Collecting and analyzing qualitative data for system dynamics: methods and models

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Abstract

System dynamics depends heavily upon quantitative data to generate feedback models. Qualitative data and their analysis also have a central role to play at all levels of the modeling process. Although the classic literature on system dynamics strongly supports this argument, the protocols to incorporate this information during the modeling process are not detailed by the most influential authors. Data-gathering techniques such as interviews and focus groups, and qualitative data analysis techniques such as grounded theory methodology and ethnographic decision models could have a strong, critical role in rigorous system dynamics efforts. This article describes some of the main qualitative, social science techniques and explores their suitability in the different stages of the modeling process. Additionally, the authors argue that the techniques described in the paper could contribute to the understanding of the modeling process, facilitate communication among modelers and clients, and set up a methodological framework to promote constructive discussion around the merits of qualitative versus quantitative modeling. Copyright © 2003 John Wiley & Sons, Ltd.

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System dynamics is a powerful tool in the creation of feedback theories. Since its beginnings, the founders of the field have developed a series of guidelines for the model building process (Randers 1980; Richardson and Pugh 1981; Roberts *et al.* 1983; Wolstenholme 1990; Sterman 2000) and a series of tests to build confidence in the models created (Forrester and Senge 1980; Sterman 2000). As depicted by the classical literature, the development of system dynamics models is an iterative process. Each iteration results in a better and more robust model. Although system dynamics models are mathematical representations of problems and policy alternatives, it is recognized that most of the information available to the modeler is not numerical in nature, but qualitative. For example, while describing the information sources for the model building process, Forrester (1994) suggested that these qualitative data reside in the actors' heads (mental database) and in the form of written text (written database). Moreover, he recognized that the most important source, both in quantity and significance for the modeler, is the mental database (Figure 1):[1]

> As suggested by the figure, the amount of available information declines, probably by many orders of magnitude, in going from mental to written information and again by

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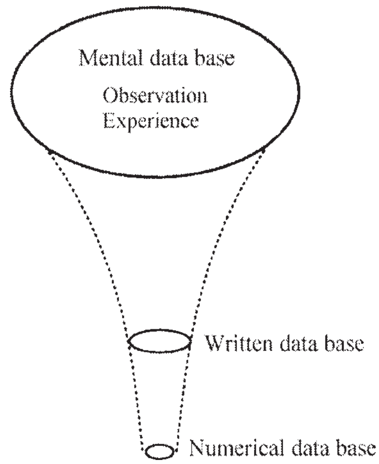

Fig. 1. Mental database and decreasing content of written and numerical databases (*Source*: Forrester 1994, p. 72)

> another similar large factor in going from written to numerical information. Furthermore, the character of information content changes as one moves from mental to written to numerical information. In moving down the diagram, there is a progressively smaller proportion of information about structure and policies.
>
> Forrester (1994, p. 72)

Forrester identified qualitative data as a main source of information in the modeling process in several other papers (Forrester 1975a). Moreover, this perception is shared among mainstream authors in the field (Randers 1980; Richardson and Pugh 1981; Roberts *et al.* 1983; Wolstenholme 1990; Sterman 2000).

Although there is general agreement about the importance of qualitative data during the development of a system dynamics model, there is not a clear description about how or when to use it. The lack of an integrated set of procedures to obtain and analyze qualitative information creates, among several possible problems, a gap between the problem modeled and the model of the problem. That is to say, it is not always easy to understand the links between the observations of reality and the assumptions or formulations in the model. This gap is more noticeable especially when the model involves the use of soft variables, such as "customer satisfaction," "product quality," "pressure to decrease price," "engagement," or "perceived productivity." The problems associated with the quantification and formulation of qualitative variables have led some experts in the field to the conceptualization of a qualitative system dynamics practice (Wolstenholme 1990). In some cases, the uncertainty associated with the quantification of qualitative variables has caused experts to believe that the results from ensuing simulations could be misleading, or at least, very fragile (Coyle 2000).

On the other hand, social scientists have developed a series of research approaches oriented toward the collection and analysis of qualitative data. Counted among data-collecting methodologies are interviews, focus groups, Delphi studies, and participant–observer research. In the social science arena of data analysis are discourse analysis, grounded theory methodology, and ethnographic decision models (Bernard 1999). These methodologies were created both to test theories and to build and generate new theories (Newman and Benz, 1998). These methodologies provide a powerful set of tools to promote formal inquiry and theory inference through the analysis of qualitative (mainly textual) data.

Purpose

This paper has two main purposes. First, after discussing some of the issues in system dynamics literature about qualitative data, it describes some of the main qualitative research methods, providing some illustrations of their use in the social sciences. Second, it explores some examples of the use of qualitative research methods to build confidence in both the process of building and formulating a model, and in the model itself. We believe that the formal incorporation of these social sciences methods can both guide system dynamics practitioners during the modeling process, and provide a powerful way to uncover and contribute to the understanding of the modeling process itself. Many researchers in the area have suggested approaches to teach system dynamics (Andersen and Richardson 1980; Clauset 1985; Davidsen 1994; Saeed 1995). We recommend that programs that teach system dynamics incorporate formal courses in collecting and analyzing qualitative data for use in system dynamics models as another component of the system dynamics process.[2]

Initial definitions

Before discussing the approaches to qualitative data in the system dynamics literature, the present section establishes some basic assumptions and definitions of key concepts that appear several times in the rest of the paper.

First, the authors recognize data and variables as artifacts created by researchers or practitioners in the process of observing the world. Most, if not all such observations (or variables) are initially qualitative in nature. That is to say, particular communities of people create categories of the objects in the world on the basis of qualitative characteristics. These categories, though rich in meanings, have a high degree of uncertainty and ambiguity. In order to reduce the ambiguity, different groups of people produce measurement artifacts to quantify their observations. Scientists recognize that measurement can be done by the use of ordinal, interval and ratio scales. However, in the process of eliminating ambiguity, the observer also loses meaning. For example, saying that a room is hot is meaningful to most people in practical terms, but the meaning is ambiguous given that hot can mean different things to different people. On the other hand, saying that a room is at 75 °F is not ambiguous, but it is hard to identify its practical meaning, and can even be meaningless for a person who is not familiar with this interval scale. Moreover, the way in which a particular observer decides to record a variable (in a qualitative or quantitative way) is influenced both by the theoretical frameworks she is using and by her mental models.

