Reflections on theory building and theory integration following a system dynamics approach

Birgit Kopainsky[1] and Luis F. Luna-Reyes[2]

[1] *Corresponding author. Swiss Federal Institute of Technology, Institute of Agricultural Economics, 8092 Zurich, Switzerland, Phone: +41-44-632 53 28, Fax: +41-44-632 10 86, email:* *birgit.kopainsky@iaw.agrl.ethz.ch*

[2] *Universidad de las Américas, Puebla, Business School, NE221J Santa Catarina Mártir, Cholula, Puebla, México, Phone: +52 (222) 229-2000 ext. 4536, Fax: +52 (222) 229-2726 email:* *luisf.luna@udlap.mx*

1 Abstract

Conceptualization is a critical task in the development of system dynamics models, which starts early in the modeling process, and extends to later stages in the development of any system dynamics project. The procedures and characteristics of model conceptualization have striking parallels with the process of theory building as described in many different strands of literature. Considering also that the modeling process as a whole is an iterative process of comparing and contrasting data and current theories by means of a rigorous yet intuitive process, it seems appropriate to reflect on the modeling process as a theory building effort, which is the main purpose of this paper. In order to illustrate the differences between theory building approaches, the paper presents two examples of system-dynamics-based theory building efforts. Thinking of the model development work as a theory building process has the potential of bringing new insights to the conceptualization of system dynamics models, and to the criteria used to assess the suitability of our models. The paper concludes with the introduction of a set of criteria to assess good theories and with reflections on the further development of these criteria for model validation purposes.

Reflections on theory building and theory integration following a system dynamics approach

"Conceptualization is at once the most important and least understood of all modeling activities. Conceptualization is really jargon for the mysterious process of creating a new idea, a word designed to make the creative act sound scientific, scholarly and repeatable" (John Sterman 1986).[1]

1 Abstract

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[1] A quote from the presentation of the reprint of Mass' (1986) introductory address to the Conceptualization Table at the 1981 System Dynamics Conference.

2 Introduction

The purpose of a system dynamics modeling project is to gain understanding about some problematic behavior in order to design policies or strategies for improving system performance over time (Richardson and Pugh, 1981; Sterman, 2000). Problem conceptualization constitutes a key element to project success, given that this is the "stage that establishes the focus of the study – the general perspective and the time horizon. The critical decisions are made on what part of reality to study and how to describe it" (Randers 1980:118). Moreover, instead of a discrete step within the modeling process, Randers (1980) describes conceptualization as a recursive process closely related with the formulation of the model. Since Randers' effort to describe the conceptualization process in 1980, influential texts in system dynamics agree on the idea that problem conceptualization consists of an iterative process of analyzing data, clarifying the problem boundaries and pinning a dynamic hypothesis (Richardson and Pugh 1981, Roberts et al. 1983, Wolstenholme 1990, Sterman, 2000). In spite of many efforts to get better tools and methods for the conceptualization stage,[2] model conceptualization still is "the most important and least understood of all modeling activities," where the modeler uses her intuition, data from the field, and existing literature to focus on a specific problem.

Given the similarities of the conceptualization process as described in the previous paragraph with the process of theory building as described in many other strands of literature (Benbastat 1987, Glaser and Strauss 1967, Eisenhardt 2002, Hanneman 1987, Klein and Myers 1999, Lee 1989, Walsham 1995, Yin 1994, Strauss and Corbin 1998), the proposition of this paper is to enrich our understanding of the modeling process by analyzing it as the development of dynamic theories in order to explain phenomena or design policy. Looking at the modeling process from this perspective will not only

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2 See Richardson and Pugh (1981), Morecroft (1982), and Sterman (2000) for progress in mapping tools to represent structure; Saeed (1992), and Sterman (2000) for techniques to analyze reference modes; and Fey and Trimble (1993), Lane and Oliva (1998), and Keating (1998) for efforts to support the conceptualization process with tools and techniques used in other scientific disciplines.

contribute to better modeling practices, but also enrich the criteria used to assess system dynamic models.

The purpose of this paper is to explore theory building and integration using system dynamics from different points of view. We analyze the benefits and pitfalls in the model building process and differentiate between different approaches to modeling (Section 3). To illustrate the differences between approaches, we present two examples of theory building and integration in public policy. The first example (Section 4) follows a top-down theory building approach which can often be found in the economic literature. The second example illustrates a bottom-up approach which can be found in the information technology management literature (Section 5). Section 6 shows a comparison of these two approaches in terms of several criteria developed to assess "good theory," and the paper ends with some concluding remarks and further work (Section 7).

3 Model conceptualization as a theory-building process

In the problem identification and model conceptualization phase the modeler develops a statement of the context and symptoms of the problem, sketches reference modes of behavior, articulates the purposes of the modeling study, settles on a system boundary, and develops a view of the system structure in terms of feedback loops. The last step represents the model conceptualization in the narrow sense and consists in developing the physical structure of the problem and adding information flows, perceptions and pressures arising from perceptions that influence change in the system (Richardson and Pugh 1981).

