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Digest: A New Tool for Creating Insightful System Stories

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Abstract

Creating insightful feedback rich system stories for strategy formulation and conducting model-based dialogues aimed at the advancement of a shared vision call for a shift in focus from detail complexity to dynamic complexity. One way to master dynamic complexity is to divulge the dominant structure within a mass of interrelationships in a system dynamics models. Despite its importance, tools for understanding the linkages between the structure and dynamic behavior in simulation models are lacking. A new software approach, *Digest*, is developed to bridge this gap. In this presentation, we introduce *Digest* and demonstrate how it can help you pinpoint the most influential feedback loops as the behavior of your model unfolds. Just save the equations of your model, built in any system dynamics software package, as a text file and watch how shifts in loop dominance give rise to the dynamics of the system.

Introduction

Imagine you have built a running System Dynamics simulation model. The model is developed to tackle a very important and persisting problem in your organization. It captures the principal cause-and-effect interrelationships that characterize the system under study. You are aware that the model is a "good enough" representation of the real system. You can easily simulate the model and see the behavioral consequences of the structure in the form of graphs over time. The over time behavior of the most variables appear to be sound and correct. The historical data shows a close correlation with the simulation results. The future patterns simulated by the model are acceptable. You know that patterns of behavior are driven by the structure and nothing but endogenous processes have generated the behavior.

In the processes of developing your model, you have been in touch with a few thinking skills: you have gone through operational thinking that assisted you to highlight the integration or accumulation points and you have learned how those integration points are determined. You have then closed the loop and discovered how changes in a variable can influence other variables and ultimately lead to a bigger or a smaller change in the same variable. Thinking dynamically was another step that your modeling exercise has walked you through. By simulating your model, you conceived the dynamics of the structure. Now you may have learned a lot about your problem. You can take another step and begin to examine the effectiveness of various policies in changing the behavior of the model to some patterns that are more desirable. Going through a few exercise enables you to come up with strategies that could potentially solve your persisting problem and move the system to a superior state.

What you have at hand is indeed valuable. The battle, however, is not over. The next challenge is the implementation of what you have learned from your modeling exercises. Even noble strategies if they are not implemented, have little merit in solving prevailing problems. Your success in putting your strategies into practice depends on how convinced the individuals in the organization are about your assertions on the effectiveness of the new strategies. One can not "sell" insight just because it is developed through a good modeling exercise. "The model say so, thus, let's do so" does not seem to bring much success in practice. Insights infused by models have to make sense; it must be "communicable". If so, managers discover new vicinity to think about. This may lead to a shift of focus, which ultimately influences the decisions. The challenge in the implementation phase is, therefore, how to make sense using a language by which you could easily communicate your discoveries achieved by model building. Being able to share what you have learned from your model calls for a shift of attention from detail complexity to dynamic complexity. This of course does not mean that details about the structure do not matter, rather it indicates the need for organizing complexity into coherent story that illuminates the cause of the problem in a way that managers could easily grasp.

What you have done in the process of developing your model was basically overcoming the detail complexity by restructuring and reorganizing a mass of information that characterize your system. The outcome is a better understanding of dynamic consequences of the underlying structure of the system. The hurdle, which remains untouched, is to communicate the insight gained by the model in an effective way with others. What you have learned through this experience is subtle and the ability to disseminate and communicate among the people who did not have the same experience could be troublesome. The question is that "is it possible that non-modelers learn lessons ingrained by models without mastering those skills that are required for model building?" If "yes", what are the skills that non-modelers must learn in order to be able to get at the understanding that good model builders attain? What sort of technology is needed to make the dialogue among modelers and non-modelers possible? Is the language and techniques that modelers engage appropriate for such purpose?

Overcoming the Complexity

During the last 45 years a large body of literature has been developed to help people in uncovering the "right way" to take on complex problems. The fundamental assumption in the literature is that formal models, including system dynamics models, facilitate attaining effective policies for solving prevailing problems. What models do in the process of problem solving is reorganizing and restructuring available information that exists in managerial mental models. The argument is that while complex systems carry enormous variables, connections and relationships within a system, the mental models of managers and analysts are singularly ill-prepared to comprehend the complexity of reoccurring processes. There seem to be a consensus that the mangers' mental model has this information, however, they are not organized in a way to produce the knowledge necessary for managing their organization. Senge (1990) suggests that "... The increasing complexity of today's world leads manager to assume that they lack information to act effectively." Senge adds "I would suggest that the fundamental 'information problem' faced by managers is not too little information but too much information."(p. 128).

