From Narrative to Number: A Role for Quantitative Models in Scenario Analysis

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Abstract: There is growing concern that the predictive mathematical models conventionally used in policy analysis are too limiting to serve as tools in futures studies, because they cannot reproduce the sudden changes seen in real societies. The field of complex systems has successfully produced similar changes in simplified model systems, but has been less successful in practical futures work. Some recent scenario exercises (such as the IPCC scenarios, UNEP's GEO-3 scenarios, the work of the Global Scenario Group and the European VISIONS project) have addressed this issue by combining wide-ranging narratives with quantitative models, demonstrating that a synthesis between qualitative and quantitative approaches is possible. However, there is no consensus on an appropriate methodology. In this paper it is argued that there are essentially two analytical challenges that scenario models must address in order to achieve the goal of more robust planning in the face of both gradual and sudden change. One is to represent complexity, while the other is to represent what might be called "complicatedness." Complex behavior arises from the interrelatedness of different components of a system, while "complicatedness" as used here means that there are a lot of factors to keep in mind—constraints, actors, resources, etc. It will further be argued that complexity is best dealt with in narratives, and complicatedness is best dealt with using computers. The characteristics of appropriate computer models will be presented, and extant exemplars of appropriate models described.

***Keywords**:* Scenarios; Modeling; Futures Studies; Complex Systems.

1. INTRODUCTION

From its earliest inception, there has been a tension in Futures Studies between the use of qualitative and quantitative techniques. At times this has taken the form of a contest. Modelers, in particular, have cast themselves as the guardians of rigor in a field struggling to gain legitimacy, and it can perhaps be argued that in the past decade, with the increasing use of Integrated Assessment (IA) models and Computable General Equilibrium (CGE) models, quantitative approaches have dominated. Yet there has always been an argument for combining narrative and number (see, e.g., deLeon [1984]) and recently, as the weaknesses of quantitative models have once again become apparent [Smil, 2000; DeLeon, 1997; Höjer and Mattsson, 2000], there are increasing calls for balancing qualitative and quantitative approaches in futures work.

In this paper, we join the chorus of authors calling for change, arguing that a robust scenario emerges from the interaction between the quantitative and qualitative contributions. For evidence of the usefulness of a synthetic approach, we can turn for examples to recent scenario exercises, such as the IPCC scenarios [Nakicenovic and Swart, 2000], UNEP's GEO-3 scenarios [UNEP, 2002], the World Water Visions scenarios [Cosgrove and Rijsberman, 2000], the work of the Global Scenario Group [Gallopín et al., 1997] and the European VISIONS project [Rotmans et al., 2000]. However, despite the considerable work that has been done, there is no consensus on how to go about synthesizing qualitative and quantitative scenario approaches. As a contribution to this emerging type of futures work, we offer a set of methodological guidelines for a successful synthesis.[1]

Key to the approach described here is a distinction between *complexity*—the subject of complex systems theory—and what we call *complicatedness*—merely keeping track of the numerous factors, such as physical-economic-social relationships, that can influence a scenario. It is argued in this paper that complexity is best dealt with using traditional qualitative scenario techniques, while quantitative models—especially computer models—are best suited to keeping track of complications. In this view, the narrative drives the scenario development, while quantitative models are developed in response to the narrative.

2. MODELS: COMBINING NARRATIVE AND NUMBER

A model is a representation of a system. A good model behaves sufficiently like the real system that conclusions can be drawn from the model's behavior to aid in making decisions about the real system. How "good" a given model is therefore depends on its purpose. In traditional policy modeling, comprehensive, predictive mathematical models have been the norm. However, this sort of model has a poor record when confronted with the complex nature of social systems [Rihani, 2002]. In Vinay Lal's pithy remark, "Since the human being is the one unpredictable animal, many planners for the future find *Homo sapiens* to be a rather unpleasant reminder of the impossibility of a perfect blueprint" [Lal, 1999]. In contrast, more "intuitive" scenario exercises, presented in narrative form, have captured some of the surprising features observed in real social systems.

Of necessity, both mathematical studies and narrative exercises employ models, although of very different kinds. In the mathematical approach the model is explicit, as a set of mathematical formulae, a computer program, a diagram in Stella, or some other formal representation that can be translated into a sequence of numerical calculations. In the narrative approach the model is generally implicit in the form of the narrative, which reflects the shared mental model of its authors. There are advantages and disadvantages to both the mathematical and narrative approaches. The challenge is to combine narratives with formal mathematical analysis in a way that builds on the strengths of the two approaches.

What are those strengths? There are essentially two analytical challenges that scenario models must address. One is to represent *complexity*, while the other is to represent *complicatedness*. By "complexity," we mean the behavior of complex systems, as described by complex systems theory. In particular, it refers to the behavior arising from the interrelatedness of different components of a system, a feature of real systems that helps make the world so interesting. In contrast, by "complicatedness" we mean the sort of bookkeeping that is necessary when there are a lot of factors to keep in mind—constraints, actors, and resources.