The process just described fits the general description of a theory, considered to be made of 4 main components (Wacker 1998): definitions (of the variables and assumptions), a specific domain (model boundaries), a set of relationships between variables (feedback structure), and specific predictions (past or forecasted behavior over time explained by the feedback structure).

Besides the data from a specific phenomenon, it is common to find a vast body of literature speaking about aspects of the problem at hand. Existing theories are mostly static, either listing elements of the physical structure of the system or describing specific information flows. Given that the feedback nature of the problems is frequently described "between the lines," representing these static theories in a dynamic model represents an important challenge to the modeler.

The challenge of building a dynamic simulation model from the data at hand and existing theories is twofold. A first task is to elicit the feedback complexity inherent to static theories. Second, different theories that cover different aspects of the problem have to be combined and integrated into a consistent theory about the nature of the problem. Often, the variables and linkages that comprise the relevant processes of a dynamic problem are well established in the literature, but taken together they provide a new, more parsimonious view of the processes. The development and analysis of a simulation model helps characterize the range of organizational outcomes that these processes generate. The end result is an internally consistent theory that is firmly grounded in data and previous work, but reaches a new level of specificity concerning the determinants of the processes underlying the problem at hand (Patrick 1995, Repenning 2002). The dynamic simulation model is, in the end, a concrete realization of this theory (Hanneman and Patrick 1997).

A dynamic simulation model is based on both data and theoretical statements about the operation of causal processes over time and makes concrete and explicit the concepts and causal processes identified by actors in the problem and previous researchers. The study of simulation models can be very useful in understanding and revising theory because they provide an explicit and systematic way of deducing the implications of a theory as it operates under particular circumstances to make predictions about outcomes over time (Hanneman 1987).

There are two broad possibilities to build a dynamic theory. A top-down approach is theory driven and mostly characterized by a high level of aggregation. The purpose of the model building process is mostly to analyze some general case of a problem (similar to the concept of *homo economicus* in economics). The simulation models resulting from such an approach are simplified models that mimic the general behavior of a system but fail to explain the observed behavior of individual cases in detail. The conclusions drawn from model analyses provide general decision support and strategic guidelines. A bottom-up approach, on the other hand, is more data and problem oriented and directed at understanding and managing individual cases of an observed problematic behavior. The resulting simulation models include all the elements essential to the case and are able to replicate the relevant processes. Implications from model analyses lead to a set of concrete policies that can be directly implemented.[3] The difficulties of a bottom-up approach lie in the generalization of the results, i.e. in identifying the generic features of the theory (Lee and Baskerville 2003, Yin 1994, Wacker 1998). Table 1 summarizes the main characteristics of the two modeling approaches.

The central problem is therefore to find the right balance between sufficient theoretical orientation and sufficient data concern. On the one hand, data and problem oriented research runs the risk of lacking an appropriate theoretical framework, maturity, effectiveness, persistency, and consensus concerning concepts and methods. On the other hand, theoretical orientation may again reduce problem orientation to questions of a newly developed disciplinary matrix (Conrad 2002). The next two sections will therefore explore the issues of theoretical orientation and data concern for the two model building approaches.

Table 1: Key differences between a top-down and a bottom-up modeling approach (adapted from Eckert 2004: 695)

	Top-down approaches	Bottom-up approaches
Research goal	Development of generally valid behavior principles	Understanding specific phenomena
Assumptions about reality	Reality is objectively given	Reality is subjectively constructed
Method of analysis	Highly standardized	Not or weakly standardized
Number of units of analysis	High	Low

[3] In a report on best practices of system dynamics modeling, Martínez-Moyano and Richardson (2002) found these two approaches to modeling as one of the main points of disagreement among the experts. While some modelers in their sample prefer to work on a specific problem, others think that the modeling process should focus in a more generic kind of problem to which the particular case belongs.

4 Top-down approaches: theory building in economics

Theoretical orientation is predominant in economics. Positive methods that contribute to theory building formulate hypotheses based on an existing body of theory. The hypotheses are tested against an empirical background. The size of the sample for the empirical background needs to be statistically representative and the relevant criterion for assessing the validity of a theory is the significance level (Eckert 2004). Positive methods explain a given economic situation and its development. They aim at improving the basis for forecasts about the future performance of the system (Sterman 1988).

Normative approaches in economics, on the other hand, identify the best ways to achieve a given goal (Keusch 2000). Normative economics must have recourse to the analysis and findings of positive economics. As it is not possible to prescribe what should be done unless there are clear ideas about what would happen if certain economic measures were taken or withdrawn. Such knowledge involves acceptable hypothesis about the structure of the system (Mishan 1981). Positive methods also provide the basis for other methods of mathematical economics in general and of economic dynamics in specific (Shone 2005).