On the other hand, the authors also recognize that the measurement systems used by researchers or practitioners are imperfect and susceptible to error. For the purposes of this paper, hard variables are those that it is possible to measure with little error, and soft variables are those that involve greater measurement error. As the reader can imagine, it is maybe useful to consider a continuum with the purely hard and soft variables in the extremes. However, most of our observations of the world imply a certain level of softness.

Finally, it is important to recognize that in every social system it is even possible to identify characteristics that cannot be observed directly or that are multidimensional in nature. In such cases, the observer creates proxies or constructs that he believes are correlated with the characteristic that he is trying to observe. For example, managers observe and measure revenue or gross profit as proxies to assess the level of success of a company, and psychologists create scales to measure multidimensional constructs such as intelligence, potential of success, or happiness. The difficulties associated with these measurement problems introduce a different kind of softness in the variables used in the social and managerial sciences.

System dynamics and qualitative data

The question for system dynamics appears not to be whether to use qualitative data but when and how to use it. What method should be used to gather data? From whom should data be gathered? At what stage in the modeling process might qualitative data be an appropriate, perhaps even a preferable information source? How should we analyze and use qualitative information, expert judgment, and group consensus? How is qualitative data linked to model structure?

As a precursor to this discussion there are a number of critical semantic distinctions to consider. System dynamicists use soft variables in their models of social systems. This will always be the case. There are some data such as willingness or happiness that require quantitative scaling for use in models.[3] At the same time there is qualitative modeling, also called "systems thinking," that goes through the process of formalizing and analyzing feedback loops but never results in the simulation of a mathematical system dynamics model.

Table 1. The system dynamics modeling process across the classic literature

Randers (1980)	Richardson and Pugh (1981)	Roberts *et al.* (1983)	Wolstenholme (1990)	Sterman (2000)
Conceptualization	Problem definition	Problem definition	Diagram construction and analysis	Problem articulation
	System conceptualization	System conceptualization		Dynamic hypothesis
Formulation	Model formulation	Model representation	Simulation phase (stage 1)	Formulation
Testing	Analysis of model behavior	Model behavior		Testing
	Model evaluation	Model evaluation		
Implementation	Policy analysis	Policy analysis and model use	Simulation phase (stage 2)	Policy formulation and evaluation
	Model use			

Finally, there are qualitative data collection and analysis methods. This paper does not argue the efficacy of systems thinking versus simulation, but poses the formal incorporation of qualitative methods in the conceptualization, formulation and assessment of system dynamics models.

When describing the modeling process, experts have organized the main modeler activities using different arrangements, varying from three to seven different stages (Table 1). At one extreme, Wolstenholme (1990) visualizes the process in three stages. At the other extreme, Richardson and Pugh (1981) conceptualize the modeling process as involving seven different steps. Randers (1980), Sterman (2000), and Roberts *et al.* (1983) have grouped the activities in four, five and six stages respectively.

Although the ways of grouping the activities vary among the different authors, the activities considered along the different stages remain fairly constant across them, allowing the building of a comparison like the one depicted in Table 1. For example, Randers' (1980) conceptualization stage or Wolstenholme's (1990) diagram construction and analysis consider activities that can be mapped onto the problem definition and system conceptualization stages from Richardson and Pugh (1981) and Roberts *et al.* (1983). Sterman's (2000) dynamic hypothesis stage involves the same activities described in the system conceptualization stage of Richardson and Pugh (1981) and Roberts *et al.* (1983). Similarly, model behavior analysis and model evaluation (Richardson and Pugh 1981; Roberts *et al.* 1983) include the same activities considered in the testing stage (Randers 1980; Sterman 2000). Regardless of the differences in the ways of grouping the activities, all authors conceptualize them as parts of an iterative process in which the modeler will test a dynamic hypothesis that represents a feedback theory or causal structure generating a series of behaviors over time, allowing the problem actors to learn about the situation, and to design or redesign their guidance policies. Below we use a four-stage view of modeling behavior to argue that the use of qualitative data is ubiquitous to all stages of the modeling process.

The conceptualization stage (problem definition and system conceptualization)

This stage, in which the modeler focuses on a part of the real world, a "mental model," including "a verbal description of the feedback loops that are assumed to have caused the reference mode" (Randers 1980, p. 119) would seem to be a highly qualitative point in the modeling process. For example, Richardson and Pugh (1981, p. 19) recognize that the behavior over time (reference mode) of several key variables could reside in some of the actors' mental databases:

> It does not require, as some might expect, that the modeler have access to explicit numerical data. . . . While data are very helpful, one is often faced with a dynamic problem in which a key variable is not traditionally quantified or tabulated. It is even more likely, however, that the modeler or the client knows the dynamic behavior of interest without referring to data.

Sterman (2000) also recognizes the need to access the client's mental database, and the written database during the problem definition process. For example, he stresses the use of both databases during the development of the initial characterization of the problem through the interaction of the modeler and the client, stating that "usually the modeler develops the initial characterization of the problem through discussion with the client team, supplemented by archival research, data collection, interviews, and direct observation or participation" (Sterman 2000, p. 90).

Coyle (2000) states that qualitative data had their place in the pre-modeling stage, stopping short of the actual formulation stage at the point of "system description" (pp. 225, 233), going on to emphasize that "qualitative modelling can be useful in its own right and that quantification may be unwise if it is pushed beyond reasonable limits" (p. 227). His use of "Qualitative Politicized Influence Diagrams" (QPID) is an example of using system dynamics methodology but stopping short of the mathematical modeling stage (Coyle 2002). Wolstenholme (1990) shares this point of view by considering that the phase of diagram construction and analysis could be considered itself as a qualitative branch of system dynamics. The use of qualitative data has, at the very least, been cause for debate about whether or not to simulate based upon qualitative materials.

