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Best Practices in System Dynamics Modeling

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Abstract

This research is set out to (a) discover of a set of *core* practices in the system dynamics modeling process and then (b) find the *best* of them according to the knowledgeable opinion of a world wide recognized group of experts in the field. The paper will address (1) what areas of the system dynamics modeling process are common to all model building regardless of the modeler, the model, the type of practitioner, the tool used or the purpose of the model? (2) Which of these areas can we describe as "best practice"?
We used a multi-method approach starting with interviews, then we conducted a virtual meeting with the former presidents and award winners from the System Dynamics Society to elicit the practices, and lastly, we developed a discussion on the results and the implications for further research.
The paper identifies 41 Best Practices grouped into categories of *problem identification and definition* (15), *system conceptualization* (8), and *model formulation* (11). Most importantly, the study identified seven practices of which experts appear to disagree.

Keywords: System Dynamics, Theory, Conceptual Framework, Best Practices, Modeling Process, and Knowledge Management.

Introduction: the importance of best practices

This research is set out to (a) discover of a set of *core* practices in the system dynamics modeling process and then (b) find the *best* of them according to the knowledgeable opinion of a world wide recognized group of experts in the field. It is an initial effort that will latter be extended to a wider group of practitioners. The paper will address (1) what areas of the system dynamics modeling process are common to all model building regardless of the modeler, the model, the type of practitioner, the tool used or the purpose of the model? (2) Which of these areas can we describe as "best practice"?
We used a multi-method approach starting with interviews, and included a virtual meeting with the former presidents and award winners from the system dynamics society. Elicited in that virtual meeting the *"best"* practices, and lastly, we developed a discussion on the results and the implications for further research.
The system dynamics literature brings together examples related to the concept of *"best practices"* from a number of threads. Start with the earliest work done by Jay Forrester in *Industrial Dynamics* (Forrester 1963) and *World Dynamics*

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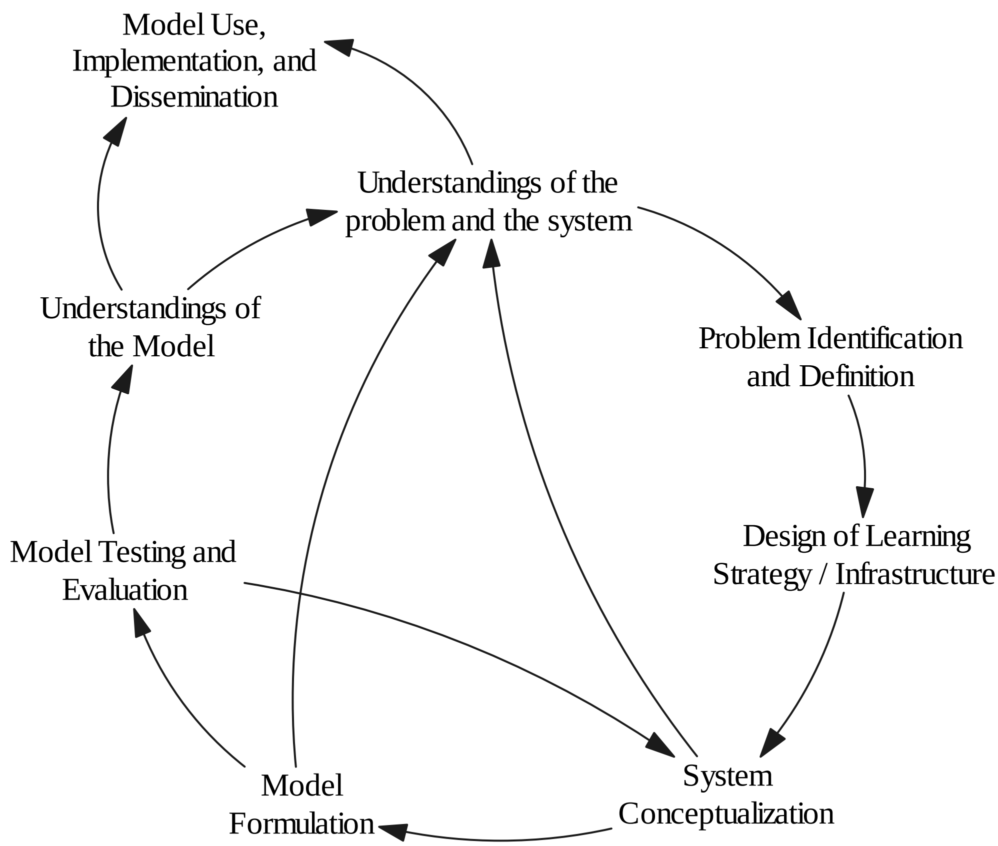
(Forrester 1973). Second, we find important collections of papers such as *Modeling for Management* (Richardson 1997) or *Modeling for Learning Organizations* (Morecroft and Sterman 1994). Thirds include specific pieces on what practices are currently used as *best* like *Benchmarking the System Dynamics Community* (Scholl 1995). Finally, we find textbooks in which we locate many, if not all, the best practices that are there in the field such as *Business Dynamics* (Sterman 2000) or *Introduction to System Dynamics Modeling* (Richardson and Pugh 1981).