4.1 Theories about employment and population dynamics in lagging rural regions

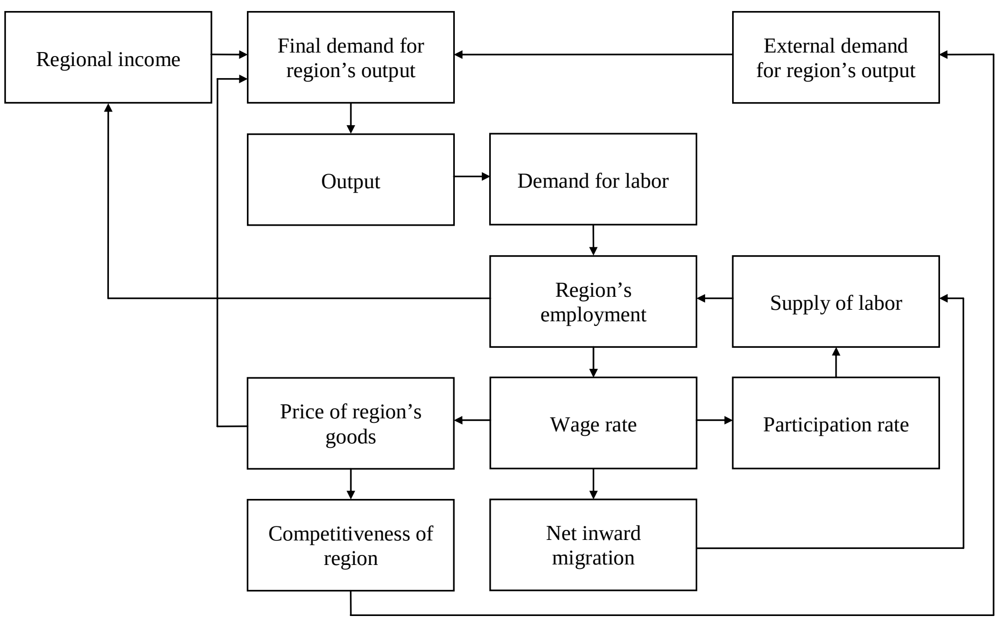
Econometrics is the measurement of economic relations that derive from preexisting theories (Gujarati 1995, Maddala 2001). However, in applied socioeconomic contexts, a specific research problem often encompasses elements from different strands of theory.

Theories that conceptualize the driving forces behind economic development in rural regions of industrialized countries, for example can be found in various disciplines. Regional economics and rural studies offer promising prospects as the former focuses on regional economic development and the latter concerns rural development. The debate on economic development in rural studies is especially concerned with the organizational aspects of the rural economy. Regional economics, on the other hand, focuses more on the interplay of the production factors of capital and labor, often affected by several other factors (Terluin 2003). Theories in regional economics are therefore often called factor-oriented theories while theories in the field of rural studies are labeled as being actor-oriented (Egger 1998).

Contrary to factor-oriented theories that use only few variables and formal models to explain development, in actor-oriented theories a considerable number of variables are introduced but only very few attempts to formally model them have been undertaken so far.

Factor-oriented theories focus on explaining growth of a region's output. As rural development policy is not only concerned with output growth but with providing employment opportunities as well, Figure 1 introduces a diagram of the interaction between a regions' product market and its labor market.

Figure 1: Basic scheme of a regional economy with linkages between the product market and the labor market (adapted from Armstrong and Taylor 2000: 30)