The formulation stage

This stage, positing a detailed structure and selecting the parameter values, can also contain elements of qualitative data. In regards to the formulation of qualitative concepts, Richardson and Pugh (1981, p. 160) suggest, "the modeler may wish to represent such a concept explicitly. To do so requires the invention of units and a measurement scale, and consistent treatment throughout the model." The importance of the inclusion of these qualitative constructs in models is stressed by Sterman (2000, p. 854). "Omitting structures or variables known to be important because numerical data are unavailable is actually less scientific and less accurate than using your best judgment to estimate their values." Nonetheless, this is the area in which system dynamics practitioners have questioned the use of qualitative variables. Nuthmann (1994), for one, states that there is a basic problem with modeling social judgment. He asked, "Can psychological variables be treated with the same mathematics as physical variables?"

Richardson (1996), in fact, devotes a section of his article on future problems in the field to the issue of qualitative mapping and formal modeling (pp. 148–150), using the term "qualitative systems thinking" (p. 149). He presents a balanced set of arguments, looking at the positive and negative discussion and effects of using qualitative data approaches. In the final analysis, however, Richardson (p. 150) provides a series of questions—future research issues, rather than a set of guidelines for the systems modeler:

> What are the system conditions that suggest that a qualitative mapping approach can produce reliable inferences? What are the conditions under which a qualitative mapping may yield unreliable or false inferences? Are word-and-arrow maps showing explicit stocks and flows more reliable, although less accessible, for various practitioners or audiences? What are the implications of packaging systems insights in systems archetypes? Do archetypes limit or expand people's capabilities to reason in circular causal settings? Finally, is it possible to state conditions which require quantitative modeling?

These questions get at the heart of the matter for system dynamics, but the methods of answering these qualitative questions are not easily apparent. It is appropriate to use qualitative data for some aspects of the modeling process, but the formalization stage seems to be the area where there is greatest concern about its applicability.

The testing stage (model behavior and model evaluation)

Forrester and Senge (1980) go into great detail in describing 17 tests at this stage of model development. For example, in the structure-verification test (p. 416):

> The model must not contradict knowledge about the structure of the real system. Structure verification may include review of model assumptions by persons highly knowledgeable about corresponding parts of the real system. Structure verification may also involve comparing model assumptions to descriptions of decision making and organizational relationships found in relevant literature. In most instances, the structure verification test is first conducted on the basis of the model builder's personal knowledge and is then extended to include criticisms by others with direct experience from the real system.

This particular test is not the only one in which Forrester and Senge make implicit or explicit references to qualitative data, but it serves here as an example of the sort of face validity issues that can be addressed at the testing phase.

Randers (1980, p. 129) notably makes a very strong statement about the use of qualitative data in the testing process:

> In judging how well a model meets the listed criteria, the modeler should not restrict himself to the small fraction of knowledge available in numerical form fit for statistical analysis. Most human knowledge takes a descriptive nonquantitative form, and is contained in the experience of those familiar with the system, in documentation of current conditions, in descriptions of historical performance, and in artifacts of the system. Model testing should draw upon all sources of available knowledge.

Randers (1980, p. 119) described this testing process as asking if "the basic mechanisms actually create the reference mode" and if "the assumed relationships are reasonable." These are areas that could profit from quantitative as well as qualitative knowledge of experts, although actual simulation must determine if the structure generates the model behavior.

Besides the traditional testing techniques of a model, Sterman (2000) points out the "practical and political issues of modeling. There are no value-free theories and no value-free models." As a part of the testing process, "Model users must ask about the modelers' biases (and their own). How do these biases, especially those we were not aware of, color the assumptions, methods and results?" (p. 851).

The implementation stage (policy analysis and use)

Finally, the last step of the modeling process is implementation. Here the modeling team needs to transfer study insights to the users of the model. This is a process of describing the model to individuals who are not necessarily modelers themselves. This is a qualitative process that requires discussion more than examination of parameter values and equation formulation. Furthermore, the interpretation and use of simulation results by policy makers pose several important challenges associated with understanding the many types of judgments needed during the model-building process, and the judgments needed to assess and use the output of the model (Andersen & Rohrbaugh 1992).

Thus, upon looking at Coyle, Richardson and Pugh, Andersen and Rohrbaugh, Roberts *et al.*, Randers, Wolstenshome, Sterman, and Forrester and Senge, it seems apparent that the question is not *if* to use qualitative data, but *when* and *how* to use them appropriately. Forrester and Senge (1980, p. 218) unwittingly highlight a critical issue for this paper in their use of the passive voice. With such phrases as ". . . observed in a real system," ". . . are observed in the real economy," and ". . . have been observed" they highlight the need for specific research into *who* does observing, *who* is the expert, and *how* this information is elicited from the observer.

To that end, the following sections review the ways that social scientists and system dynamics practitioners could collect and analyze qualitative data to the benefit of their models and clients.

Current use of qualitative research methods in system dynamics models

Examples of models that use qualitative variables are numerous. Forrester's classic models considered some of these qualitative concepts—*Quality of life* in the world model, *quality* and *attitude toward quality* in the corporate growth model, and *awareness of advertising* in the advertising models constitute some of these examples.

However, the ways in which the qualitative data obtained from the mental and written databases are incorporated into model formulations is not always evident. Chapter 14 in Sterman's (2000) book presents an interesting way to use qualitative data in the formulation of nonlinear functions based both on observed qualitative data and structured interactions with clients or client groups. As an illustration of the former case, Sterman presents the way in which Oliva (1996) "tested his model through a detailed field study of retail lending operations in a major UK bank. Through interviews, archival data collection, and participant observation, he gathered extensive data on the operations of the bank's major retail lending center" (Sterman 2000, p. 569).

In a different example (Chapter 13), Sterman described how Jones and Repenning (1997) formulated a decision policy as a nonlinear weighted average on the basis of their fieldwork at a major motorcycle-producing facility. The formulation is grounded in the results of interviews conducted with engineers in the organization, and illustrated with quotations from those interviews.