What is needed to overcome the mass of information is a framework to organize and process the available information in a way that expands the ability to produce the results policy makers really want. Forrester (1968) writes, "Without an integrating structure, information remains a hodge-podge of fragments. Without an organizing structure, knowledge is a mere collection of observations, practices and conflicting incidence." The contribution of system dynamics approach is to provide a framework to organize and structure available knowledge about the complex systems to produce a better understanding of the system. For such purpose a few thinking skills are required which described in details by Richmond (1997), Senge(1991), and Richardson (1981). To some extent, these skills are recognized as at least three folds: operational thinking; feedback loop thinking; and dynamic thinking.

The basic principle of organizing knowledge in system dynamics approach lies in differentiating stocks from flows and how flows are determined. Identifying the integration points facilitates understating a source of dynamic behavior in the system. An example can reveal the contribution of stock-and-flow exercises in learning about complex systems.

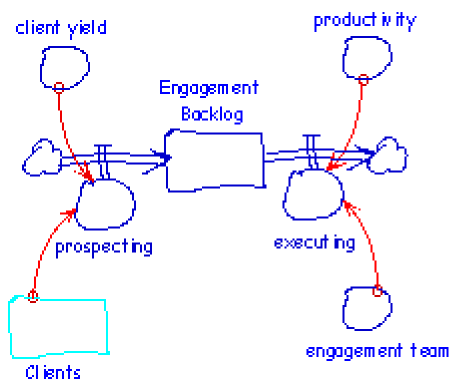

Figure 1: A simple stock-and-flow structure for Engagement Backlog

Figure 1 depicts a simple stock-and-flow structure for engagement backlog. This simple structure tells a story about the engagement backlog in a consulting firm: Engagement backlog increases by prospecting rate and decreases by executing rate. Prospecting is a product of the number of clients and client yield. Executing rate depends on engagement team efforts. It is determined as a product of the size of engagement team and their productivity.

A stock-and-flow diagram shows flows and accumulations, which are essential in creating the dynamic behavior of a system. It also gives a brief description of how flows of the system are determined. Stock-and-flow diagrams accelerate what Richmond (1994) calls operational thinking. In operational thinking one not only identifies the integration points, but focuses on how the flows, like prospecting in the above example, in the system are determined. Stock-and-flow diagrams divulge and visualize the scope and breadth of our thinking about a system as we attempt to investigate a problem.

Although stock-and-diagrams indicate the integration points, they may not reveal reinforcing and balancing feedback loops that are present in the system. Feedback loop diagrams, in turn, convey information about feedback loops and circular causality in a system. Feedback loop thinking skill is being used to explore how the operating system at the present time is impacted by its past. In feedback loop thinking also dynamic thinking skill is implicit; each feedback loop has its behavioral implications, however, the overall dynamics of the whole structure remains ambivalent. Feedback loop thinking help us to understand how a variable can influence other variables and in turn they changes the original variable.

Figure 2 shows a feedback loop concerning employee layoffs in an organization. The feedback loop states that increasing layoffs leads to a decrease in employee confidence. Booming employee confidence causes an increase in anxiety. As anxiety raises, the employee performance declines, which in turn can lead even to more layoffs.