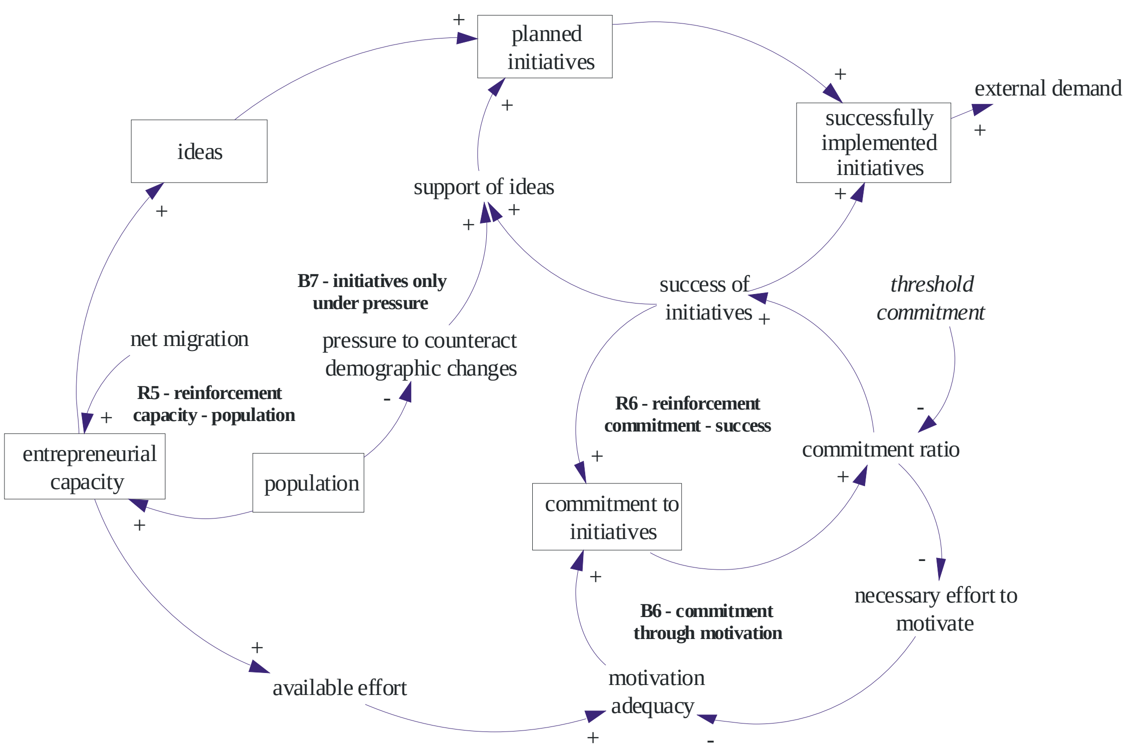


The figure shows that employment growth depends on the growth of a region's output, which is itself determined by the competitiveness of its firms, i.e. the ability of these firms to produce a certain share to meet the region's own demand and the demand of other regions.

Actor-oriented theories seek to understand the interaction between spatial structures and sociospatial processes in rural areas. They address a wide range of issues in rural areas such as people, settlements, landscape, environment, agriculture, economy, policy, minorities, gender and cultural issues (Terluin 2001). A high capacity of local actors and strong internal and external networks – often indicated as self-help capacity – are supposed to be main factors behind employment growth (Terluin 2003).

Figure 2 illustrates the dynamic complexity inherent in actor-oriented theories on regional rural development. The figure constitutes a summary of a theory integration effort that is described in detail in Kopainsky (2005) and will be further commented in the final version of this paper. The variable 'external demand' at the upper right hand side of the figure links actor-oriented theories to the factor-oriented theories in Figure 1. Net migration, the variable at the left hand side in Figure 2, is the second link between the two bodies of theories.

Figure 2: Feedback complexity in actor-oriented theories on regional rural development



4.2 Dynamic implications of these theories

The dynamic simulation model derived from the factor- and actor-oriented theories explores the evolution of the regional economy over time for a growth oriented strategy. It analyses how robust these strategies are and how a region's economy and population interact over time.

Factor-oriented theories suggest a variety of strategies directed at regional economic growth (Armstrong and Taylor 2000). Investment grants and venture capital initiatives are examples of a development strategy based on the provision of infrastructure and capital goods. Figure 3 summarizes the population effect of variations in the inflow into the capital stock. The inflow into the capital stock is determined by the depreciation rate, the ratio between current and desired capital and the fraction of available capital investment goods. In Figure 3, the fraction of available capital goods is varied between 0.5 and 1.5, i.e. from half its normal value to 150% of it.

The results are presented in the form of a three-dimensional response surface. In the plot, the vertical axis represents the outcome variable of interest, in this case the 0 to 65 years old population. The horizontal axis represents time and the third axis, which extends into the page, captures the input variable being manipulated in the experiment, in this case the fraction of available capital goods. Reading from left to right along the horizontal axis, any given line shows the time path of the outcome variable given a specific input variable. Reading from front to back along the input variable axis, any given line shows how the value of the outcome variable, at one specific point in time, changes in response to changes in the input variable. Viewing the resulting surface presents a dynamic view of how the evolution of the outcome variable is influenced by changes in the input variable.

Figure 3: Population development as a reaction to changes in available capital investment goods

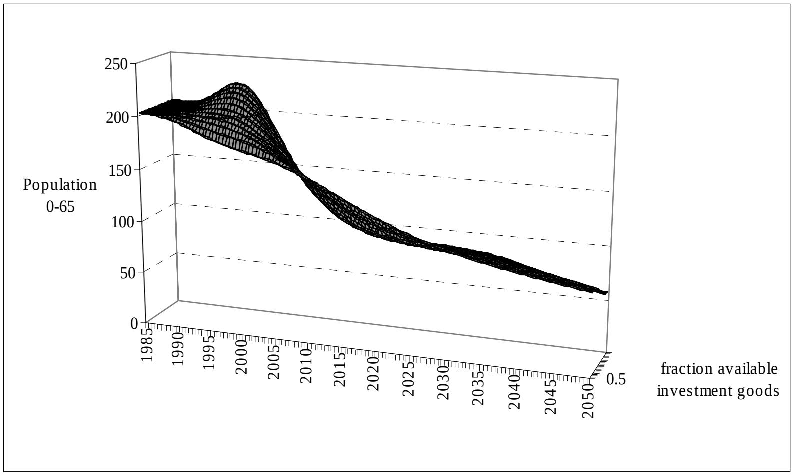


Figure 3 contains several implications. It shows that making more capital goods available results in a better-before-worse behavior pattern of the 0 to 65 years old population. Restricting capital availability to half of the desired value generates constant population decline. The normal equilibrium – transition – equilibrium development pattern is almost completely suppressed. Increasing the availability of capital above its desired value, on the other hand, leads to an initial population increase. After a short growth period, however, population starts to decline and drops below the value of the situation with restricted access to capital goods. In the long run, population recovers to a level that is approximately identical for all the values in the fraction of available investment goods. If investment in the capital stock is not followed by massive investment in an adequate increase in external demand the costs of maintaining the capital stock become too high after the initial growth period.

