GUIDELINES FOR MODEL REFINEMENT

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ABSTRACT

Model building standards within the field of system dynamics are still evolving. This paper offers some general guidelines for development and presentation of refined models. Model refinement, the core of the modeling process, encompasses incremental structural and/or parametric changes to existing models. Development and presentation of refined models are enhanced through comparison of original and refined model behaviour and through comparison of policy response. Model comparison aids the modeler in identifying misspecification of new structure. In addition, presentation of comparison results assists the reader in evaluating the merits of the refined as compared to the original model, and helps to insure that the builder and user of the refined model is familiar with original model assumptions.

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I. INTRODUCTION

System dynamics models are proliferating around the world. Major research activites are underway in Scandinavia, Eastern and Western Europe, England, the United States, and Japan. As models become increasingly available, they serve as a valuable resource for additional modeling efforts. Some day the field may even see development of a LIBRARY OF NOTEWORTHY SYSTEM DYNAMICS MODELS. A researcher could go to such a library and find documented models on nearly any subject (whether forest management (Randers, 1976), urban land use (Stanley-Miller, 1975), or the population dynamics of subsistence societies (Shantzis and Behrens, 1973)). Rather than always having to create for each study a different "one-shot" model, future researchers will often be able to refine or extend one or more existing models to fulfill their desired goals.

The advantages of starting a system study from an existing model are considerable: (1) time can be saved in the lengthy and difficult initial conceptualization process; (2) rather than rediscovering the wheel with each study, researchers can instead build upon the insights of others; and (3) an existing model will have received some form of verification. Disadvantages of using existing models are also considerable: (1) time could be wasted if the model does not actually apply to the current problem of concern; (2) if the existing model is poorly formulated, the new effort may be built upon the mistakes of others; and (3) the existing model or

the policies tested on it could be unpopular to the extent that the results of the new study are "contaminated" by use of the disputed model.

If high standards were maintained by the curator at the LIBRARY OF NOTEWORTHY SYSTEM DYNAMICS MODELS, and only "respectable" models were listed in the card catalog, some of the disadvantages of using existing models might be reduced. Currently, however, there is no curator, no LIBRARY, and little agreement on how to maintain or evaluate model standards. As an interim solution, this paper offers some general guidelines for fruitfully extending the use of existing models. The guidelines refer to development and presentation of "refined" models. Model refinement, the core of the modeling process, encompasses structural and/or parametric changes to existing models. This paper provides a definition of model refinement and describes how and why behavior of the original model may aid development of a refined model. To clarify the discussion, the paper presents an example refinement based upon Jay W. Forrester's Urban Dynamics study (Forrester, 1969), which was refined to include residential and business land use (Stanley-Miller, 1974).

II. ISSUES IN MODEL REFINEMENT

Modeling is a process of continual refinement, interspersed with occasional discontinuous "revolutions." A study begins by developing an operational preliminary model that invariably has serious flaws. Although deficient, this preliminary model is useful as a vehicle for stimulating constructive criticism and focusing debate. A progression of models usually follows, with each "new" successful version "improving" the previous model so that the model better suits the purpose of the study. Typically, the process of model development continues until the modeler runs out of either time, money, or patience. At this point a particular form of the model is "frozen," documented, and described as THE MODEL, with an appropriate and exciting title. In fact, given additional time and money, the "frozen" model suddenly can be "thawed" into an active condition.

This process sounds linear and smooth; however, rather than making small changes to an existing version of a model, the modeler may attain a conceptual "breakthough," thereby introducing a completely new and revolutionary model. This new model again becomes a preliminary model for further refinement. Such breakthroughs typically lead to a more precise definition of model purpose. Consequently, once the modeling process enters the "post-problem definition" stage, characterized by a well defined model purpose and system boundary, there will be little likelihood of discontinuous "revolutionary" improvements. The modeling process becomes one of steady incremental refinement.

A. Definition of Terms

A brief definition of terms will be useful in explaining refinement:

Model refinement: a structural or parametric change to improve an existing model while retaining original model purpose and boundary.

Model purpose: the "problem" or behavior mode that the model's causal relationships depict. For example, Forrester's Urban Dynamics model sought to explain the internal causes underlying urban growth and decay. The model relationships embody an hypothesis about causes of central city unemployment, high taxes, housing

abandonment, and general deterioration in the urban quality of life.