People are quite capable of thinking in terms of complex systems, but they are not in the habit of doing so. Many futures techniques that result in a narrative description of the future seek to draw out this latent ability, mainly by encouraging people to think "outside the box." Computers can also represent complexity. Mathematical models with very few variables, but with nonlinear interactions between the variables, or agent-based models that feature interacting agents following simple behavioral rules, can exhibit a striking array of features that parallel those seen in real systems. They key insight arising from these studies is that simple rules can lead to rich and unexpected behavior. However, the state of the art in computer modeling of societies as complex systems is too crude for applied work. Instead, it is best suited for academic studies, to learn more about the nature of complexity and to broaden thinking about social dynamics.[2] Thus, people are good at modeling complexity in real social systems, while computer models have a way to go. In contrast, people are rapidly overwhelmed by mere complication, while computers are very good at keeping track of complicated situations. This is one reason why the spreadsheet and the database became the first "killer apps" of the personal computer revolution.[3]

For these reasons, in this essay it is proposed that a scenario model should consist of two components: a set of narratives and a set of mathematical models. The dividing line between the two is not fixed, but generally the narratives should focus on the complex nature of the system and on its evolution, while the computer-based mathematical models should handle the complicated features of the system, to assist the scenario developers in making a consistent and coherent narrative.

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[1] For a different approach to a synthesis, see Alcamo [2001].

[2] The view expressed here closely matches Kohler's characterization of "Weak Social Simulation" [Kohler, 2002].

[3] Rotmans [1999] also draws a distinction between "complexity" and "complication" when describing computer models for integrated assessment. However, in contrast to the position argued in this paper, Rotmans believes that complexity should be incorporated in the computer model. We would argue that while it may be appropriate for a complex model to describe the biophysical components of an IA model, it is not appropriate for the societal components, given the current state of the art.

3. QUANTITATIVE MODELS AS A RESPONSE TO A NARRATIVE

In the discussion below, the task of building a combined narrative and quantitative scenario is broken out into two subtasks: narrative writing and mathematical analysis. Although the same person or group of people may do both subtasks, more often they are carried out by different people with different sets of skills. In this essay, the two groups will be called the "narrative team" and the "modeling team."

In the approach urged in this essay, the narrative drives scenario development, while the modeling team follows the narrative team's lead. However, the process is not all one-way: the quantitative analysis also informs the narrative scenario development.[4] Taking this reciprocal influence into account, there are four main roles that quantitative scenario development can play when implemented in response to a narrative:

1. Force a clarification of terms and mechanisms.
2. Expose contradictions in mental models.
3. Provide a feel for the scope of possible outcomes within a narrative framework.
4. Illustrate a particular scenario narrative.
5. Make a study replicable, extensible and transferable.

The first two items provide direct feedback to the narrative team about the content of the scenarios. The first is simply the result of constructing a rigorous statement of what the narrative writers mean. This is always a good thing to do, and the task of making a formal mathematical model is a particularly useful way in which to do it. If a narrative is to be translated into a formal structure—especially one that is to be coded in a computer—then many potentially ambiguous points must be nailed down and key decisions must be made. This process sharpens the narrative analysis, as the narrative team is forced to address its ambiguous goals and statements. Note that this salutary outcome is not reached when the quantitative model drives the analysis, and the narrative follows from it. In this case, the mathematical model has been built by people (the modeling team) who have already encountered ambiguities and resolved them in ways that may or may not be acceptable to the people using the quantitative outputs [van der Sluijs, 2002]. The decisions are not made jointly between the narrative and modeling teams, so they do not provoke discussion.

The second item—exposing contradictions in mental models—highlights a key role that scenarios play, that of fostering cognitive development and learning [Chermack and van der Merwe, 2003; Robinson, 2003]. Constructivist theories of cognition and learning posit that people actively construct mental models through which they filter their experiences. Those mental models are remarkably resilient, and are relinquished only when they are shown (repeatedly) to be inconsistent—either internally inconsistent or inconsistent with external reality [Kempton et al., 1997; Yankelovich, 1991]. Narratives reflect the mental models of their authors, and by translating them into formal terms, contradictions can be exposed, either through the process of developing the formal model or through manipulating the model. This benefit of modeling exercises often goes unnoticed, because generally when a formal model does succeed in changing the narrative team's mental model, it is not mentioned in the written report. There are at least two reasons for this. First, researchers do not report their conceptual errors—they report the understanding they achieve through their research. Second, when someone's mental model changes, it is extraordinarily difficult to capture the original pattern of thought. Whatever the reason, it is a pity that the insights are not reported. Incorrect mental models are widely shared, and are likely to be held by many readers of the report. If they are not explicitly addressed, they are likely to persist.