Perhaps the richest set of examples of modeling tools that deal with qualitative and judgmental data, and their incorporation in model formulations resides in the group model building literature (Reagan-Cirincione *et al.* 1991; Vennix *et al.* 1992; Morecroft and Sterman 1994; Richardson and Andersen 1995; Vennix 1996; Andersen and Richardson 1997; Vennix *et al.* 1997).

Qualitative data collection techniques that support system dynamics model building

This section reviews the basic categories of qualitative data collection in the social sciences. In particular, it looks at interviews, oral history, focus groups, Delphi groups, observation, participant observation, and experimental

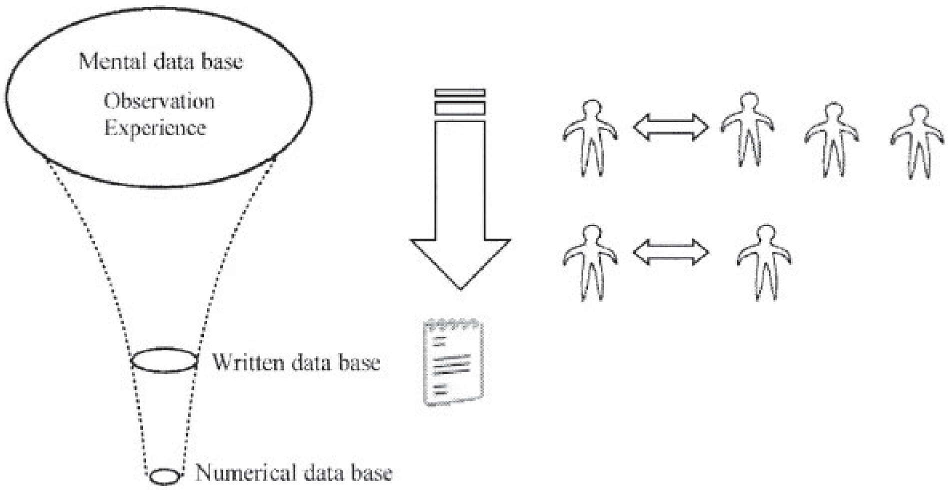

Fig. 2. The use of qualitative data collection as a tool to "retrieve" the mental database for the written database

approaches that lead to qualitative data. In all cases the system dynamics modeler is being asked to think in a new way about activities that he or she is already doing. In particular, the modeler is being asked to think more formally (scientifically) about the collection and analysis of qualitative data (see Bell and Bell 1980; Graham 2002), which has his own rules and methods (Babbie 1992; Bernard 1999). This change in thinking might require taking a class in qualitative methods or reading the noted texts that specifically describe how to elicit, record and analyze qualitative information.

As suggested in Figure 2, the authors conceptualize the data collection strategies used in the social sciences as a set of "retrieval" tools whose aim is to "query" the mental database, storing the results in the written database. The modeler interacts with individual actors, as in the case of interviews and oral history, or with actor teams or groups, as in the case of observation, focus and Delphi groups.

Interviews

Interview research is a mainstay of social science qualitative data collection. The interview, either in person or over the telephone, allows for interaction between the researcher and the respondent. This interaction can be structured, driven by a carefully worded interview script that channels the topics of the interview. It can also be highly unstructured, allowing the respondent to tell stories, give examples, and often unearth issues that the interviewer finds novel or counterintuitive. Interviews allow for clarification of definitions, elaboration on topics, and collection of the respondent's own words or usage in a way not supported by questionnaires or surveys. The researcher often asks permission to record the interview, and to quote the respondent anonymously in research reports. A strength of interviews is in the qualitative data that the researcher collects. The main role of the interviewer is to guide the dialog, clearing up any confusion before the interview is over, and remaining neutral so that the respondent's remarks are not biased by the behavior of the researcher (McCracken 1988). After conducting a number of interviews, the researcher will analyze the data, looking for patterns, definitions, stories, and lessons that cut across the material elicited from all respondents. Additionally, during and after the interview the researcher looks for dynamic hypotheses—stories about how dynamic systems work—and tests these hypotheses by asking for more specific information, or presenting the developing causal story and asking the respondent to comment upon it.

Oral history

Thought of as a mainstay of historical research, oral history has some critical differences from interviews. Oral histories are interviews of individuals in which the researcher records the words of the respondent, guiding the direction of the discussion and looking for stories rich in detail and explanation. Upon returning to the office, the researcher transcribes the results of the interview, editing out repetitions and cleaning up the record in a print format. After this editing the researcher sends the oral history back to the individual to make sure that it is an accurate representation of the respondent's thoughts and stories. Oral histories become part of a public record and often part of volumes devoted to a particular point in history. They are rarely anonymous and often the end product of the researcher's work.[4] Nonetheless, within the realm of system dynamics it might very well make sense to create oral histories for courseware, giving students good dynamic descriptions from which they can create models. Additionally, oral histories that have been verified by the respondent are an important way of preserving the thinking of experts in the field, especially if they have keen and insightful stories about how the world works.

Focus groups

While researchers conduct interviews and oral histories with one person at a time, the next several data collection techniques elicit information from groups of respondents who interact with each other in the research environment. Focus groups, similar to group model building exercises, rely heavily upon respondents building off each other's experiences and remarks. Eight to twelve individuals brought together for an hour are usually ideal. The role of the researcher is again that of guide, keeping the group focused and making sure that all respondents are heard while in particular guarding against one or two individuals taking the floor. Often the researcher is part of a team, with roles assigned for recording, leading, and analyzing the data that come out of the focus group. The team will often meet after dismissing the focus group members, taking the time to analyze what has occurred, and what lessons or new concepts emerged from the data collection (Morgan 1997).