Model boundary: The conceptual boundary dividing the model's endogenous feedback loop structure from exogenous influences. The boundary of a refined system dynamics model remains unchanged only if any feedback loops incorporated during model alterations remain completely within the original model boundary. New feedback loops may utilize variables which existed in the original model or new variables which were previously subsumed within the original model variables. For example, in the Urban Dynamics model, the category of underemployed housing subsumes both inhabitable low-quality housing and abandoned housing. Adding structure and feedback loops to represent explicitly abandoned housing would not change the original model boundary. On the other hand, incorporating feedback loops to include a suburban sector would require a change in the original boundary.

B. Reasons for Model Refinement

Policy Testing

Probably the best reason to refine an existing model is to represent real-world relationships that were too aggregated to be visible in the original model. Model refinement may then facilitate policy tests otherwise too difficult to perform or explain using the original model. For example, the land-rezoning refinement described in this paper permits an explicit representation of policy tests influencing land rezoning between residential and business uses. Without the rezoning refinement, evaluation of land-rezoning policies by means of the Urban Dynamics model would be difficult and misleading.

Improving Model Confidence

A second reason for refining original model structure is the desire to improve the model's correspondence to observed behavioral qualities of the real world. Improving confidence in a model may require structural or parametric refinements. For example, several parameter values in the Urban Dynamics model, such as total land area and total city population, do not correspond to typical values observed in American Cities. Parameter values of the original model were therefore refined to produce a more reasonable model, called UD2 (Alfeld, 1972). The UD2 model, although nearly identical to the original, is a more acceptable representation of American cities in terms of the magnitude of such variables as total land area and city population.

C. Original Model Behavior as a Reference

A refined model has a very special relationship with the original model from which it emerges. Both models have the same purpose and boundary. With relatively few exceptions, both models have an identical structure. The structure and parameters of the original model is itself a theory which shows how separate elements interact to produce observable phenomena. If the theory adequately reflects the behavioral relationships characterizing the real world, then model behavior should correspond to observable behavior (hopefully, for the same reasons in the model as in the real world). The refined model is also a theory which attempts to reflect similar aspects of real-world behavior. With consistent parameter definitions, the original and refined models should exhibit the same

behavior for any characteristic similarly represented in both models.

When refining a model, the modeler should continually compare the behavior of the evolving model with both real-world behavior and the behavior of the original model. There is a strong tendency to become intrigued with the latest version of a model to the extent that output generated by the previous model is ignored. In fact, comparing behavior of an original and refined model is very beneficial. First, this process helps detect and eliminate unreasonable or unconscious deviations from the original model. Second, during the course of model refinement, significant differences in model behavior will often reveal the inappropriateness of some element in either the original model portrayal or the model refinement.

For example, during the refinement of the Urban Dynamics model to include land rezoning, one particular initial formulation produced previously unseen oscillations in a variety of original model variables, such as labor. Analysis indicated that the new behavior resulted from an incorrect formulation of the land-rezoning sector. The addition of several important feedback loops eliminated the oscillation. Several major improvements in the land-rezoning sector have been achieved through attempts to understand and reduce differences in behavior between the refined and original models.

A final benefit of comparing behavior is that doing so forces the modeler to become intimately familiar with the original model. Understanding assumptions in the original model is especially important when a modeler is refining someone else's model. If the modeler fails to understand the assumptions in the original model, the model becomes a "black box" that may be altered or applied inappropriately. To insure proper use of original models during refinement and subsequent implementation, the modeler should be forced to present results comparing the refined and original models and to explain significant behavioral differences. This requirement would help insure that the modeler understands the original model upon which his refined version is based.

III. TESTING MODEL BEHAVIOR

Testing refined model behavior is an important part of the development and presentation of a model refinement. Two specific tests of refined model behavior include: (1) a comparison of behavior of the original and refined models; and (2) a comparison of policy response. The following discussion explains how to parameterize a refined model, and illustrates each of the two comparison tests.

A. Parameterizing the Original Model

Model comparison requires parameterizing (that is, selecting values for constants, initial conditions, and table functions) the refined model to replicate closely the behavior of the original model. Parameterizing a refined model to correspond to original model conditions is an important procedure. Several restrictions constrain the selection of values for refined model parameters. First, of course, new parameter values in the refined model must reaonably approximate their real-world counterparts. Second, parameters defined in exactly the same manner in both models should have identical values. During comparison, only new parameters introduced as a result of model refinement

or old parameters whose definitions may be altered by refinements may change. For example, when separating out the effects of land availability and land price on construction rates in the REZONE model, the modeler changed definitions of several *Urban Dynamics* model parameters. The alteration of definitions required new values for the affected parameters. In making a comparison of behavior tests, all parameter values in the REZONE model were kept identical to their original values in *Urban Dynamics*, with the exception of those parameters directly altered by the land-rezoning additions.