Because the field has been expanding with respect to the types of systems modeled and the number of practitioners across the world, the different views of the field are multiplying and the need to agree on a set of "core" practices emerges. The set of practices identified in this paper should be independent of the type of system modeled, the tool used to develop it, the purpose of the model, and the type of practitioner or the individual modeler. Practices that meet these criteria are, by definition, *core* practices. Despite the accomplishments of many talented individual practitioners, the lack of concurrence over core practices makes it difficult to broadly evaluate system dynamics as a modeling practice and can prevent the field from continued development (Scholl 1992).

The system dynamics model building process involves six key activities as shown in Figure 1.The activities are (1) problem identification and definition, (2) system conceptualization, (3) model formulation, (4) model testing and evaluation, (5) model use, implementation and dissemination, and (6) design of learning strategy / infrastructure. We used these six activities as conceptual framework in this study. The key products are the understandings of the model and of the problem and the system.

Figure 1. – Overview of the System Dynamics Modeling Approach [Adapted from (Richardson and Pugh 1981)]



Method of Study

This research uses a multi-method approach that includes interviews, a web-based elicitation process, and an analysis of the results. The description of the method appears in Figure 2. We used the web-based participation method in light of its applicability as group decision support system and the fit to the needs[1] of this specific study (Rohrbaugh 2000).

[1] Having many people to contact geographically disperse and with very different time slots available for the study.

Figure 2. – Description of the method of study.

Process

1) Preliminary Interviews

A group of experts from the System Dynamics Group at Albany was interviewed to generate the framework to be used for the study.

The framework was generated and implemented in the research design and an asynchronous facilitated web-based meeting was selected to elicit the ideas from the participants.

2) WebWide Participation Meeting

Idea Elicitation

The experts wrote their ideas.

The lists were used as a trigger for new ideas.

Idea Clustering

The complete list per area was available for the participants.

The participants put together the ideas that belonged together in clusters.

The minimum common multiple was obtained for the clusters in which all participants agreed.

Idea Prioritization

The complete list of clusters was available for the participants.

The clusters were equi-weighted initially.

The participants changed the weights on the clusters to reflect their priorities.

The weights expressed by the participants became the realtive importance of the clusters.

Products

1) Raw Data (Appendix 3)

A series of statements directly typed by the participants are reported presented by area and priority.

The original clusters are presented as prioritized by the participants.

Four tables are presented, one for each area studied and one for the controversial statements.

2) Summary the Results (Section III of the paper)

The summary presents an slighly edited version of the raw data reducing each cluster to a single summary statement.

Again, four tables are presented, one for each area studied and one for the controversial statements.

As described in Figure 2, the facilitated meeting had three parts. These parts are consecutive and designed to generate the highest participation possible in the study. The parts are (1) idea elicitation, (2) idea clustering, and (3) idea prioritization.