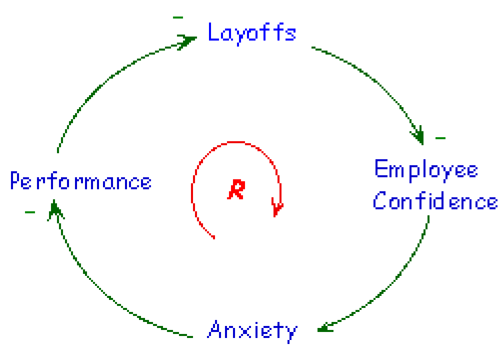

Figure 2: Employee-layoffs feedback loop

The story told in Figure 2 is based on how layoffs and anxiety interact and reinforce both layoffs and anxiety. The nature of information conveyed by Figure 1 is different than that of Figure 2. Whereas a stock-and-flow diagram focuses on how variables like engagement backlog, prospecting new engagement and executing are determined, the focal point of a feedback loop is that how changes in a variable like layoffs can lead to a bigger change in layoffs. Both types of information are constructive in learning about complex systems. Both diagrams organize available knowledge about a system that is disrupted otherwise. Both forms of information contain details on how different parts of the system are connected. Both type of information is captured in a full simulation model.

Tacking to Dynamic Complexity:

Neither stock-and flow-diagrams which reveal flows and accumulations nor feedback loop diagrams that sketch interactions in a system illuminate the dynamic consequences of inter-relationships as a whole. In a complete system dynamics model, various pieces of the structure are defined with enormous details. While each piece is associated with an over time behavior, the dynamics of the whole system is the result of the interactions between all the feedback loops and stock-and-flows in the system. Once details about the structure of a system are captured and formulated, the dynamics of the system can be determined. Computer simulation allows us to reveal the over time behavior of various variables. At this stage, we have much information about the structure and we know the overall dynamic of the whole structure. When teeing up the structure we are aware that individual pieces would do what, but in examining the behavior, we have little information as to what piece is doing that. Getting at the pieces of the whole system that is mainly responsible for creating the behavior help tacking to dynamic complexity.

The fundamental principle for creating insightful system stories is to integrate what you have learned from operational thinking, feedback loop thinking, and dynamic thinking. In stock and flow thinking, we tell stories about how market share is operationally determined. What do we exactly mean by profitability? What influences quality and how it can be change? Those are the questions that operational thinking can help in finding good answers for. But the answers have structural orientation. Although stock-and-flows have dynamic implications, they are weakly connected to the behavior of the whole system.

In feedback loop thinking, in the other hand, the story is based on how low profitability could influences other variables like insufficient investment and ultimately lead to a lower profitability. Again, feedback loops are dynamic concepts; they are associated with some sort of behavior, but they alone have little connection with the behavior of the system as a whole. The focus in both stocks-and-flow and feedback loops is in detail complexity, if they are not linked to the overall behavior of the whole structure.

In coupling behavior and structure, the focus shifts from detail structural complexity to dynamics complexity. Attention is on the part of the structure that is mainly responsible for creating the dynamic behavior of the system. The story being narrated in this stage is based on why a variable like profit is rising or falling. What is making the market share to grow? Why quality of products and services remain low despite efforts being made for its improvement? Perhaps, the key to improving managerial mental models is the ability to ventilate insightful and precise stories that trace out how the feedback structure of an organization or social system generates over time the dynamic behavior that characterize such an organization or social system (Senge, 1990)

How Can We Effectively Create System Stories?

Despite its importance, tools for understanding the linkages between the structure and dynamic behavior in simulation models are lacking. The only practical way to generate system stories about the linkage between system structure and system behavior is via repeated simulations guided by hypotheses generated by experienced modelers. Years of experience with system dynamics models is needed for launching artful hypotheses and testing them via repeated simulation but no satisfying accounts exist in the published literature prescribing a precise set of steps for completing this key task. Even for experienced modelers, the difficulty persists in the testing of their hunches about the connection between structure and behavior. Advanced mathematical analysis of dynamic models has their own drawbacks. They may not reveal, in an effective way, what managers need to learn from their models about the real system.

A new software approach, *Digest*, is developed for the researchers to bridge this gap. *Digest* uses the pathway participation techniques developed in Mojtahedzadeh, 1997, traces out the most influential feedback loops in a structure. In this section, we briefly introduce a classic simple model that generates overshoot patterns of behavior. We, then, demonstrate how

Digest can help modelers to pinpoint the most influential structure as the behavior of the model unfolds. The model being examined here generates an overshoot pattern of behavior.