B. Comparing Model Behavior

After parameterizing the refined model to replicate the original, the refined model should yield, within reasonable limits, behavior similar to the original model. The "reasonable" limits depend on the degree to which the original model buried important dynamic behavior through aggregation or misspecification. Some aspects of original model behavior may change as a result of model refinement; however, new behavior should be explainable in terms of new variables and dynamics introduced through the refinement.

Figure 1 illustrates for comparison the behavior of the *Urban Dynamics* model and the behavior of the REZONE model. Compare Figure 1a with 1b. Growth rates, peaks, and equilibria of variables in both figures show great similarity. Of equal importance, the sequence of events, such as peaks and declines, also match. The two figures do have slight differences in growth and decline characteristics. In Figure 1a, for example, labor L peaks, and then declines to a stable equilibrium.

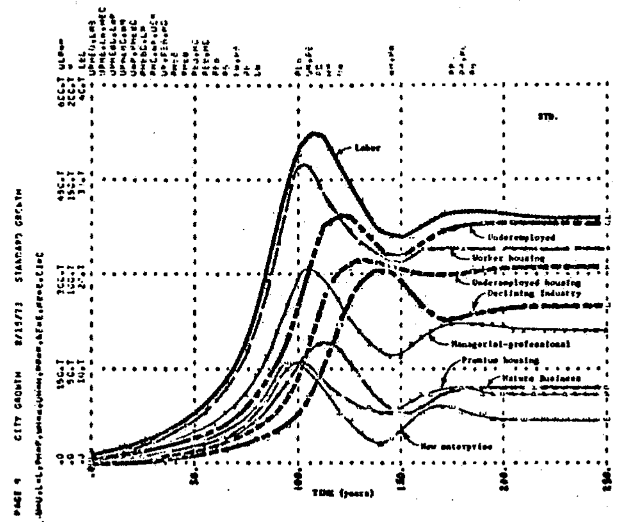

FIGURE 1a Standard Growth Run Urban Dynamics Model

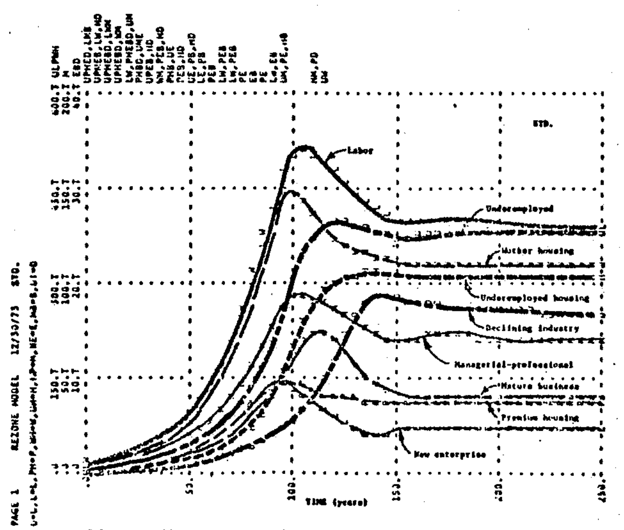

Figure 1b Standard Growth Run REZONE Model

Adding refinements which disaggregate the variables of an existing model typically alters time delays in the system. The overall behavior may not change dramatically, as depicted in Figure 1a and 1b, but changes in the dynamic response of the new model may affect the approach to equilibrium.

C. Comparing Policy Response

An important use of system dynamics models is to help determine the likely consequences of different policies. The relative desirability of various policies can be assessed by means of model simulation and analysis. An important issue in model re-refinement is whether alteration of the original model brings forth contradictory policy conclusions. A test of a refined model consists of analyzing response of the refined model to policy alternatives previously tested on the original model. When policies tested on an original and refined model produce substantially different conclusions as to the relative merit of a particular policy, attention should be focused on identifying the model changes producing the new results. The modeler should look for explanations of why the refined model behaves as it does. What are the interactions and relationships responsible for the observed dynamic behavior? Does the refined model need further improvement or is it in fact a betterportrayal of real-world conditions than the original model?