The third item, that of providing a feel for the scope of possibilities within a narrative, offers indirect but generally very useful feedback to the narrative team. How responsive is an outcome to changes in some parameter or condition? Within a "backcasting" exercise, how constraining are the long-term goals? What level of action might be required to achieve them? What is the scope for alternative approaches? Even with the simplest formal models, results from this type of exploratory exercise can be surprising. A perceived constraint may turn out not to be so constraining, or not the main factor determining the evolution of the scenario; an undesired outcome may turn out to be avoidable only with heroic efforts; and a factor that is initially small may turn out to be surprisingly large by the end of the scenario period. While less profound in its implications for the scenario narrative than the revelation of a contradiction or an ambiguity, exploring the boundaries of the model can provide valuable insight to both the narrative writers and the model builders.

[4] Some recent scenario exercises, such as the IPCC scenarios, the VISIONS project, the GEO-3 scenarios and the scenarios of the Global Scenario Group have employed this basic approach of developing quantitative scenarios in response to a narrative, and have mentioned the two-way flow of information. However, the approach described in this essay differs in some ways from those exercises.

The next item—illustrating a particular scenario narrative—is an opportunity for narrative writers and model builders to share their insights with others and invite external critique. The narrative, refined by interaction with the model, is finalized and disseminated, along with quantitative figures—one or more "illustrations" that emerge from the exploration of the model boundaries.

The final item states that by encoding key decisions by the narrative team into an agreed set of quantitative models, the model structure can be reused, either by the original team or another team. Potentially, this offers great advantages. By making the model explicit, it can be subjected to outside review. However, there is also a danger that formal models will be reused uncritically. A central feature of the combined narrative and numerical approach proposed in this essay is that the narrative and modeling teams engage in a mutual critique. When a set of scenarios generated in this way is adopted by others, or reused, it should again be subjected to critique. One way to encourage this is to always start fresh, with a new set of narratives, but allow the modeling team to reuse an existing set of models if they seem appropriate for those narratives. That is, computer models should be "cannibalized" for parts, not reused wholesale. Over time, a modeling team could develop a code base of "parts" to bring into play for different scenario exercises.

4. APPROPRIATE MODELS

What are the characteristics of an appropriate quantitative model for scenario development? Bell [1997] lists four schools of computer modeling: input-output analysis, econometrics, optimization, and system dynamics. None of these in isolation is particularly well-suited for the tasks outlined above. The problem with each, at least as they have conventionally been used, is that they attempt to encapsulate too much of the system being studied. In these approaches, there is little scope for a narrative team to redirect the analysis. The narrative team may envision an abrupt shift in circumstances—e.g., of the same magnitude as the fall of the Berlin Wall, the events at Tiananmen Square, the spread of HIV/AIDS, or the demonstrations against the World Trade Organization—but in general it will be difficult to represent it within an existing quantitative model. This is not to say that such models cannot be useful. In fact, they can provide very important insights and a well-defined structure to a scenario exercise, but they are not best suited—when used in isolation—to the development of wide-ranging scenarios.

Another type of model is needed. In fact, examples of appropriate models already exist, but their common features have not (to the authors' knowledge) yet been enumerated. Below, we list the desired characteristics. In addition, we provide what is essentially a job description for the modeling team.

Appropriate models for exploratory scenario analysis should:

1. Represent the narrative.
2. Reflect fundamental constraints (e.g., land and energy balances, economic balances).
3. Reflect the spatial and temporal scales of key processes.
4. Offer several "levers" (although not too many) for the narrative team and other users.
5. Implement likely correlations.
6. Reflect a knowledge of the relevant literature.

These conditions place considerable demands on the modeling team. Not only must it have access to a variety of modeling techniques but it must also be cognizant of the literature in various fields. The modeling team is also required to represent whatever narratives the narrative team might produce. The modeling team must try to identify the model implicit in the narrative, and interpret it in a formal mathematical model. This requires flexibility and creativity. Perhaps even more demandingly, the conditions above require the modeling team to yield up a large measure of control to the narrative team. That is, what the modeling team should produce is not a predictive model, although it may have causal components (such as a demographic cohort model). Instead, it should produce a model that allows a narrative team to explore a numerical "neighborhood" of possibilities that is consistent with its narrative. The main role the quantitative model plays is to take care of complications, by keeping track of constraints and correlations. The complexity of the system—arising from the mutual interactions between its constituent parts—is addressed principally by the narrative team.