Figure 3 shows a classic structure that explains how Industrial Structures grow over time until they reach their limitation. The model captures three real-world processes:

1. Industrial Structures grow with new industries through a reinforcing loop and demolish by a balancing loop, (shown in blue),
2. Industrial Structures consume water which decreases water reserves (shown in green),
3. water shortage affects new industries indirectly (shown in red),
4. water availability controls water consumption (shown in gray).

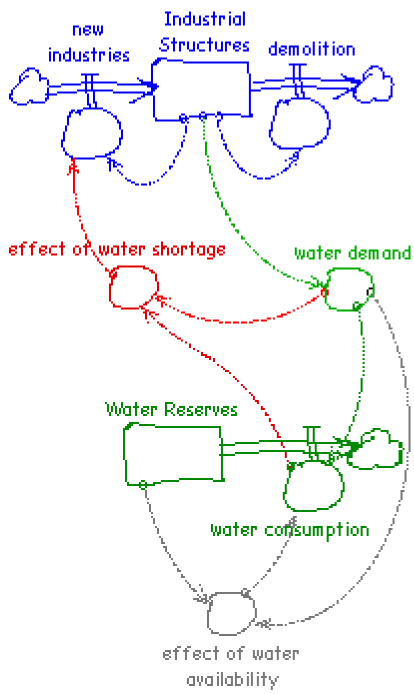

Figure 3: A simple model for the growth of Industrial Structures

The behavior of these processes is an overshoot in Industrial Structures while water reserves follows an S-shape decline. In explaining the behavior of the model the question is what feedback loops are more influential in generating the behavior of the variable of interest. For example, what is making water resources to decline rapidly and what controls it. What is deriving population to grow rapidly in the first few years? What part of the structure is responsible for the decline of population followed by its growth? What is the relative importance of each feedback loop in creating the dynamics of Water Reserves? It is the understanding of the most influential piece of structure that helps us to shift our focus from detail complexity to dynamic complexity.

***Digest* on the deck:**

Using *Digest* enables you to uncover the most influential feedback loop in creating the behavior of the variable of interest at any point in time. Just save your equations of your model as a text file and open the file in the *Digest* environment. There are four windows in the *Digest* environment; once you open the file containing the model equations, a list of variables of the model will appear. The left side of each variable shows whether the variable is a stock, flow or auxiliary. Figure 4 depicts the first window of *Digest* when the industrial structure growth model is opened.

Figure 4: The first window of *Digest*: A list of variables of the model

By clicking on the variable, you will see the causal route of the variable of interest. This diagram reveals how the variable of interest is determined. Now suppose you have selected the state variable Industrial Structures as your variable of interest. Figure 5 shows the causal route diagram that is associated with Industrial Structures.

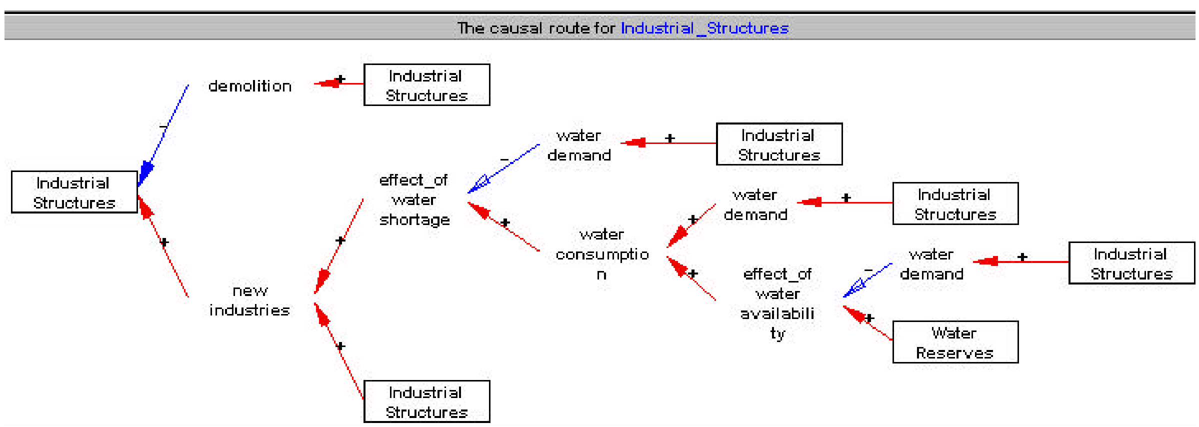

Figure 5: Causal route for Industrial Structures

Arrows in red indicate a direct (positive) impact of the independent variable on the dependent variable and a blue arrow refers to an indirect impact of the cause on the effect (a negative or indirect relationship).