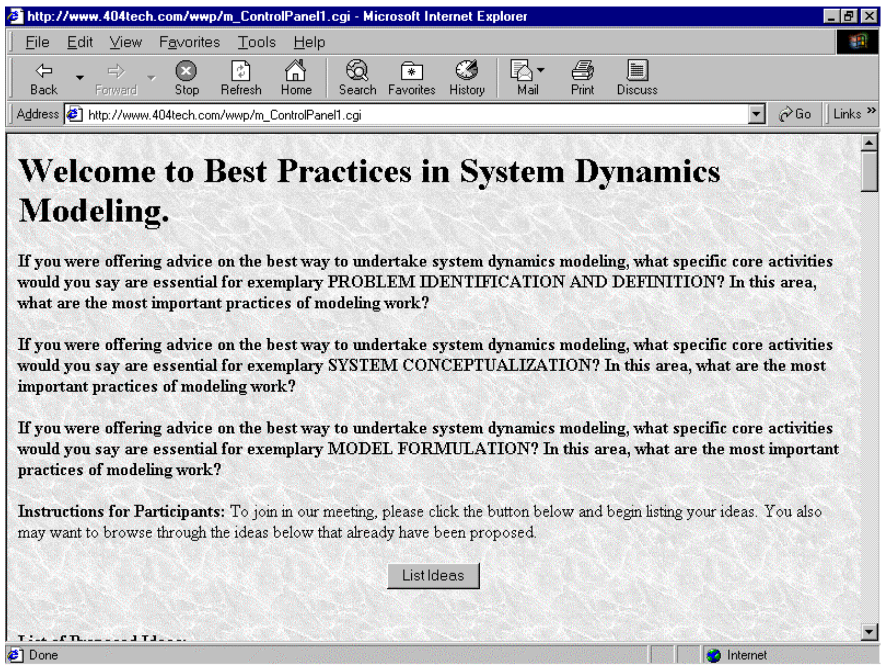
Participants of the Study

The group of people who participated in the research includes the former and future presidents of the society and the winners of awards from the society (Jay W Forrester Award and The Lifetime Award). We selected this purposeful expert sample to be able to have a group of individuals with the highest level of recognition in the field. One important consideration made regarding the composition of the sample was their busy schedules and the probable low-level time available for this project. Out of 23 people invited, only two declined at the very beginning due to time constraints. The participation level was 70%, 16 out of the 23 experts invited participated in the study.

The WebWide Participation Meeting

The total time span for the facilitated meeting was six weeks. All three stages each lasted two weeks. In the first stage, the participants listed ideas related to the *eliciting question* posted on the web site for the meeting. The participants browsed in the web and looked at a screen presented as Figure 3.

Figure 3. – Web Page for the Facilitated Meeting (Part 1)



The three elicitation questions for this part were:

(1) If you were offering advice on the best way to undertake system dynamics modeling, what specific core activities would you say are essential for exemplary PROBLEM IDENTIFICATION AND DEFINITION? In this area, what are the most important practices of modeling work?
(2) If you were offering advice on the best way to undertake system dynamics modeling, what specific core activities would you say are essential for exemplary SYSTEM CONCEPTUALIZATION? In this area, what are the most important practices of modeling work?
(3) If you were offering advice on the best way to undertake system dynamics modeling, what specific core activities would you say are essential for exemplary MODEL FORMULATION? In this area, what are the most important practices of modeling work?

After the two-week period of idea generation, the participants then clustered the ideas elicited in the first stage into categories that included ideas that they considered similar or that belonged together. Individually generated clusters were compared and extracted the minimum common multiple, or the ideas that everyone considered that belonged to the same cluster. The final *"group"* clusters were the ones used in the next part of the study.

In the third part, the participants assigned priority scores to the clustered ideas according to the relative importance of each one as essential for the particular area covered. To complete this task, the participants received the next set of instructions.

> **Instructions for Participants:** After clicking on the button "Prioritize Categories" you will see ***X*** categories with one to ten ideas listed in distinct clusters. At first, all ***X*** categories are shown with 100 points as equally important, but you may believe that some categories of best practices may be more or less important in specific area. You may raise or lower the 100 points for each category as you prefer: a category with 1000 points would be interpreted as a more important best practice by ten times a category with 100 points. Any time you click on a "Sort" button, your screen will be refreshed with all the categories reordered by your changes. The full set of ***X*** ideas is displayed below.

For *Problem Identification and Definition* 81 ideas were generated and placed in 49 categories, for *System Conceptualization* 65 ideas were generated and placed in 38 categories and, for *Model Formulation* 69 ideas were generated and placed in 42 categories.