Delphi groups

Delphi groups are an extension of focus groups, although they can also be used with survey or interview analysis. The researcher asks individuals, in whatever group format, to create a list of critical issues (e.g., policies, competencies, or causal factors). The researcher's initial job is to collect and collate this list.[5] Rohrbaugh has developed techniques to do this data collection asynchronously through listservs and online discussion lists.[6] After collation, the researcher sends the materials back to the respondents, individually or in a second Delphi group, asking the respondents to rank order the list according to some standard set by the researcher. This could be most to least important, or, for example, into larger groups of "critical," "valuable," "nice but not necessary," or "unnecessary." Although full consensus of the group is not always possible, the researcher will arrive at a good understanding of the critical issues under discussion, both where there is consensus and where there is disagreement among group members. Rowe and Wright (1999) discuss some methodological problems in the use of the Delphi technique, as well as possible ways to overcome them.

Observation

Observation is "fly on the wall" research. If done carefully, and ethically, it can produce a wealth of information about social structures, culture, process, and human interaction (Brewer and Hunter 1989). Nonetheless, it is difficult for a researcher to watch and to collect data for a long period of time without in some way affecting the environment he is watching. There is also the ethical issue of whether or not the researcher needs to announce her presence in the social situation. Sometimes it is enough to obtain the permission of a supervisor or upper level staff member, if the research is unobtrusive, and the means to an important end.

Participant observation

In order to avoid the ethical issues of strict observational data collection, participant–observer research assumes that the researcher will interact in a study situation. The researcher needs to be aware that his behavior could affect the results of the study. For both observation and participant observation, the standard data collection methods are notebook diaries and collections of documents, if any, produced by the group being studied. This method of data collection can be paired with interview collection in order to unearth individual motivations or behaviors that are not immediately obvious in a group setting (Lofland and Lofland 1984).[7]

Experimental approaches

Data collection through experiments can take a wide variety of formats (Babbie 1992, Chapter 9). An example of such an experiment might be asking individuals to perform a search task on the Internet, videotaping their performance. The researcher could look for numeric data—how many key strokes it took to get to a particular result, or qualitative data—verbal cues that would indicate how comfortable the respondent was with the task. This paper particularly focuses on the second case, where the data collection process will produce qualitative results. These data could be concerned with willingness scales before or after an intervention, with quality, satisfaction, or perceived productivity before and after training or instruction. When the data show different visions of the problem, the modeler can talk with actors to reach consensus. If it is hard to go back to the actors or reach consensus, then she needs to keep a record of the differences, perhaps designing a series of parametric or structural sensitivity analyses.

Qualitative data analysis

As described in the previous section, most qualitative data collection techniques are devoted to the elicitation of knowledge about a particular problem, enriching the written database to be used in the modeling process. Although some of these techniques involve some data processing, there is still the problem of how to translate the texts obtained through this process into a system dynamics model (Figure 3). The analysis techniques presented in this section constitute alternatives developed by social scientists, which the modeler can use to ground with textual information the assumptions used in the model-building process and to build a robust documentation of the model. Additionally, quotations from the texts can help the modeler to build "rich stories" containing the main insights from the process in order to communicate model results or to promote constructive dialog among the problem actors.

Hermeneutics

Derived from biblical exegesis, social scientists have applied the hermeneutic method to any kind of text, including conversations, images or videotapes. The main purpose of hermeneutic analysis is to find meanings and how they are connected to the expression of culture. Social scientists use this method to identify contextual explanations (in the same text or in the surrounding

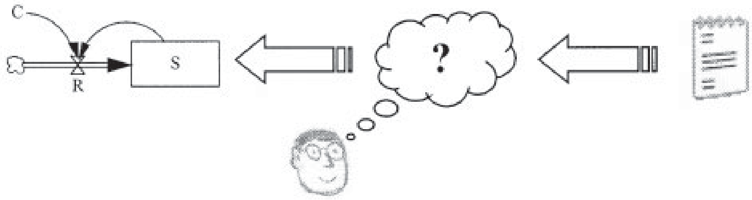

Fig. 3. A pictorial representation of the gap in the incorporation of textual information into system dynamics models

culture) of apparent contradictions found in textual data (Bernard 1999). Forrester (1975a, p. 161) uses a hermeneutic approach when he describes the use of observations and conversations with problem actors. "This material is sifted and compared. Cross-verification and contradictions are sought. Similarities begin to emerge between the new information and previous systems which are already understood."

Discourse analysis

A qualitative method used to study interactions among people in the context where they occur naturally, discourse analysis can be used any time the modeler selects observation as a method to collect data. Once the observations are transcribed, the researcher selects the pieces of text related to the problem under study. In a way similar to other interpretive analysis techniques, the researcher transcribes chunks of text, followed by a commentary that extracts the wisdom and understanding that the specific passage adds to the research effort. Bernard (1999, p. 442) describes how Waitzkin *et al.* (1994) used this method to understand how topics such as aging, work, gender roles and socio-emotional problems are treated in encounters of older patients and primary care internists. In a system dynamics modeling effort, texts could be describing behavior over time for a specific variable or a causal structure inside the group's mental models. The "commentary" following the text can take the form of a reference mode or a feedback loop to be included in the formulation of the model.

Grounded theory

Perhaps one of the most interesting textual techniques for the modeler is grounded theory. Consistent with the focus on meanings of hermeneutics and discourse analysis, grounded theory consists of a set of techniques to identify themes or concepts across texts. However, one of the main objectives of grounded theory resides in linking these concepts to generate meaningful theories. Since "linking" is at the heart of system dynamics, grounded theory speaks to the same goal of drawing relationships among factors in a targeted system. The texts used in grounded theory range from promotional ads to transcriptions of interviews, memoranda, meeting minutes or any kind of textual data. In applying the technique, the researcher develops a set of categories or concepts that emerge across the texts (and these texts can be the transcripts of interviews, focus groups or observations). These categories could become stocks and flows for a system dynamics model, or ratings of a particular variable (e.g., very difficult to very easy) that could be quantified by the modeler.