To illustrate the comparison of policy response, two policies tested on the <u>Urban Dynamics</u> model have also been tested on the REZONE model. To compare policy response, the REZONE model is brought to equilibrium conditions similar to those present in the <u>Urban Dynamics</u> model. Model equilibrium conditions exhibit symptoms of the urban problems that the proposed policies should alleviate. A comparative test of policy response must start with both models having the same definition of the problem as determined from equilibrium conditions. In addition, starting from similar equilibrium conditions facilitates the comparison of model responses.

Parameterizing a refined model to replicate behavior of an original model, as described previously, should produce fairly similar equilibrium conditions between the two models. Table 1 shows, for comparison, equilibrium values for nine important variables from the REZONE model and the Urban Dynamics model. The equilibrium conditions for the variables are nearly identical.

Variable	Equilibrium Value		
	Urban Dynamics model	REZONE model	Change (%)
Managerial-professional MP	71130	70790	-.48
Labor L	392550	389960	-.66
Underemployed U	377310	379040	+.46
Premium housing PH	110940	109610	-1.20
Worker housing WH	335650	327840	-2.33
Underemployed housing UH	310080	311610	+.49
New enterprise NE	4866	4817	-.80
Mature business MB	7806	7718	-1.12
Declining industry DI	16474	16647	+1.05

Table 1. Comparison of equilibrium conditions of the Urban Dynamics and REZONE models.

Low-Cost-Housing Construction

Urban Dynamics tests a policy of building low-cost-housing for the underemployed. Figure 2a depicts the behavior of variables from the Urban Dynamics model during the policy test. Figure 2b shows the same variables on the same plot scales for the identical low-cost-housing program policy test conducted on the REZONE model. A comparison of figures shows that variables from the REZONE model change in the same direction and with approximately the same magnitude as those from the original model.

The low-cost-housing program increases pressure for residential development. Because the city becomes more attractive for the underemployed, the population distribution within the urban area shifts toward a higher concentration of low-skill individuals. As Forrester points out in Urban Dynamics, "The higher land occupancy, unfavorable population ratio, and rising tax rate all combine to reduce the kinds of new construction the city needs most....The housing program, aimed at ameliorating conditions for the unemployed, has increased unemployment and has reduced upward economic mobility both in absolute numbers and as a percentage of population." (Forrester, 1969). The conclusions concerning the low-cost-housing program follow from an analysis of either the REZONE or Urban Dynamics model. Treating land rezoning explicitly does not significantly affect the outcome of the low-cost-housing program.

Urban Revival

The most effective policies for improving the urban area in Urban Dynamics consisted of simultaneously demolishing slum