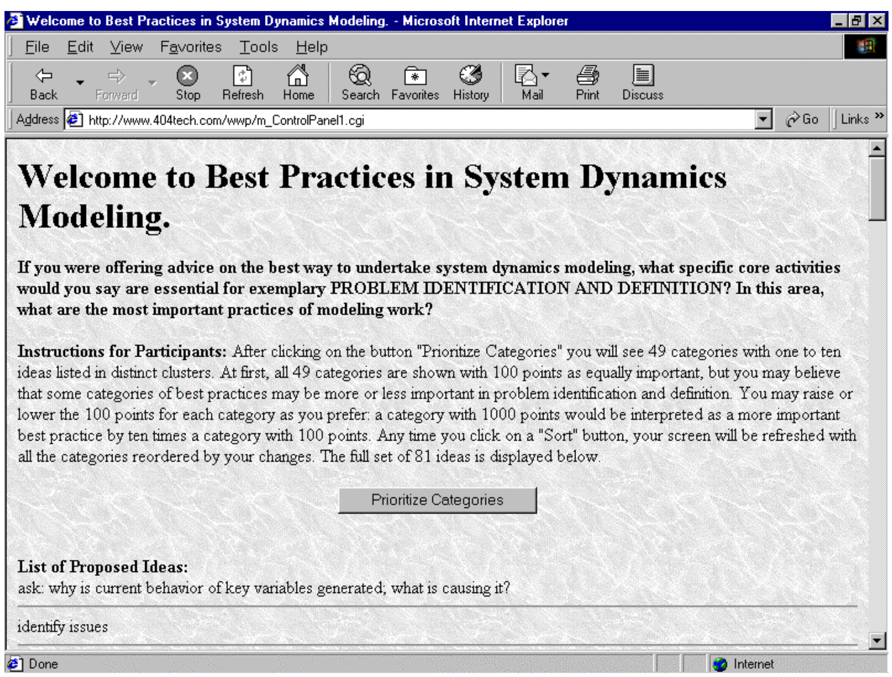


Figure 4. – Web Page for the Facilitated Meeting (Part 3)

Figure 4 shows the screen that the participants saw during the prioritization part of the meeting. Each participant used a different scale to evaluate the categories of practices; the sum of the ratings accounts for a total that served as a normalizing factor for the evaluations. Then it was accumulated with the others' responses and weighted to obtain the total relative assessment for the category or practice[2]. There were four thresholds chosen for the final selection process. The meeting was facilitated by 404 Tech Support (L.L.C.) that administers the WebWide Participation pages that were used for this study.

This paper reports on the first phase that included (1) Problem Identification and Definition, (2) System Conceptualization and, (3) Model Formulation. Phase 2 will include (4) Model Testing and Evaluation, (5) Model Use, Implementation, and Dissemination, and (6) Design of Learning Strategy/Infrastructure[3].

Summary of the Results

The results of the three-part meeting are presented [4] in tables 1, 2, and 3 below. These tables are part of what constitutes *best practice* in systems dynamics modeling as seen by the group of experts from the system dynamics society that participated in the study. Each table focuses on one of the three key areas of activity in system dynamics modeling – problem identification and definition, system conceptualization, and model formulation. – Each item in these tables summarizes a cluster of ideas generated by study participants and ranked highly by all participants. The exact words in Table 1, 2, 3 and 4 was selected by author team and represents a slight editing on one of the participants own words shown in the "raw data" tables in Appendix 2. Table 4 differs from tables 1, 2, and 3 in that it represents in summary form clusters of practices on which study participants disagreed. These are practices that tend to divide the opinion of leaders in the field.

[2] For details on the computation method, see appendix 1 of the paper.
[3] This area was not considered in the beginning of the study and was added thanks to an especially meaningful contribution to the project from a very committed participant, Barry Richmond. The authors want to acknowledge and thank his contribution.
[4] For the raw data, see appendix 2 of the paper.

Table 1. - Best Practices in Problem Identification and Definition

Highest Rated

1) Talk and listen reflectively to problem owners (clients).
2) Clarify the purpose (e.g. strategy/policy, theory building, education, training).
3) Identify the reference mode: The central "process" or time development to be studied and use reference mode diagrams to explore people's expectations of future behavior.
4) Ask why is current behavior of key variables generated, and what is causing it.
5) Formulate the dynamic hypothesis (i.e., "this behavior is caused by that structure").

Highly Rated

6) Clearly identify clients of the model or the person to whom you need to answer.
7) Identify and engage key stakeholders.
8) Describe clearly the symptoms that initiated the modeling proposal.
9) Identify carefully the time horizon and the time unit of the model (years, months, weeks).
10) Develop and sketch out desirable vs. undesirable futures of key variables over time.

Moderately Highly Rated

11) Verify whether problem stated by client is suitable for system dynamics study.
12) Form a study team consisting of technical people and system participants.
13) Generate a concise and specific dynamic feedback time-dependent problem statement.
14) Identify available time and budget for the study.
15) Identify all available data sources.