Better-before-worse behavior as shown in Figure 3 bears important policy implications. If population stabilization or population growth are development goals in lagging rural areas, a strategy based on increasing the availability of capital goods results in initial success. The unintended consequence of it is, however, that the initial success is not sufficient to keep population at such a high level. After an initial growth period, a distinct decline occurs.

Regional economic growth can also be brought about by locally and regionally initiated economic activities. The number of initiatives that are created and flow through the system until they end as determinants of endogenously created external demand depends on initiative creation, initiative support and initiative implementation decisions as illustrated in Figure 2. The successful implementation of initiatives is coupled to actors' commitment to the initiatives. Commitment is influenced by the success of (past) initiatives and the motivation that actors experience during the implementation phase.[4]

If commitment and success are at minimum levels, the reinforcing feedback loop *reinforcement commitment – success* keeps the system at minimum performance. A shift in loop direction can only be caused by the balancing feedback loop *commitment through motivation*. If commitment is lower than the threshold commitment for success, motivation is necessary to raise commitment. Necessary motivation increases the lower the ratio between current and necessary commitment is. Entrepreneurial capacity and external support determine the level of available motivation which in turn determines whether commitment can be sufficiently raised or not. A third set of experiments therefore analyzes the reaction of commitment to changes in necessary and available motivation. For this purpose, the system is initialized to equilibrium and hit with a step increase in necessary success as above. Available motivation is varied between 0.2 (low motivation) and 0.8 (high motivation).

This experiment can be interpreted as varying entrepreneurial capacity either by increasing management skills, political and administrative support or improving communication infrastructure. The results are presented in Figure 4. In the plot, the vertical axis represents the outcome variable of interest (in this case actors' commitment to an initiative) and the horizontal axis represents time. Each line captures the reaction of commitment to the input variable being manipulated in the experiment (in this case the degree of motivation that

[4] The conceptualization of this model part is taken from Repenning (2002) and adjusted to the public domain.

local actors experience). Reading from left to right, any given line shows the time path of the output variable given a specific input variable.

Figure 4: Reaction of commitment to changes in capacity to motivate actors involved in an initiative

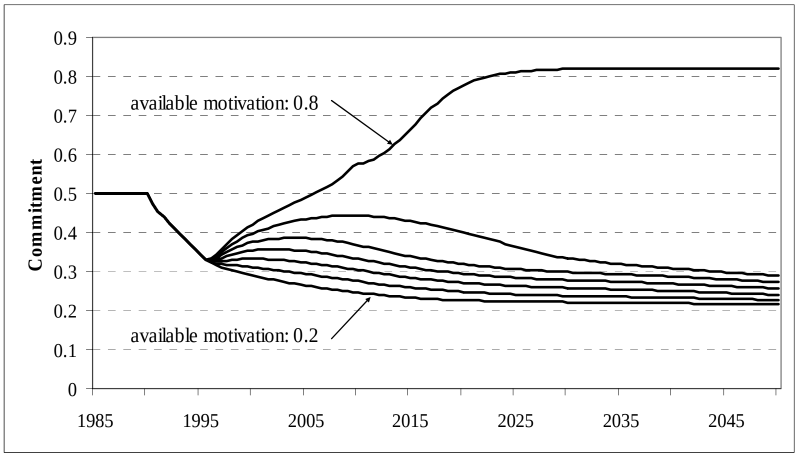


Figure 4 shows that the success of initiatives (resulting from actors' commitment) depends critically on the motivation that actors experience. The behavior is determined by the interaction between the reinforcing loop *reinforcement commitment – success* and the balancing loop *commitment though motivation.* As a reaction to the step increase in the success threshold, the reinforcing loop works in a downward direction and thus drains commitment and success. As some entrepreneurs start motivating the actors involved in the initiative, the reinforcing loop is less of a drain on commitment. If motivation is high enough, commitment continues to grow and success becomes sufficient to generate more commitment. At this point, the reinforcing loop shifts direction and begins to work in an upward direction. Once this shift occurs, *reinforcement commitment-success* generates rapid growth in commitment.

Policy failure can therefore have two reasons: underinvestment and wrong choice of policy. The exemplary results show that development strategies based on strengthening local collaborative activities have the potential to influence employment and population development and that policy failure mainly arises from underinvestment in management skills and entrepreneurial capacity.

5 Bottom-up approaches: theory building in information systems development

Similarly to the field of economics, factor analysis starting with theory is a common approach to understand information systems development (ISD).[5] These approaches contribute to our understanding of ISD by offering a linear-static view of a complex-dynamic process such as information systems development and implementation (Newman and Robey 1992).

A complementary approach consists in the use of case study research, which offers a process-oriented, and dynamic view of the information systems development process (Newman and Robey 1992). Similarly to the actor-oriented theories in economics described in previous sections, case-based research in ISD introduces many variables when compared with factor-oriented research. Moreover, case-based system dynamics models have proven useful for studying information systems development processes given its ability to deal with complex and dynamic systems (Abdel-Hamid 1988, Abdel-Hamid and Madnick 1990, Bennett et al. 1999, Lehman and Ramil 2002).