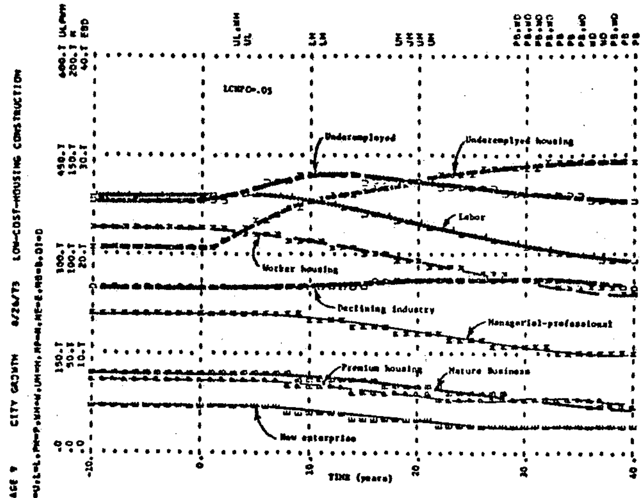

FIGURE 2a Low-Cost-Housing Program Urban Dynamics Model

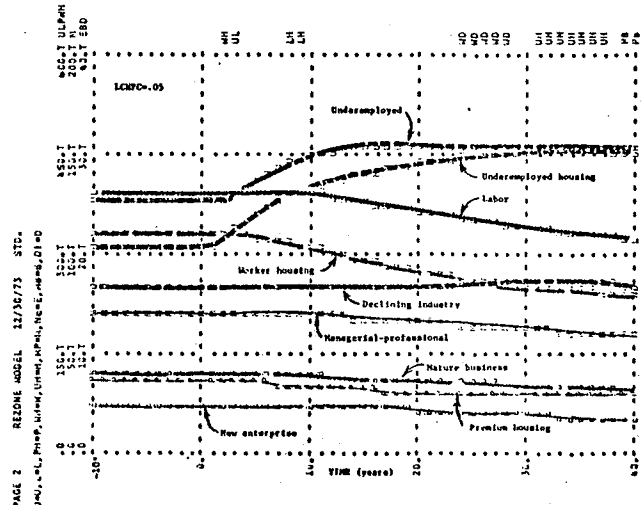

FIGURE 2b Low-Cost-Housing Program REZONE Model

housing and providing incentives for new enterprise construction. Figure 3a reproduces computer output from Chapter 5 of Urban Dynamics, in which the effects of demolishing 5% of slum housing each year and increasing new enterprise construction by 40% each year are modeled. Figure 3b shows the same policy test on the REZONE model. As in the case of low-cost-housing construction, the variables from the REZONE model move in the same direction, although in this case with a smaller magnitude, as the original model. The difference in magnitude reveals how a refined model may add clarity to the original, even when testing other policies than those for which the refined model was principally designed.

The REZONE model variable whose magnitude of change perhaps differs most from the original model is new-enterprise NE. In the original model, new-enterprise NE increases considerably as a consequence of the revival policies. The increase results from additional land becoming available through slum housing demolition and increased incentives for new business. The same policies, altough successful, are less effective in the REZONE model. In the REZONE model, slum housing demolition increases the amount of residential land RL available for development. Pressures must still develop internally to rezone this available residential land RL for business use. Industrial encouragement can not take place until residential land RL is rezoned for business development. Figure 4 depicts the behavior of REZONE variables during the urban revival policy test. Business land BL and residential land RL change little as a result of the policy. Almost no net rezoning from residential