Table 2. - Best Practices in System Conceptualization

Highest Rated

1) Recognize that conceptualization is creative –there are no recipes– approach it from different angles and avoid rigid separation of the identification / conceptualization stages.
2) Generate a dialogue with the problem's owners that addresses their mental models and the dynamic hypothesis.
3) Start with major stock variables to describe the system, draw their reference modes and make sure their names are nouns, not verbs or action phrases.

Highly Rated

4) Set main goal to generate an endogenous dynamic hypothesis.
5) Be sure dynamic hypothesis boundary is large enough for endogenous orientation.
6) Identify key variables representing behavior.

Moderately Highly Rated

7) Be sure that each variable is measurable –at least in principal.
8) Look at all available data.

Table 3. - Best Practices in Model Formulation

<u>Highest Rated</u>

1) Start small / simple and build out / add complexity later quantifying the structure a bit at a time.
2) Leverage the power of dimensional consistency; use it from the very beginning.
3) Be sure equations make sense: all parameters must have real life (explicable) meaning.

<u>Highly Rated</u>

4) Set main goal to generate the smallest model that captures dynamic hypothesis.
5) Simulate as early as possible and often, testing even simple models extensively.
6) Discuss model and simulation outcomes with a study team that includes the client, and revise as necessary.

<u>Moderately Highly Rated</u>

7) Develop a small (<100 equations) prototype (full scope not detailed) and use it to test dynamic hypothesis and identify shortcomings.
8) Avoid making equations unnecessarily complicated and avoid chained table functions.
9) Bear bounded rationality in mind, especially in rate equation formulation (but also in general).
10) Try always to describe truthfully what happens in real world (limited rationality / information).
11) Take an apprenticeship (1 – 2 years) with an experienced system dynamics coach and acquire experience with many types of models from the literature.

Table 4. – Controversial Best Practices.

Problem Identification and Definition

1) Identify the class of systems to which the particular case belongs.
2) Model the class to which the case belongs, not the case at hand.

System Conceptualization

1) Iteratively sketch causal loop diagrams, identify state variables / levels, identify system boundary.
2) Draw the structure of your dynamic hypothesis as a causal-loop diagram if stock-and-flow structure presents difficulties. Concentrate first on identifying main connections and major loops (loop explanations for reference modes).
3) Identify / draw stock-flow structures (resources, customers, products / services) and identify influences on flows.

Model Formulation

1) Select a "*core*" piece of structure and grow from it (select / add / analyze) never straying too far from a running model.
2) Think of extreme condition tests in writing equations; simulate different extreme conditions and check if equations work in those conditions; otherwise modify the model.

Figures 5, 6, and 7 present the percentages of agreement across the different areas of study. We can see that the percentages are very similar. Roughly 66% of the issues received mixed or low priority ratings. These issues are called "*indistinct issues.*" The indistinct issues are those issues that were proposed by the experts as exemplary work in system dynamics modeling and the group did not ranked them even moderately highly. This means that for the individuals of the group two out of three clusters of ideas did not rank even moderately highly, even though the design invited all participants through the eliciting question to contribute examples of exemplary work in system dynamics.

Figure 5. – Percentages of Agreement on Clusters related to Problem Identification and Definition.

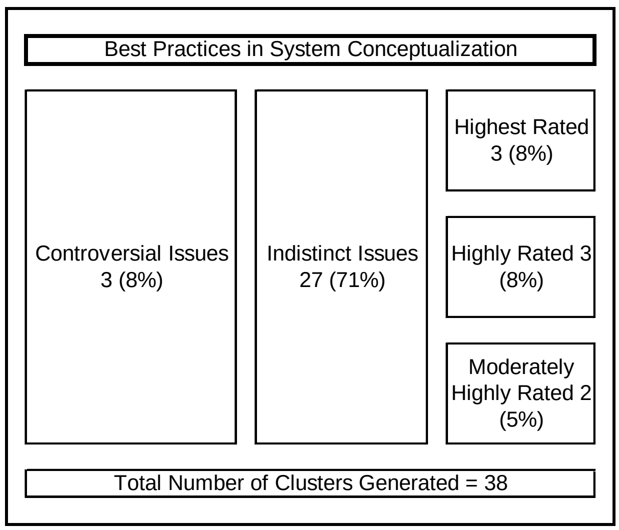


Figure 6. – Percentages of Agreement on Clusters related to System Conceptualization.