In the third quadrant, you see the behavior of the variable of interest and its phase. Each phase is shown in different colors. Figure 6 depicts the behavior of the variable of interest, Industrial Structures, and its phase. As indicated by the figure the variable of interest have four phases: whereas in the first phase Industrial Structures follows a reinforcing growth, in the second and third phases the variable of interest creates a balancing growth followed by a reinforcing decline. Finally, in the last phase, Industrial Structures show a balancing decline.

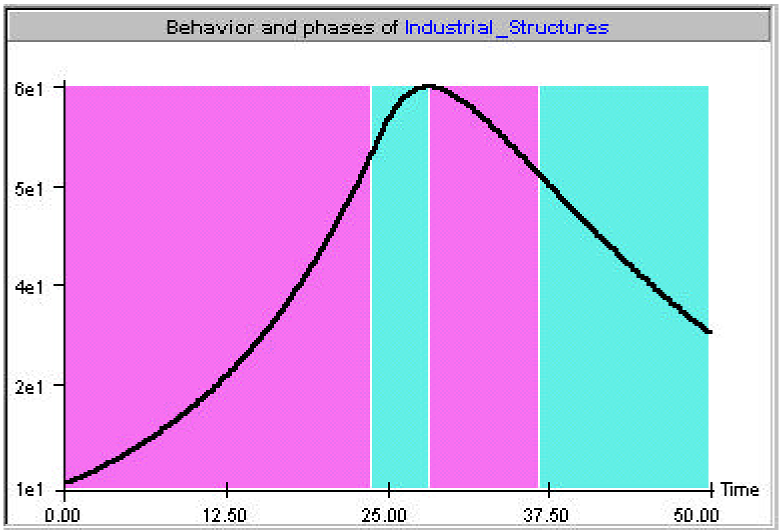

Figure 6: The behavior of the variable of interest, Industrial Structures and its phases.

The feedback loop(s) that are more influential in creating the behavior of the variable of interest is shown the fourth quadrant in the software environment. As mentioned before, *Digest* uses pathway participation techniques and determines the relative importance of each pathway involved in the variable of interest. (For mathematics of pathway participation techniques see Mojtahedzadeh, 1997.) The most influential pathways, then, gets selected based on the measures of the relative importance of pathways. A table of those measures is available in *Digest*. Figure 7 depicts the feedback loop that is mainly responsible in forming the behavior of the variable of interest, Industrial Structures. The steepening growth in the behavior of Industrial Structures is induced by a reinforcing feedback loop: A higher level of Industrial Structures attracts more new industries. Nothing would limit the growth of industries!

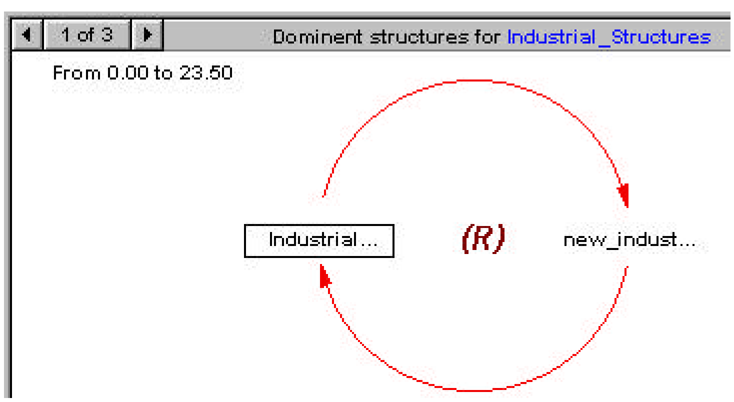

Figure 7: The most influential structure in the first phase of the behavior of Industrial Structures

In the second and third phase of its behavior, as mentioned before, Industrial Structures generates a balancing growth followed by a reinforcing decline. The most influential structure in this phase is shown in Figure 8.