Thus, in the particular case of system dynamics, these themes can be variables, dynamic behaviors, or policy-related topics. Every theme is "grounded" in a set of quotations or exemplars across the database of texts. The data associated with the categories identified are pulled out from the database in order to be compared and analyzed, in order to link them and build formal theories. The theories created must be iteratively contrasted and compared with the data, especially against negative or contradictory cases. The result of this kind of research is a model of a theory that is usually presented illustrated by exemplars from the text.

Memoing is a widely used technique in the theory building process. The modeler writes down all his thoughts that surface during the coding process, similar to the notes taken during an interview or a participant observation process. These notes are the basis of the model developed during the process (Strauss and Corbin 1990). Although the identification of themes could be done with printouts of the texts and color markers, there exists specialized software to help the researcher during the process (NUD*IST and ATLAS.ti are two of the most widely used software tools).[8]

Ethnographic decision models

One of the main challenges in the model building process is to understand the decision processes or policies that govern the rates of the system. Ethnographic decision models are qualitative analyses oriented to understand why a person makes a decision in a determined circumstance. The method can be used to analyze one-time decisions such as adopting a particular technology or implementing a particular quality program, but also recurring decisions (policies) such as recycling behavior or staffing policies. The researcher's interviews are oriented toward a specific decision or policy in the system, for example why people decide to engage in an information technology initiative. After interviewing several actors, the modeler can build a decision tree (or dendrogram) describing the decision alternatives and processes. Although an ethnographic decision model can grow indefinitely, most social scientists test the predictive ability of the model, looking to account for at least 80 percent of the decisions with the smallest set of rules (Bernard 1999).

Content analysis

Content analysis is a powerful technique that can be used in the identification of reference modes and parameter estimation from textual data. Content analysis is a deductive coding technique, in the sense that the researcher starts by defining the set of codes to be used in the process. Once the analyst defines the codes, she applies them systematically to a set of texts. Researchers who use this technique are concerned about the reliability of the coding process, and have developed some statistical measures to test the level of agreement between coders such as Cohen's Kappa. Researchers organize their data into a matrix of codes and texts according to the unit of analysis selected for the study (for example, a paragraph or a memo). They then can analyze the matrix using almost any statistical method. As in any quantitative approach, sample selection becomes an issue any time that the modeler is interested in statistical inference (Weber 1990).

All of the above techniques present challenges for the system dynamics modeler. They require moving between qualitative and quantitative techniques, constantly testing to ascertain if the data indeed mirror the reality of the system under study or the client's mental models. For example, the modeler could combine content analysis of interview data with grounded theory techniques as a confirmatory step during the testing stage of the model building process. Given the vocabulary of social science research, and the techniques to elicit qualitative data, the modeler can add to his tool bag of techniques that make better models. This is the essence of using qualitative data in model building. Using these data does have costs in both time and effort. The next section discusses both the limitations and the advantages of using qualitative data in system dynamics models.

Limitations and costs of qualitative methods

There are several tradeoffs when choosing to collect and analyze qualitative data. Collection of such data takes time. Interviews, experiments and observation are both time and labor intensive. The preparation for such data collection, in terms of interview protocols, surveys, or observation sheets is formidable. Furthermore, analyzing such data is much more labor intensive than conducting numeric analysis of quantitative data sets. There are costs associated with transcribing interviews, with coding documents, and with reading and rereading materials to be sure of patterns and meanings. Testing alternate theories or challenging the structure of a model based upon second rounds of interviews is also costly in time and labor. The tradeoff is in the results from such techniques. Qualitative data collection and analysis, when done properly, are ways of bringing formality and rigor into the modeling process. They add richness and details that numbers cannot provide. They also allow for insights about the mental models of experts in the field and the variety of individuals' understanding about meanings and connections, and uncover the complexity of real world systems through detailed stories and descriptions.

Table 2. Conceptualization and potential qualitative methods

Steps in the modeling process		Qualitative methods potentially useful
Conceptualization	Problem definition	Techniques that can be used for problem identification and elaboration of a dynamic hypothesis • interviews • oral history • focus groups • hermeneutics • discourse analysis • content analysis
	System conceptualization	

Proposed applications and uses of qualitative research methods in system dynamics

The results of this exploration into qualitative research can be conceptually pictured as a set of matrices that map specific applications of qualitative data collection and analysis on the steps in model building and on the tests for building confidence in system dynamics models. These initial matrices constitute a set of suggestions that are neither final nor definitive. The only limits for the application of these techniques to the different stages in the modeling process are the researcher's imagination and creativity. (See Table 2, 3, 4, and 5.)

Conceptualization

Among the qualitative data gathering techniques described in the previous sections, the authors consider such techniques as interviews, oral histories, and focus groups to have great potential for the system dynamics researcher (Table 2). The researcher directs the flow of questions and information in such data gathering exercises and can carefully elicit rich stories from participants' mental databases. Hermeneutics and discourse analysis fit the needs of initial conceptualization efforts particularly well since they emphasize finding connections and patterns in the qualitative data—a critical aspect of creating dynamic hypotheses. Similarly, content analysis has potential in the construction of reference modes based upon textual data, extracting behavior over time from individuals' descriptions of dynamic phenomena.

Researchers and practitioners in the field recognize the need for interviews with problem stakeholders or clients in early stages of any system dynamics project. During these early interviews, the modeler gets an initial understanding of the problem, and identifies the main variables and constructs involved in it. Although the initial contact is frequently through individual interviews, some researchers also work with groups to develop problem understanding. The concrete contribution of social science methods is to provide a rigorous approach in the development of these tasks. Social scientists have identified several kinds of interviews, ranging from the informal conversation to standardized, closed, fixed-field response interviews.

Vennix (1996, Chapter 4) provides a series of guidelines for conducting semi-structured interviews for model conceptualization, and a 4-step protocol to elicit feedback loops in an interview. In Chapter 6 of the same book, he describes techniques to elicit causal structure from groups. Richardson and Andersen (1995; Andersen and Richardson 1997) describe alternatives consistent with focus group techniques.