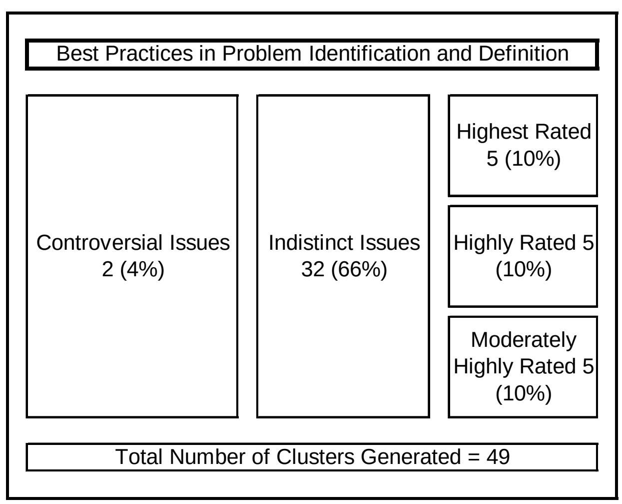
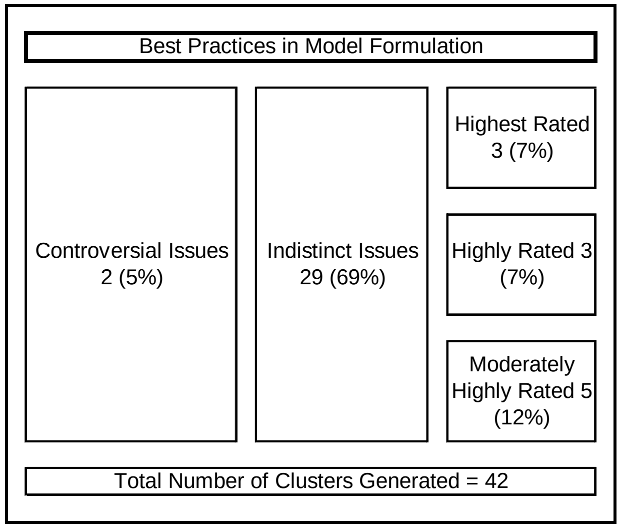


Figure 7. – Percentages of Agreement on Clusters related to Model Formulation.



In addition, we can see that the number of controversial issues is also steady, (between 2 and 3) which represents an average of 6 % of the practices generated.

Discussion and Conclusions

The main implications of this study group into four categories to (1) tangible results and their implications, (2) the general process followed in this study, and finally (3) the controversial category. The discussion and conclusions follow.

Tangible Results

The results of the study (Tables 1, 2, and 3) represent what these group of experts in the field think are the key elements in *problem identification and definition*, *system conceptualization*, and *model formulation*. There are no big surprises in these results. The distinctive element of these lists is the advantage of having them presented in a concise form. Additionally, the group of experts that participated in the study shares the perception of these practices being "*best practices*" in the field, which brings credibility and guidance to a larger group of practitioners.

General Process

The processes followed in the study allowed the participation of experts in the field that are geographically disperse. This, in itself, is an interesting product of the study that enlightens us about the capacity of collaboration that the field has today. A great deal of what happened during the course or this research was a group process of alignment of visions.

Controversial Category

The controversial category is a very interesting finding of the study because it represents what these experts in the field do not agree on and, therefore, can generate (or has already generated) distinct threads of thinking within the field. These disagreements are not necessarily detrimental for the field; these disagreements can be a natural and even beneficial event in the growth of the field. When different worldviews collide, a different environment emerges; this new status can generate a major break-through way of thinking that would expand the borders of the field that experiences these differences. Alternatively, they could lead to divisions, miscommunication, and a lot of annoyance.

In *problem identification and definition*, there is a clear debate over modeling the class of the system or the case at hand. This difference of opinions can be explained by the differences in the types of practitioners who participated in the study. This difference tell us that there is a group of practitioners who consistently prefer to model the case at hand, as opposed to other group who thinks that the adequate way is by modeling the class to which the system belongs.

In *system conceptualization*, even though there is agreement on starting with major stock variables (best practice C), there is disagreement on iteratively using a casual-loop diagram approach or a stock-and-flow approach to conceptualize. Most of these experts agreed on where to start the conceptualization (stocks) but not on how to proceed from there.