Recognizing the differences of system dynamics with other mathematical modeling methods, Black (2002) equiparates the modeling process with other qualitative theory-building approaches where the researcher builds iteratively a theory by interpreting, comparing, and contrasting observations, and patterns of behavior with previous theories (Glaser and Strauss 1967, Walsham 1995, Eisenhardt 2002).

5.1 Theories about trust and collaboration in information systems development

The example outlined in this section deals with information resources for programs serving the more than 29,000 homeless people who receive emergency shelter and a diversity of support services each day in New York State. Homeless services costs are estimated to be $350 million each year, $130 of which are spent on service programs (CTG, 2000). The

5 See Larsen (2003) for an extensive review of a sample of 212 studies on information systems development from 1954 to 1999.

information needed to assess the effectiveness and impact of the services provided to the homeless is distributed in several agencies and nonprofits, such as the Bureau of Housing Services (BHS), and the New York City Department of Homeless Services (DHS). The lack of integration of the data sources makes very difficult to assess them. Starting in 1998, the Office of Temporary and Disability Assistance (OTDA), Bureau of Housing Services (BHS) started a series of efforts to create an integrated decision support system to help both government and nonprofit organizations to manage and assess homeless services called the Homeless Information Management System (HIMS). The system would integrate information from a variety of sources. Demographic data would be obtained from the individual shelters, payment information would come from the state Welfare Management System (WMS), shelters' information would be gathered from the BHS's providers certification database, medical information from the State Department of Health, and data on substance abuse or other services from other State Agencies. Although BHS is an oversight agency, which manages and regulates temporary housing programs in New York State, it shares its regulatory functions in New York City with the NYC Department of Homeless Services.

Problems like the one just described make collaborative approaches appealing for many managers (Gray 1989, McCaffrey et al. 1995, Bardach 1998). However, there is an important gap between managers' appreciation and the actual proportion of initiatives using a collaborative approach (McCaffrey et al. 1995). The gap between the managers' beliefs and current practices can be understood as a lack of theories to understand the processes and phenomena involved in collaboration, and to guide our current practices.

Luna-Reyes (2004) developed a knowledge-and-trust-based collaboration theory based on the HIMS case. Through the analysis of interviews and archival documentation[6] of the case,

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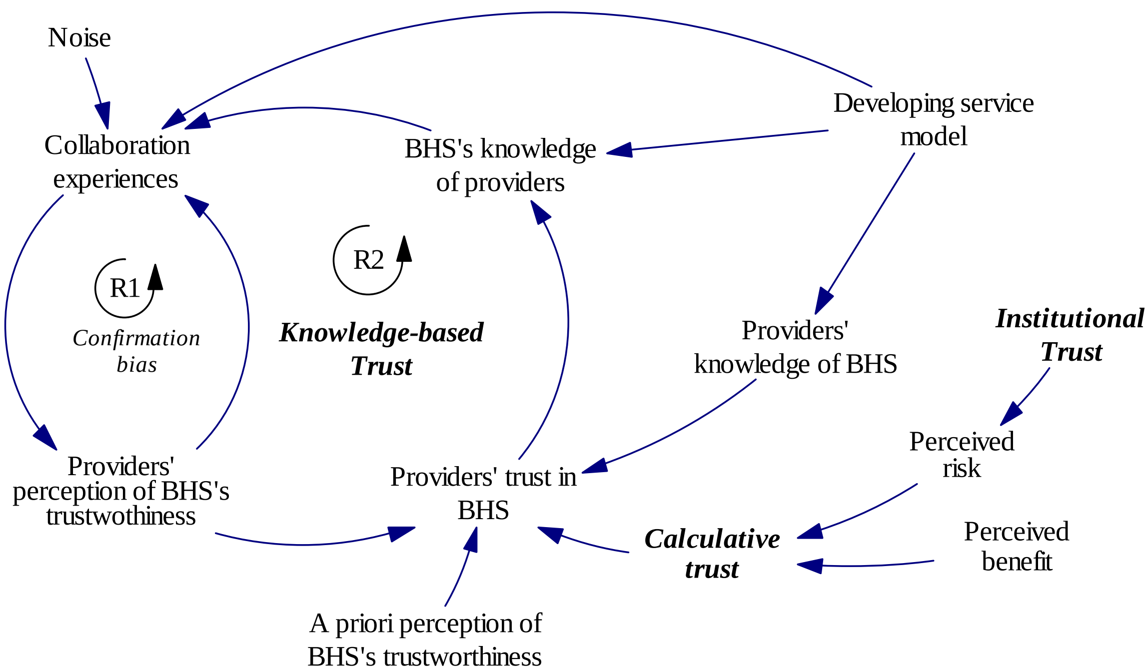
[6] Longitudinal data from the case was gathered as a component of a Project in which the main objective was to develop a better understanding of knowledge creation and sharing in interorganizational networks. The project is part of the research program at the Center for Technology in Government (CTG) in Albany, NY.

he identified three main themes that became the main backbone of the modeling effort: *trust development*, *stakeholder engagement*, and *requirement definition as a social process*.

