes viewed as similar to a causal loop diagram, especially if one is focused on a decision problem. According to Lumina Analytica, an influence diagram is a simple, visual representation of a decision problem. Influence diagrams are said to "offer an intuitive way to identify and display the essential elements, including the decisions, uncertainties and objectives and how they influence each other." But the arrows in these diagrams do not have the same meaning as the arrows in causal loop diagrams. According to Lumina Analytica:

An arrow denotes influence.
A influences B means that knowing A would directly affect our belief or expectation about the value of B. An influence expresses knowledge about relevance.
It does not necessarily imply a causal relation, or a flow of material, data or money.

The focus of these diagrams is the "decision problem," and decision problems are often displayed in the form of a decision tree. The Lumina Analytia webpage presents a useful comparison of the influence diagram and a decision tree.

System dynamics models can certainly be put to good use to simulate the outcomes involved in a decision problem. Fig. 1 illustrates with a decision problem from the 1980s at the Bonneville Power Administration. The diagram is a decision tree with a single decision node and four uncertainty nodes. The decision was characterized as selecting between a "blitz" program for conservation (efficiency) programs and "no further incentives." System dynamics was used to show the simulated outcomes for metrics of importance to utilities and consumers in the Pacific Northwest (Ford and Bull 1989).

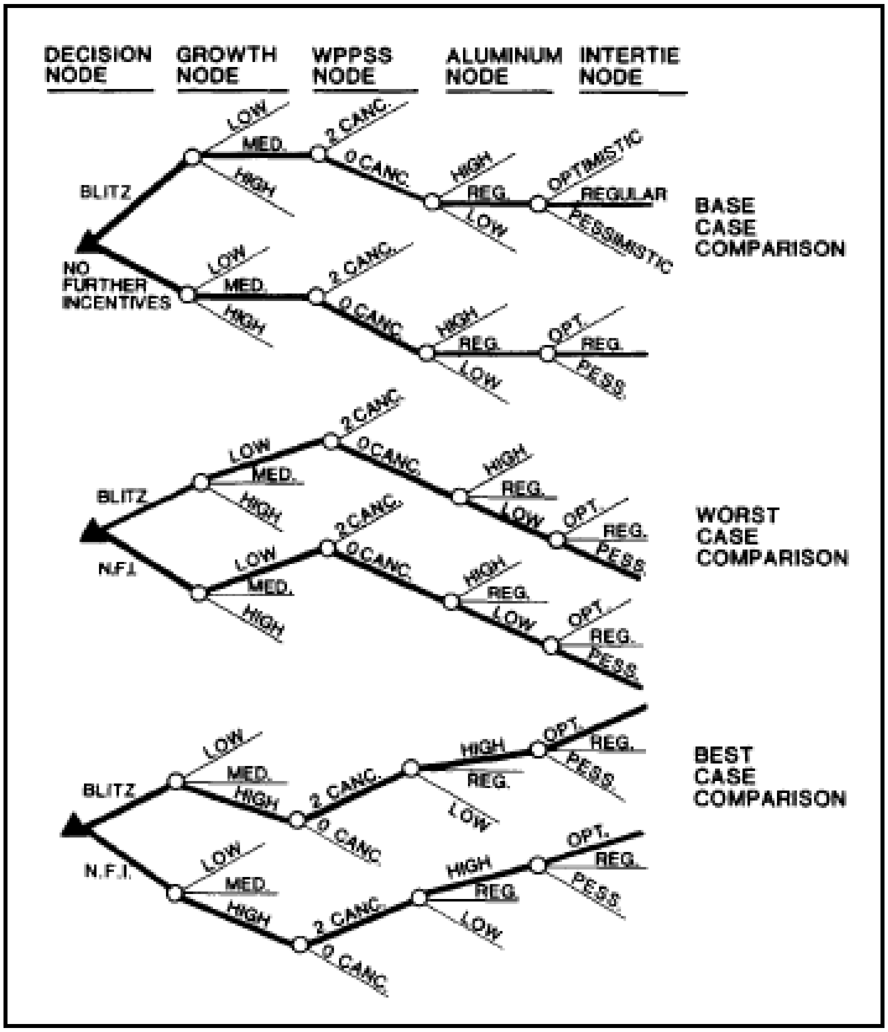

Fig. 1. Decision tree for the conservation program decision-making at the Bonneville Power Administration (Ford and Bull 1989)