Both semi-structured interview and focus group techniques recognize the complexity associated with conducting the interview or facilitating a group session while building a model. Recording and revisiting notes from the interview as well as from documents collected along with the interviews is an important activity to refine conceptual understandings about the problem. Procedures and activities suggested by hermeneutics and discourse analysis are consistent with this iterative modeling process. Revisiting the sample of texts looking for contradictions and alternative hypotheses serves as a safeguard against biases in the process, and keeps a record which facilitates model documentation or the explanation of the model rationale.

Finally, content analysis serves to build reference modes on the basis of memoranda, minutes from meetings or other textual information. It is common in the social sciences to assess the importance of a theme or variable for a group by counting the instances of this topic in a sample of documents through time. For example, Verner and his colleagues (Verner *et al*. 1999) registered the number of citations per year for Brooks classical book *The Mythical Man-Month* from 1974 to 1999, finding an oscillatory pattern of citations over time. Although the purpose of Verner's paper was not dynamic modeling, it constitutes an example of the use of content analysis to derive reference modes from text.

Formulation

Model formulation (Table 3) is a stage for which qualitative data could appear less useful. However, it is very common for system dynamicists to include variables and nonlinear relations for which quantitative data are not available. In the particular case of nonlinear functions, even when numerical data exist, "they often do not cover a wide enough range to reveal extreme values or saturation points" (Sterman 2000, p. 585). Under these circumstances, modelers use judgmental data to build the model, and qualitative techniques have the potential to add formality to the process. Some techniques appear to be more useful to obtain parameters and policies to be included in the model, such as interviews, focus and Delphi groups, observation, and content analysis because they elicit critical information from individuals, groups or texts. Others, such as grounded theory and ethnographic decision models, can guide and

Table 3. Formulation and potential qualitative methods

Steps in the modeling process		Qualitative methods potentially useful
Formulation	Model formulation	Techniques to obtain parameters and policies: • interviews • focus and Delphi groups • content analysis • participant observation Techniques to guide model formulation: • grounded theory • ethnographic decision models

enrich the identification of key structures and formulations, since they look for meaning and connections.

The most common way to elicit parameters and non-linear relations from problem owners is through the use of interviews and group sessions. Delphi groups can successfully elicit parameters from experts. The modeler asks group members to individually give an estimate for an unknown parameter. After collecting initial, individual judgments, the modeler gives back a summary of the values gathered. It is common to use the upper and lower limits and a central tendency measure such as the median or the mean. Once the group knows the results from the first round, the modeler asks for a second estimate. It is common to reach a reasonable level of agreement after three or four rounds. One can design sensitivity tests with different values when strong disagreement occurs.

A known problem of the technique is that the upper and lower limits serve as boundaries for following rounds, anchoring personal judgments to some value in the middle. While playing a key role to reach consensus, this anchoring can push the estimate away from the real value if it is outside the initial upper and lower limits. An important activity for the facilitator is to challenge both limits during the process.

Formulation of nonlinear functions is a highly qualitative process. Chapter 14 of Sterman's book contains several techniques to build such functions using data from participant observation (Sterman 2000, pp. 569–573) and interactions with clients (pp. 585–595).

From the authors' point of view, the system dynamics modeler is different from other mathematical modelers, and more similar to an ethnographer, because of the intense use of many sources of data in the formulation of rich feedback theories. In this way, techniques of grounded theory have the potential to enrich and add formality to the formulation process, by keeping track of changes, thoughts, and insights in the modeling process. The ethnographer doing grounded theory reads and revisits several times her database of texts looking for themes or variables relevant to the problem under study. She then pulls from the database of texts the data associated with the categories, comparing and analyzing to build causal theories to explain the problem, similar to a system dynamics analyst. Consistent with practices in both grounded theory and system dynamics, the theories (or models) created must be iteratively contrasted and compared with the data, especially against negative or contradictory cases.

Jay Forrester's practice in building system dynamics models provides a fine example of "memoing" (described previously in the section on grounded theory). He formulates models in an iterative way, gradually adding new elements to the structure. Every time he adds a piece of structure to the model, he runs a series of experiments and analyzes the behavior produced by the model, keeping a log in a lab notebook along with copies from the model output and the thoughts emerging from these partial experiments.

Although system dynamics models' focus is on policy rather than decision rules, rules derived from ethnographic decision models also have potential as guides for the modeler in the form of "reality checks" (Peterson and Eberlein 1994). Reality checks involve the introduction of a series of logical statements involving plausible behaviors of the model as a result of a given constraint. For example, a simple reality check for a project model could be "No effort, No progress." This logical statement is translated into an equation in the model, which can be tested at any point during the modeling process.

Testing

Table 4 shows the qualitative tools that have applicability during the testing stage. The authors recognize the existence of advanced statistical techniques to calibrate system dynamics models, and their potential use to estimate unknown parameters (Graham 2002). Although these techniques are powerful aids to assess models, they cannot stand by themselves because of the intrinsically qualitative nature of system dynamics models. Their use is also limited when the modeling effort is guided by reference modes based on judgmental data. In this way, the modeler needs to ask for expert assessments about model structure and behavior through the use of interviews, focus or Delphi groups.

Vennix (1996, Chapter 6) described an approach based on "workbooks" to conduct model assessment with individuals or groups. The workbooks conform to specific questions about causal relations and behavior of the model. Some questions are oriented to measure the level of agreement with a specific causal link using Likert-type scales. The interviewee is asked to establish not only his level of agreement, but also to explain the reasons of the agreement or disagreement. An alternative way to present questions to the expert is to show her a specific piece of model structure, asking her to challenge it and to suggest alternative theories.

An important constraint of the workbook proposed by Vennix is the assumption that the expert understands the language and symbols used by the system dynamics modeler, which may not always be the case, even when the expert has been involved in a modeling intervention. For example, one of the authors

Table 4. Testing and potential qualitative methods

Steps in the modeling process		Qualitative methods potentially useful
Testing	Analysis of model behavior	Techniques to obtain expert judgment about model structure and behavior • interviews • focus groups • Delphi groups • experimental approaches
	Model evaluation	

recalls a conversation with a client around a stock-and-flow structure with some feedback loops. Although the client had about a year of experience working in the project, he slowed down the conversation several times to decode and understand the model structure.