For this illustration, we present a model that focus in the first theme, analyzing interpersonal trust dynamics (see Figure 5 for a high-level representation of the model). The model constitutes a generic representation of the interaction between two actors, BHS and homeless service providers. The model is grounded in the longitudinal case study of the HIMS. The case study produced observational and interview data about these interactions that indicated substantial growth in the levels of interpersonal trust among these participants. There was considerable evidence of feedback and learning as important factors in how trust developed over the roughly two-year course of the project.

Figure 5: Developing trust among providers



As shown in the figure, the model identifies two important feedback processes associated with the development of trust. The feedback process R1 represents the confirmation bias identified in the trust literature as our tendency to assess positively our experiences with people that we perceive as trustworthy, or to assess negatively our experiences with people that we perceive untrustworthy (Klimoski and Donahue 2001). Providers' collaboration experience is represented in the model as their memories of good and bad experiences in their interaction with the Bureau of Housing Services (BHS). These experiences can be distorted by external noise that interferes in the perceptual process, and when there is no previous experience, an a priori component of the perception appears to operate. The feedback process R2 represents BHS's ability to build its reputation as a trustworthy party.

It was possible to compare some portions in the model with several mechanisms of "trust production" identified in the literature: Institutional trust, calculative trust, knowledge-based trust, and identification-based trust.

Institutional trust refers to the existence of an institutional framework that regulates the relationship between the trustor and the trustee. In any case, the existence of this mechanism to facilitate trust reduces the trustor's perception of risk in the interaction (Williamson 1993). Calculative trust refers to the trustee's estimation of the risks and pay-offs intertwined in the interaction (Rousseau et al. 1998). Knowledge-based trust is related to the ability of the trustor to assess the trustworthiness of the trustee (Mayer et al. 1995), and it is associated with the history or the process of the relationship. Finally, identification-based trust is associated sometimes with emotional bonds, or with the existence of shared values or objectives between the actors (Shapiro et al. 1992).

The model assumptions about the way in which the "trust production" processes operate is consistent with the views proposed by Rousseau et al. (1998), who consider that the calculative trust plays a more important role in early stages of the relationship, changing towards a knowledge-based trust as the relationships matures. In this way, providers' knowledge of BHS can be interpreted as a weight between these two types of trust.

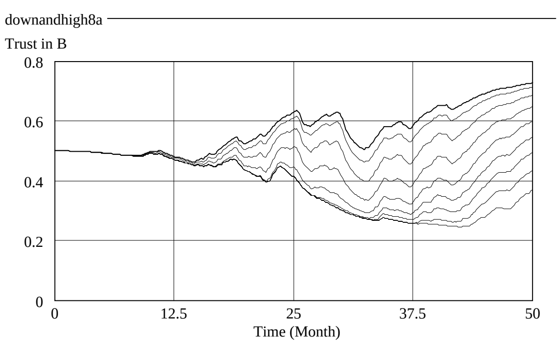
Although the model does not add any new term to the trust literature, it presents a new way of interrelate all the existing concepts in a dynamic framework.

5.2 Dynamic implications of these theories

The model described briefly in the previous section was tested for internal consistency by a series of experiments with diverse inputs, testing model sensitivity to changes in diverse parameters. Some experiments were inspired in some studies of negotiation that suggest that trust outcomes vary according to the rate of early versus late concessions. A pattern of small early concessions leading to larger later ones tends to produce better outcomes than a large-to-small concession pattern or constant-rate small concessions (Hamner and Yukl, 1977). The behavior of the model reflects this same pattern (see Figure 6). In the first experiment (Figure 6a), the pattern of concessions began small and then increased in size later in the time period. The growing divergence in results shows one type of evidence of path dependence. In addition, a higher proportion of the path's lead to increased rather than lower trust, as would be expected from the theory.

Figure 6: Behavior of trust in BHS for (a) low initial concessions gradually increasing at different later times and (b) high initial concessions gradually decreasing at different times.

(a)



(b)

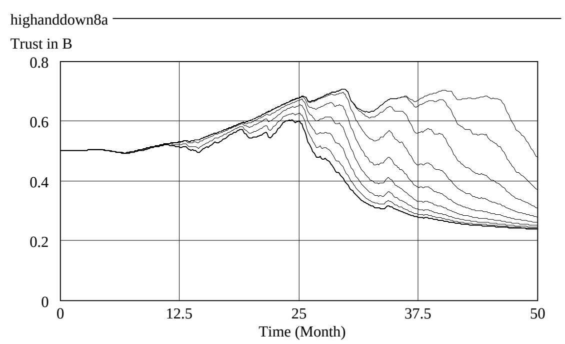


Figure 6b above shows the results of the alternative concession pattern, i.e., larger initial concessions decreasing at a later time. The high initial concession rate leads to high trust levels in the early stages, which drop steeply down as the concession rate drops. A high proportion of the paths lead to overall lower trust. This is consistent with the generally accepted view of trust as being susceptible to betrayal, which is how the high-to-low concession pattern can be viewed. That is, the early pattern of high concessions can be thought of as establishing high expectations for the outcome, which are "betrayed" by the shrinking size of later concessions.