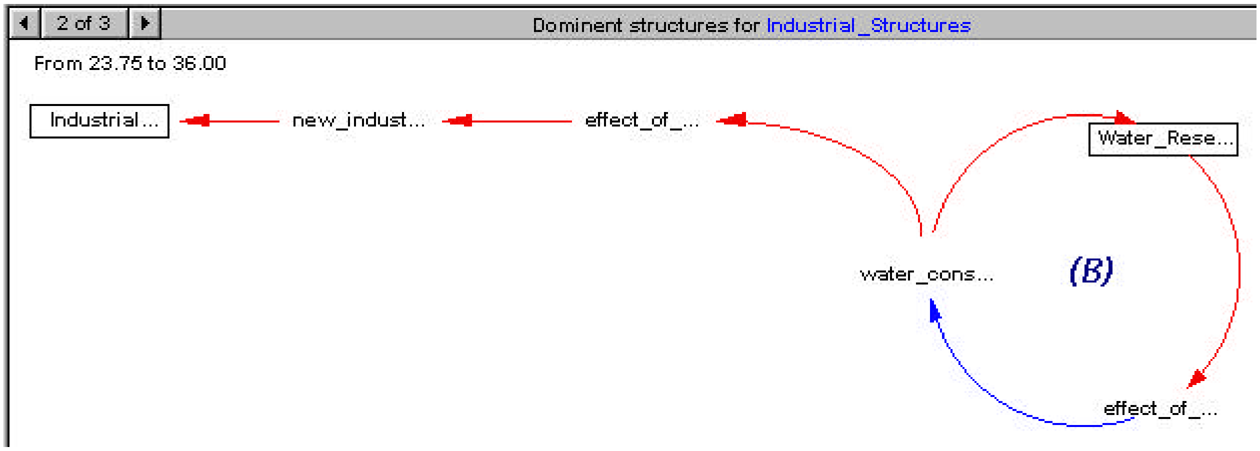

Figure 8: The most influential structure in the second and third phases of the behavior of Industrial Structures

It is not difficult to imagine that the balancing loop, which controls water consumption, limits the development of Industrial Structures. Water availability due to a continuous fall of water reserves is dropping and, therefore, new industries can not grow any more. But this balancing pattern in the behavior of new industries is followed by a reinforcing decline. Some people may look for a reinforcing feedback loop when tracing out the cause of a growing decline. They may think since the steepening growth is usually associated with a reinforcing feedback loop, thus, the steepening decline should have the same basis. In this model, what is driving population to fall faster and faster is exactly the same process that controls it. The balancing loop that controls water consumption pushes Industrial Structures to the edge by continuously plunging new industries and once new industries falls behind industrial demolition, the Industrial Structures generates a steepening decline. Here, the impact of integration in the Industrial Structures is induced by a balancing loop that causes new industries to fall.

Figure 9 shows the most influential structure in the fourth phase of Industrial Structures. In this phase the behavior of population follows and balancing decline pattern and the responsible feedback loop for creating such behavior is the balancing loop associated with the demolition of Industrial Structures.

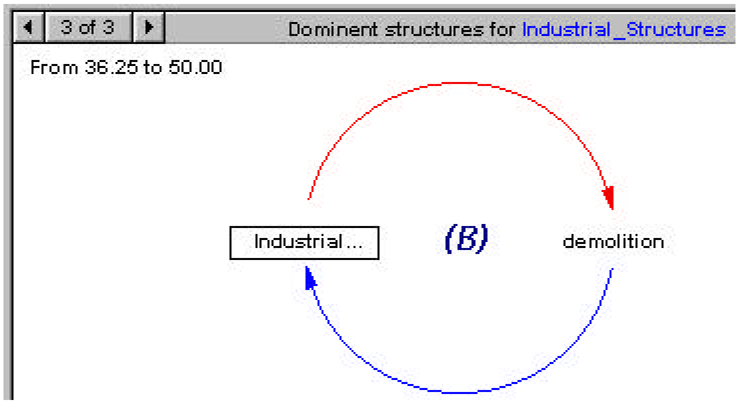

Figure 8: The most influential structure in the fourth phase of the behavior of Industrial Structures