In a similar approach to model assessment, Rich (2002) prepared a workbook with behaviors of key variables for several scenarios in his model. He used this workbook to engage in personal interviews with experts in the subject, assessing the feasibility of each scenario and each behavior. He transcribed and analyzed each interview transcript to assess the model on the basis of the expert's judgment. As a result, he got a detailed list of the main strengths and limitations of his model that he could use for further model refinement.

Both approaches described above "extract" from the model the main issues to be considered by the expert, framing them as questions in a workbook. In this sense, the expert is exposed only to the parts of the structure and behavior chosen by the modeler. However, it is also feasible to ask the expert to interact directly with the model in a computer, following an experimental approach. In this case, the modeler will facilitate the interaction, registering both the elements of the model that the expert prefers to explore, and the motivations for the exploration.

Policy analysis and implementation

Finally, Table 5 contains the main qualitative techniques that can be used in the stages of policy analysis and implementation. During this stage, the techniques can test specific policies, create insightful stories about policy experiments, and generate discussion among the problem actors about these results. Experimental approaches help with policy analysis. Oral history and grounded theory help make sense from the simulation results and the modeling process itself by providing a record of the ways in which variables or pieces of structure were formulated or reformulated along the way. Finally, group techniques generate discussion among actors about the meaning of both the results of the policy experiments and the stories generated by the model.

In oral history, discourse analysis, and grounded theory, the modeler also uses the learning accumulated during the modeling process. That is to say, the

Table 5. Implementation and potential qualitative methods

Steps in the modeling process		Qualitative methods potentially useful
Implementation	Policy analysis	Techniques to test policies • experimental approaches Techniques to create insightful stories to communicate model results • oral history • grounded theory • discourse analysis
	Model use	Techniques to generate discussion among problem actors • Delphi groups • focus groups

modeler can use quotations from the database of text as exemplars to help the model tell the client story, using the same vocabulary and context in order to clarify policy options and implementation possibilities.

The uses of qualitative data and data analysis in system dynamics are rich, and could be richer still. The authors' perception is that many system dynamicists use to some extent various techniques described in this paper, but in many cases following their intuition without more formal training. The literature described in this paper has already provided instances of the use of qualitative methodologies. An exploration of system dynamics articles will undoubtedly lead to current practice in the field. Finally, live forums such as system dynamics conferences will allow for discussion and greater insights into how qualitative data could be effectively and validly used to create better models.

Future research

The methodological framework described in this paper suggests at least four different, but related research threads.

As suggested in the previous section, an immediate research project could be oriented toward the analysis of a sample of papers involving system dynamics modeling in order to describe the current use of techniques by practitioners in different areas. This kind of meta-analysis would reveal the current and best practices in the use of textual data in the modeling process.

A second thread concerns the conversion of mental data to textual data. Experts have rich stories to tell. These stories are in the form of mental models that exist nowhere on paper, and that, in fact, might never have been verbalized by even the expert himself. Although social scientists and oral historians concern themselves with eliciting stories from their respondents, system dynamicists might very well need to create their own methods for extracting critical dynamic data from the stories that others tell.

The third thread is related to the development and testing of formal protocols involving qualitative social research techniques to support the modeling process. The application of these protocols in one or more case studies could lead to specific recommendations to enrich system dynamics practice.

Finally, experiments involving the use of some of these techniques with textual data across a variety of system dynamics modelers would help to look for similarities and differences of interpretation among them. The comparison of approaches followed by experienced modelers would capture an understanding of the mental processes involved in the modeling process. This design is inspired by a discussion on the system dynamics list about how to build software to extract models from text (Richardson 2002). The use of some of the tools described in this paper will help to make more transparent modeling processes by helping modelers to ground their feedback theories in the information gathered through the textual data presented in them. Making a more transparent process could promote constructive dialog among modelers with regards to points of disagreement such as the quantification of soft variables and the suitability of the use of qualitative mapping versus simulation. System dynamicists would do well in committing to make and test better processes for using qualitative data techniques, while at the same time clearly communicating these processes, formal or not, so that others can evaluate and learn from them.[9]

Research in the social sciences requires that findings be hypothesis-driven. Social scientists worry about the replicability, reliability and generalizability of their findings, whether research is qualitative or quantitative. They worry about sample size and random selection of respondents. These issues all fall under the heading of rigorous data collection and analysis. Without formal, well-understood mechanisms for collecting and analyzing qualitative data it is easy to say that these data are flawed or biased. By introducing strong, sound qualitative methodologies, system dynamics can add to its tools for creating models, strengthening the modeling process by systematically eliciting the information contained in the mental databases of the experts.

Notes

1. This diagram is used here and in subsequent figures with the permission of its creator, Jay W. Forrester.
2. Some readings describing in detail the techniques presented in the paper, as well as providing examples of their use and limitations are Westbrook (1999), Babbie (1992), and Bernard (1999).
3. See Roy and Mohapatra (2003) and McLucas (2003) for a discussion of problems associated with the incorporation of soft variables in system dynamics models.

4. See the Department of History, University at Albany website, Talking History, Aural History Productions http://talkinghistory.org/, which includes oral history materials.
5. Babbie (1992, p. 496) suggests that the Delphi method requires anonymous input so that individuals of different ranks in an organization are on equal footing.
6. See Richardson and Andersen (1995) for a discussion of group model building techniques, and Martinez and Richardson (2002) for an example of using Rohrbaugh's online discussion lists in identifying best practices in system dynamics modeling.
7. See Brewer and Hunter (1989, p. 44ff.) for a discussion of participant observation in particular, and field work in general.
8. Additional information about both applications can be found in their websites: http://www.qsr-software.com/ for NUD*IST and http://www.atlasti.de/ for ATLAS.ti.
9. The authors would like to thank the reviewers who provided comments on an earlier draft of this paper, which was presented at the International System Dynamics Conference in Palermo, Italy, July 2002.

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