Other experiments with the trust structure suggest that, although the a priori component has an important impact in trust development, the efforts to build trust in the day-to-day interactions can overcome the initial weight of the a priori component. Moreover, early efforts to develop trust are more effective than those that occur in later stages of the interaction. Although the development of trust, because of the attention to the relationship, is a gradual process, the lack of attention to the relation can revert the process much faster. Finally, managing the institutional component of trust (i.e., reducing risk) could be a strategy to break the initial trap of distrust.

The model suggests that is hard to create a history-based trust in as short a period of time. Simulation experiments with the whole model (not only the trust portion of it) suggest that the most important component of trust during the development of the HIMS prototype was the calculative one. Given this situation, the team could have accomplished its goals in a very similar period of time in a situation in which there was little interest in fostering a trusting environment. The behavior of trust, however, suggests that the knowledge-based component will be more important in subsequent project stages.

6 Comparison of the approaches and examples

Reflection about the selection of a top-down or bottom-up approach requires careful consideration. From the two examples presented in this paper, it may seem that top-down approaches could be well suited to problem areas where well-established competing theories claim to have the best explanation to the observed behavior. Dynamic simulation in those situations can contribute to identify the "true" differences among the approaches, the elements where the existing theories are complementary, and the elements where there is controversy. The bottom-up approach appears to be useful in areas like the research on trust, where many competing points of view attempt to describe a particular phenomenon recognizing that there is a lack of clarity in the academic debate. In these situations, the rigor of the modeling process can help to clarify concepts and relationships, ordering the main concepts and causalities.

Although both approaches need to rely on data and current theories, it seems that top-down approaches rely mainly on current theory, while bottom-up approaches rely mainly on data from concrete cases. A commonality in these two approaches is the iterative review of data and theory, guided by the intuition and interpretation of the researcher (Black 2002).

System dynamicists share the belief that judgments about the validity of a model must be linked to the purpose of the modeling effort (Richardson and Pugh 1981, Forrester and Senge 1980, Barlas 1996, Sterman 2000). Accordingly, some distinctions can be made between judgments about the adequacy of a model developed to help a client group, and a model developed to increase understanding in a specific phenomenon from the academic point of view (Coyle 2000). Considering the modeling process as a theory building process to increase our scientific understanding of a particular phenomenon opens a whole new set of criteria to use when judging the adequacy of a system dynamics model.[7] A clear example of one of such criterion could be the claim of the generalizability of the theory to other specific instances.

Wacker (1998) presented a list of common criteria used to assess "good theories" (See Table 2). From our point of view, it is needed to review the current tests to build confidence in models to assess their suitability to support judgment in this set of criteria.

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[7] In our discussion of the validity of system dynamics models as "good science" we adhere to the relativist philosophy of science rather than the logical empiricist one. See Barlas and Carpenter (1990) for a complete discussion of these two philosophical approaches.

Table 2. Virtues of “good theory.“ Extracted from Wacker (1998: 365)

Criterion	Description
Uniqueness	The proposed theory is different from other theories existing in the literature
Parsimony	The better theory is that with less assumptions, variables and causal relationships, yet with power of explanation of observed behavior
Conservatism	Current theories cannot be replaced but by better theories (more parsimonious, generalizable, etc.)
Generalizability	The theory can be applied to several areas
Fecundity	The ability of a theory to raise new questions and hypotheses
Internal Consistency	All relationships inside the theory are well justified and explained
Empirical riskiness	The theory must be refutable
Abstraction	Independence from time and space

Deciding between a top-down or a bottom-up approach to theory development and integration constitutes an important decision to be made by the modeler. The consequences of this decision affect all the criteria listed in Table 2, specifically the issues of generalizability and abstraction.

7 Concluding remarks

The purpose of this paper was to reflect on the theory building process in system dynamics. Based on the premise that a model is a concrete realization of prior theories we analyzed the implications of building a dynamic theory from a body of related static theories and data. While the additional insights gained from such an approach have been widely discussed in the system dynamics literature some aspects have received less attention. We specifically emphasized the similarities between model conceptualization in the system dynamics literature and theory building in other strands of literature such as sociology or operations management. After reviewing some of the literature on model conceptualization and theory building we introduced two case study examples of theory building in public policy. The examples differed in the underlying discipline and the aim of the model building process. The first example was rooted in economics and aimed at identifying generic processes and determinants of regional rural development. The second example was situated in the management of technology innovations and designed to analyze a real case about trust and collaboration in developing technology innovations in the public sector.

As additional guidelines for assessing the validity and usefulness of a system dynamics model we introduced a list of criteria to assess good theories. Adding these elements to the validation of a system dynamics model seems to be promising. The criteria to assess good theories ensure that the model not only serves its purpose in terms of the specific problem at hand. Instead, they also shift the focus to more general issues such as the contribution of the simulation model to existing theories. By asking questions about uniqueness of the developed theory or others, learning from the model building process can be improved. The contributions of a well validated system dynamics model to static theories and to the various existing theories that speak to a specific issue can also be made more transparent.

However, the criteria have to be further operationalized to be fully applicable for evaluating the usefulness and contribution of a system dynamics model. In future versions of this paper we will use the two case study examples to develop a preliminary set of criteria that can be used both for top-down and bottom-up approaches to theory building and integration.

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