System dynamics and decision analysis can be used together to inform planners and policy makers. But to avoid confusion, the causal loop diagrams used in system dynamics should not be mistaken for the influence diagrams that are familiar to the decision analyst. The arrows in causal loop diagrams do represent causal connections and they may represent the flow of material, data or money. The purpose of the causal loop diagram is to draw our attention to the feedback structure of the system, not to the structure of a particular decision problem.

References:

Ford 1999
David Ford, A Behavioral Approach to Feedback Loop Dominance Analysis, System Dynamics Review, Vol 15, No 1, Spring 1999, p. 3-36.

Ford and Bull 1989
Andrew Ford and Michael Bull, Using system dynamics for conservation policy analysis in the Pacific Northwest, System Dynamics Review, Vol 5, No 1, Winter 1989.

Ford and Flynn 2005
Andrew Ford and Hilary Flynn, Statistical screening of system dynamics models, System Dynamics Review, Vol 21, p 273-303

Forrester 1983
Nathan Forrester, Eigenvalue Analysis of Dominant Feedback Loops, The 1983 International System Dynamics Conference, System Dynamics Society, Albany, NY.

Goncalves 2005
Paulo Goncalves, Jim Hines, and John Sterman, The Impact of Endogenous Demand on Push-Pull Production Systems, System Dynamics Review, Vol 21, No 3, Fall 2005.

Gonçalves 2009.
Paulo Goncalves, Behavior modes, pathways and overall trajectories:
eigenvector and eigenvalue analysis of dynamic systems. System Dynamics Review
25: 35-62.

Guneralp 2006
Burak Guneralp, Towards Coherent Loop Dominance Analysis: Progress in Eigenvalue Elasticity Analysis, System Dynamics Review, Vol 22, No. 3, p 263-280-20, Fall 2006.

Kampmann 2004
Christian Kampmann, Feedback Loop Gains and System Behavior, working paper from the Center for Applied Management Studies, Copenhagen Business School, May 2004.

Kampmann and Oliva 2008.
Christian Kampmann and Rogelio Oliva. Structural dominance analysis and theory building in system dynamics. Systems Research and Behavioral Science 25: 505-519.

Mojtahedzadeh 2004
Mohammad Mojtahedzadeh, David Andersen and George Richardson, Using Digest to Implement the pathway Participation Method for Detecting Influential System Structure, System Dynamics Review, Vol 20, No. 1, p 1-20, Spring 2004.

Mojtahedzadeh 2008
Mohammad Mojtahedzadeh, Do parallel lines meet? How can pathway participation metrics and eigenvalue analysis produce similar results? System Dynamics Review, Vol 24, No. 4, p 451-478, Winter 2008.

Richardson 1986
George Richardson, Dominant Structure, System Dynamics Review, Vol 2, No 1, p 68-75, 1986.

Richardson 1996
George Richardson, Problems for the Future of System Dynamics, System Dynamics Review, Vol 12, No. 2, p. 141-157, 1996.

Saleh 2010
Mohamed Saleh, Rogelio Oliva, Christian Kampmann and Pal Davidsen, A comprehensive analytical approach for policy analysis of system dynamics models. European Journal of Operational Research 203: 673-683.

Taylor 2010
Timothy Taylor, David Ford and Andrew Ford, Improving model understanding using statistical screening, System Dynamics Review, Vol 26, No 1 (Jan-March 2010), 73-87.