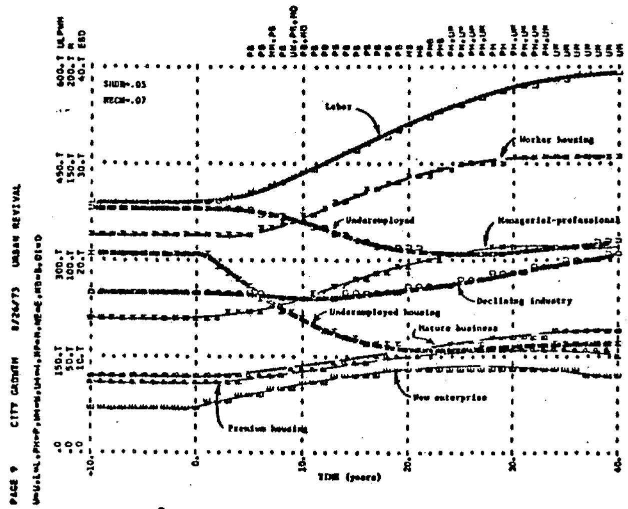

FIGURE 3a Urban Revival Program Urban Dynamics Model

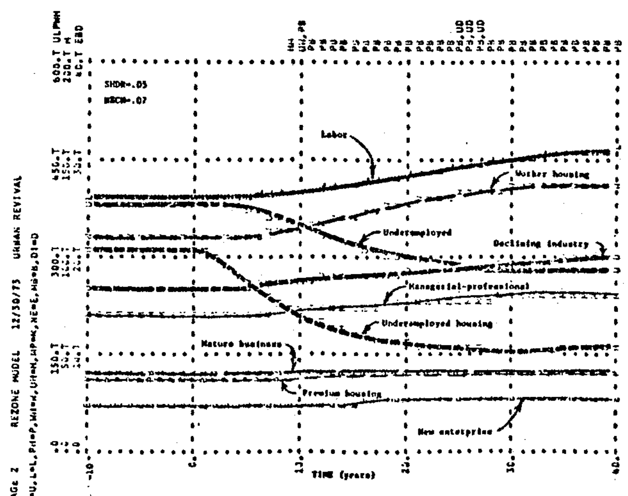

FIGURE 3b Urban Revival Program REZONE Model

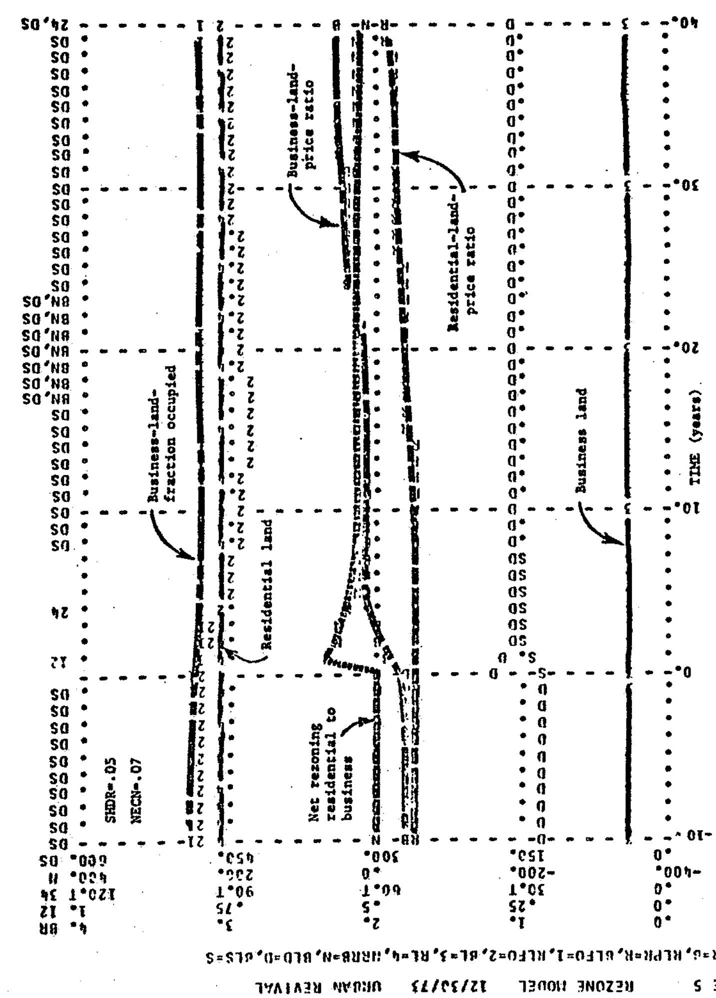

FIGURE 4 Urban Revival Program REZONE Model

to business use takes place. Apparently, rezoning alterations allocate only a small portion of land made available from slum housing demolition to business use.

In the _Urban Dynamics_ model all land cleared by slum housing demolition was assumed to be immediately available for business use. In the REZONE model, several internal pressures prevent the rezoning of all available residential land to business land. For example, pressure from housing conditions PFHC reflects the assumption that urban residents apply pressure to decrease rezoning of residential land RL for business use as slum demolition proceeds and the housing market becomes tight.

Urban Dynamics suggests that housing demolition and business encouragement policies may improve such urban conditions as unemployment, high taxes, and low economic mobility among underemployed. When tested on the REZONE model, the policies produce similar but less effective results as on the original model. The REZONE model, indicates that, for maximum effect, the revivial policies should also emphasize land rezoning to transfer land cleared by housing demolition to allowable business uses. Without land rezoning from residential to business uses, the policies become less effective at stimulating urban economic and social revival.

Original model behavior proved a useful guide in developing the REZONE model because of continuity in the original model purpose and boundary. When tested, REZONE model behavior compares favorably with original model behavior during both growth and policy analysis. The REZONE model either leads

to similar policy conclusions or adds further insights that do not contradict the results of the original model.

IV. CONCLUSIONS

System dynamics is a comparatively new approach to understanding social behavior and policy. Model-building standards within the field are still evolving. This paper offers some general guidelines for developing and presenting refined models. The presentation of any model (original or refined) should include, as a minimum, a statement of model purpose; a description of model structure; an explanation of model assumptions; and adequate documentation to allow easy reproduction of results. In addition, the presentation of refined models should include a detailed comparison of the behavior of the refined and original models. Model comparison assists the reader in evaluating the merits of the refined model as compared to the original, and helps to insure that the builder and user of the refined model is familiar with original model assumptions.

The following points summarize guidelines for performing model refinement:

(1) Make sure to understand the purpose and boundary of the original model.

(2) Make sure that the purpose and boundary of the refined model do not differ from the original model.

(3) Try to make only necessary changes to the original model, especially with regard to parameter values.

(4) Continually compare refined and original model output. Where differences in behavior occur, first check to see if any new parameters are unrealistic; next check new structure to see if important relationships are missing; finally try to collect further data to verify whether the original or refined model is a better portrayal of reality.

(5) Once overall refined model behavior is satisfactory, compare the policy response of the refined and original models. Differences in behavior should be explicable in terms of new structure.

(6) Avoid the tendency to add more structure than is necessary to achieve refined model goals.

(7) Avoid the tendency to ignore the original model once the refined version is operational.

(8) Avoid the tendency to think that the refined version is inherently "better" than the original, so that any differences are automatically assumed to be a result of inadequacy in the original model.

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