Some examples of suitable models will be given in the next section. However, before proceeding to them, a comment is in order about the fifth and sixth points in the list above. The fifth point states that "likely correlations" should be implemented. This is perhaps the most heterodox suggestion in this paper. A common complaint against econometric models, as traditionally used, is that they interpret empirically correlated data as being causally related, when that might not be the case. Elaborate analysis and relatively large and dense data sets are necessary to demonstrate causality, so such analyses are only carried out in a few contentious cases. In the approach proposed here, however, models need not be causal—for many purposes, correlations are sufficient. This is because causal connections should be captured in the narratives (where they should be made quite explicit), while the quantitative models should explore the likely consequences of those narratives to aid the narrative team in making consistent narratives. One way to do this is by exploiting likely correlations.

An example can help clarify this point: An economically liberal narrative may describe rapid economic growth in a context of liberalized markets, while saying nothing about transport choices. But if the environmental implications of the narrative are of interest, then transport should be considered. In this case, empirical correlations between economic output per capita and transport patterns might be introduced by the modeling team. If they are, then the modeling team should inform the narrative team, which may respond by either accepting the empirical pattern or explicitly stating in the narrative that the historical pattern is broken.

Such an approach is not without its dangers: it is only too easy to interpret a correlation as a causal link, and to treat correlations as laws of nature. An open mind equipped with a pragmatic mind-set is required for this task.

The sixth point is that the model should reflect a knowledge of the relevant literature. In practice, this implies that the modeling team should have a grasp of the literature on a diverse range of technical fields, such as economics, engineering, urban studies, ecology, agronomy, etc. But saying this does not mean that they need to be experts in those fields. They should not, for example, expect to be able to do basic research in the fields. Perhaps a reasonable benchmark is that they should not be surprised by something that would not surprise an expert in the field. Even this level of understanding is unlikely to be reached by a modest-sized team over a wide range of topics, but to the degree it is approached, it should enable the modeling team to converse meaningfully with subject experts and allow the modeling team to supply references, provisional parameter values and insights to the narrative team when an expert is not on one of the teams.

5. EXAMPLES

There already exist models that meet many of the criteria listed in the previous section. Three examples are discussed below. The list is intended to be illustrative, and is far from exhaustive. These examples may function as exemplars for those wishing to do an exercise of the sort described in this paper. While none of the examples below is a causal model, this possibility is not ruled out. For example, stock-flow models and cohort models could easily satisfy the requirements for an appropriate model as proposed in this paper, and if a narrative suggests a particular causal, predictive model then it may be appropriate to introduce it.

One sector-specific example is the PODIUM model of the International Water Management Institute (IWMI).[5] PODIUM is implemented as a Microsoft Excel workbook, and is intended to be used by decision makers in an interactive session. The decision maker moves through a sequence of pages, making choices about possible future developments on each page. At the end, the implications of the decision maker's choices are presented in terms of agricultural water use. The PODIUM model meets several of the criteria of an appropriate model as envisioned in this paper: 1) it reflects a narrative (a basic "development" narrative that matches the framework of the target audience); 2) it reflects fundamental constraints (e.g., constraints on food production); 3) it offers several "levers" for the decision maker to manipulate; 4) it reflects a knowledge of the relevant literature.

An example of a model that incorporates several sectors is the model developed for the Georgia Basin Futures Project (GBFP).[6] This study intends ordinary citizens to be enlisted as narrative writers. The GBFP team developed a wide array of possible narratives, and built structurally simple (but not simplistic) mathematical models that cover the range of futures allowed by those narratives. The user is offered a series of choices, and as with the PODIUM model, once the model is run the implications of those choices are presented to the user. The GBFP model satisfies all of the criteria for an appropriate quantitative model, according to the framework presented in this essay.

The final example is that of the "convergence algorithm" of the PoleStar team for the Global Scenario Group (GSG).[7] While many aspects of the GSG scenarios fit the conditions for an appropriate model as outlined in this paper, the way that the fundamental narrative of convergence was implemented deserves special mention. To give coherence to the illustrative quantitative scenarios, the PoleStar team introduced an algorithm, called the "convergence algorithm," for calculating energy intensities, emission factors and activity levels in developing regions [Kemp-Benedict et al., 2002]. This model meets four of the criteria listed in the previous section: 1) it implements the scenario narrative; 2) it reflects the temporal scale of technological change; 3) it

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[5] http://www.iwmi.cgiar.org/tools/podium.htm

[6] http://www.basinfutures.net/

[7] http://www.seib.org/polestar and http://www.gsg.org/

reflects a knowledge of the relevant literature, in this case the literature on dematerialization and technological leapfrogging; 4) it implements likely correlations, in that within the scenario narrative, rising income in developing regions leads to convergent patterns of consumption and resource use.

6. SUMMARY

The emerging realization that predictive mathematical models are limiting in futures work is leading to interesting new approaches in scenario development. Several recent scenario studies have attempted a synthesis of narrative and quantitative approaches. However, there is no consensus on methodology. This paper proposed a set of criteria for appropriate mathematical models (as well as for the modelers themselves) and discussed how models can be joined with narratives to make robust scenarios.

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