In *model formulation*, there are two major areas of disagreement on how to formulate models. The first relates to the issue of starting small and continuously simulate and preferably, always having a running model. This disagreement indicates us that there is a group of experts who formulate piece by piece and always try to have a running model at hand, and another group who prefers to formulate in big chunks and is not concerned about continuously having running prototypes.
The second disagreement in this category relates to the use of extreme condition tests on the model. This disagreement seems to indicate that some experts think that the use of the extreme condition tests is crucial and some do not think of it as important. The authors just do not have a way to understand why is this issue controversial.

The results presented in this paper are consistent with the literature and indicate us areas of opportunity for growth in the field. The disagreements encountered can be a vehicle to expand the limits of the approach. The issue of identifying a comprehensive list of practices and ranking them is not addressed in these publications, perhaps because what makes a determined practice in a field (e.g., system dynamics) a "*best practice*" is the relation between the personal judgment of the practitioner and the social judgment of the community of that field. The interaction of the individuals of the community and the community itself generates the social construction of "*best practices.*" In fact, the very existence of the community is the result of the creation of it by individuals. The world is as complex as we create it through our worldview and through the systems that we create to explain it, because we know that the systems we create are conceptual formulations that aid us in the process of handling complexity in the world as we experiment with it (Checkland and Scholes 1990).

The two most important findings of the study are that (1) we are not in agreement with respect to how to do exemplary work in system dynamics modeling (indistinct issues), and that (2) there are specific controversies regarding the way to do it (controversial category). One plausible explanation for these results can be related to the process followed in the study. How we conducted the elicitation, the amount of time available to do it, the impossibility of clarification of the meanings of the contributions through a discussion of the issues, among other factors.

Next Steps

The next steps include exploring the last three areas of the system dynamics modeling process used as theoretical framework for the study as presented in Figure 1. These areas are (4) Model Testing and Evaluation, (5) Model Use, Implementation, and Dissemination, and (6) Design of Learning Strategy/Infrastructure. Additionally, we plan to involve more practitioners in the study so we can get a more comprehensive view of "best practices" and the actual use of them. We want to explore more the emerging result that roughly 2/3 of proposed best practices are not embraced as best by experts in the field.
The results of this study have generated additional questions related to "*best practices*". The questions are (1) does this results hold up under different ways of eliciting or clustering and with larger groups? and (2) is this in the nature of practice in a complex field?

References

Checkland, P. and J. Scholes (1990). Soft Systems Methodology in Action. Chichester, UK, Wiley.

Forrester, J. W. (1963). Industrial Dynamics. The Encyclopedia of Management. C. Heyel. New York, Reinhold Publishing Company: 313-319.

Forrester, J. W. (1973). World Dynamics. Cambridge MA, Productivity Press.

Morecroft, J. D. W. and J. D. Sterman, Eds. (1994). Modeling for Learning Organizations. System Dynamics Series. Portland, OR, Productivity Press.

Richardson, G. P., Ed. (1997). Modeling for Management: Simulation in Support of Systems Thinking. International Library of Management. Brookfield, Ashgate Publishing Company.

Richardson, G. P. and A. L. Pugh, III (1981). Introduction to System Dynamics Modeling with DYNAMO. Cambridge MA, Productivity Press.

Rohrbaugh, J. (2000). The Use of System Dynamics in Decision Conferencing: Implementing Walfare Reform in New York State. Handbook of Public Information Systems. D. Garson. Raleigh, North Carolina, Marcel Dekker, Inc.: 618.

Scholl, G. J. (1992). “Benchmarking the system dynamics community.” System Dynamics Review **8**(3): 263-266.

Scholl, G. J. (1995). “Benchmarking the system dynamics community: research results.” System Dynamics Review **11**(2): 139 to 155.

Sterman, J. D. (2000). Business Dynamics: Systems Thinking and Modeling for a Complex World. Boston MA, Irwin McGraw-Hill.

Appendix 1 Method of Calculation

Computation Method of the Third Stage of the Facilitated Meeting.
Each participant used a different scale to evaluate the categories of practices; we built a matrix with those unstandardized scores of the participants. The matrix *a* (1) has elements $a_{i,j}$ which represent the unstandardized score for element (i) from participant (j).