In sum, in examining the behavior of a simple model introduced in this paper, we identified a reinforcing feedback loop and two balancing feedback loops that seem to be mainly responsible for creating the overshoot in the level variable, Industrial structures. The reinforcing feedback loop is the minor loop that involves Industrial Structure and new industries. Once there is no limit to growth this feedback loop causes a reinforcing growth in the behavior of Industrial Structures. When Water Reserves get depleted, the balancing loop that controls water consumption ultimately works against the growth of Industrial Structures. Finally, the balancing feedback loop that contains demolition and Industrial Structures takes over and generates the long-run behavior of Industrial Structures.

Conclusions

Modeling is a powerful tool for understanding the complexity of managerial systems. It helps to organize and structure available knowledge about the system understudy in an effective way. In the processes of the development of a model one walks through operational thinking, feedback loop thinking skills. These are the skills to master structural interrelationships in the system. The focus in this stage is on detail complexity. Once the model is complete and the behavior of the whole system is revealed, the challenge is to promote share understanding. Others must learn about the model. Having model consumers to walk through the same process that the model producer experiences in the modeling exercise could be time consuming and expensive. What is needed at this stage is a language that captures all the mentioned skills and helps the modeler to share his/her understanding with your colleagues. The language must be simple to make it easy for every body to convey what is needed. At the same time, it must be adequate. A combination feedback loops and stock-and-flow thinking, with an eye on the overall dynamics of the whole system is the language that can be appealing to managers and policy makes.

Digest is developed, as a research tool, to make system dynamics models more understandable and more communicable. It highlights the most influential structure as the behavior of the model unfolds and help you to explain why the model does what is does. Identifying the most influential structure allows modelers to shift their focus from detail complexity to dynamic complexity. Such shift could be an excellent step for conducting model-based dialogues among team members and for creating insightful feedback rich system stories to achieve shared vision and policy assessment.

Technically speaking, *Digest* reads the equations of models built in Vensim, iThink, Dynamo and, Powersim, and does some useful analysis, i.e. it identifies feedback loops in a system dynamics model, determines their polarities, calculates the relative importance of each loop in creating system's behavior, and finally highlights the most influential feedback loops.

Digest as a research fellow is waiting for more works. One of the areas that calls for more investigation is the connection between the most influential structure identified by *Digest* and the concept of dominant structure in the system dynamics literature. The concept of dominant structure is not yet well-defined (see Richardson 1994). As a result people have their own perception about what dominant structure is. One way is to examine simple models to find out how much of this expectation is met when using Digest to explain the behavior of system dynamics models.

Appendix

A list of the equations of the Industrial Structures growth model (iThink version)

Industrial_Structures(t) = Industrial_Structures(t - dt) + (new_industries - demolition) * dt
INIT Industrial_Structures = 10
new_industries = Industrial_Structures*effect_of_water_shortage*normal_growth
demolition = Industrial_Structures*dem_frc
Water_Reserves(t) = Water_Reserves(t - dt) + (- water_consumption) * dt
INIT Water_Reserves = 10000
water_consumption = effect_of_water_availability*water_demand
dem_frc = .05
normal_growth = .12
water_demand = Industrial_Structures*water_demand_per_industry
water_demand_per_industry = 10
effect_of_water_availability = GRAPH(0.1*Water_Reserves/water_demand)
(0.00, 0.00), (0.1, 0.06), (0.2, 0.14), (0.3, 0.255), (0.4, 0.395), (0.5, 0.535), (0.6, 0.685), (0.7, 0.825), (0.8, 0.92), (0.9, 0.975), (1, 1.00)
effect_of_water_shortage = GRAPH(water_consumption/water_demand)
(0.00, 0.00), (0.1, 0.06), (0.2, 0.14), (0.3, 0.255), (0.4, 0.395), (0.5, 0.535), (0.6, 0.685), (0.7, 0.825), (0.8, 0.92), (0.9, 0.975), (1, 1.00)

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