(1) $$a = \begin{bmatrix} a_{1,1} & a_{1,2} & a_{1,j} \\ a_{2,1} & a_{2,2} & a_{2,j} \\ a_{i,1} & a_{i,2} & a_{i,j} \end{bmatrix}$$

Then a standardized score was calculated using the total sum of the scores of the participant to normalize the scores to 100 and to capture the relative weight given to the specific element. The standardized scores (2) $\chi_{i,j}$ represent the relative weigh put on element (i) by participant (j).

(2) $$\chi_{i,j} = \left[\frac{a_{i,j}}{\sum_{i=1}^{n} (a_{i,j})} \right]$$

Matrix (3) *b* was built using these standardized scores to calculate the top elements for the group.

(3) $$b = \begin{bmatrix} \chi_{1,1} & \chi_{1,2} & \chi_{1,j} \\ \chi_{2,1} & \chi_{2,2} & \chi_{2,j} \\ \chi_{i,1} & \chi_{i,2} & \chi_{i,j} \end{bmatrix}$$

A total score (4) A_i was calculated per element (category) using the elements from matrix *b*.

(4) $$A_i = \sum_{j=1}^{N} \chi_{i,j}$$

And a vector (5) with these total scores was built to be used as determinant element for distinction among elements.

(5) $$TotalScores = \begin{bmatrix} A_1 \\ A_2 \\ A_N \end{bmatrix}$$

Four thresholds were selected for the selection process. (1) Threshold I “Highest Rated”, (2) Threshold II “Highly Rated”, (3) Threshold III “Moderately Highly Rated”, and (4) Threshold IV “Indistinct Rated”.

As a metric for general agreement, a dispersion measurement *d* was calculated using the means and the variance of the scores (6).

(6)

$$d_i = \left[\frac{\dfrac{\sum_{j=1}^{n} (X_{ij} - \overline{X}_{ij})^2}{n}}{\sum_{j=1}^{n} X_{ij} / n} \right] *100 = \frac{s_i^2}{\mu_i} *100$$

Appendix 2 Raw Data of the Study

Appendix Table 1. - Best Practices in Problem Identification and Definition

Highest Rated

Listen carefully to Client Stories Let most senior client say "What brought us together" Talk and Listen reflectively to problem owners (clients) Make sure you understand the client's problem Ask client sufficient questions –avoid giving premature answers Check whether (dis) agreement on problem exists (When you are working with more than 1 person)
Clarify purpose (e.g. strategy/policy, theory building, education, training)
Dynamic thinking –drawing graphs over time Have client draw about 5 to 7 reference modes Use reference mode diagrams to explore many people's expectations of future behavior Identify the reference mode: The central "process" or time development to be studied Develop history of key measures Sketch a graph of the time behavior of the supposed problem Observe the behavior of key variables of interest over time Select subgroup of time histories with simpler patterns to represent behavior of interest Draw reference modes of behavior Plot time histories of what ever is available
Ask why is current behavior of key variables generated, and what is causing it.
Formulate the dynamic hypothesis (i.e., "this behavior is caused by that structure")

Highly Rated

Clearly identify clients of the model Pick or invent the person to whom you need to answer Create a common ground of understanding between me (the modeler) and the issue owner (the client)
Identify key stakeholders Immerse yourself in the organization and engage stakeholders
Describe clearly the symptoms that initiated the modeling proposal
Identify carefully the time horizon Select carefully the time unit
Develop desirable vs. undesirable futures of key measures Sketch out the desired behavior of key variables over time

Moderately Highly Rated

Check whether problem stated by client is suitable for System Dynamics Study
Form a study team consisting of technical people and system participants
Set main goal to generate an interesting dynamic feedback problem Define the dynamic feedback problem Generate a concise and specific problem statement Find a puzzling time-dependent problem
Identify available budget for study Identify available time for study
Identify available data sources Look at all available data

Appendix Table 2. - Best Practices in System Conceptualization

Highest Rated

Avoid rigid separation of identification / conceptualization / formalization stages Approach conceptualization from different angles like a new creation Recognize that conceptualization is creative –there are no recipes
Discuss the dynamic hypothesis with a study team Engage in conversations around conceptual building blocks Elicit client's mental models
Identify levels / states first to describe system with and without symptoms of interest Identify the few (critical) main system variables (normally levels; 1-3) Select stock variables in reference mode Make sure stock variable names are nouns, not verbs or action phrases Select one key stock variable in a single conservative system if more than one variable is present Write names of selected stock variables with space between them to draw perceived causal links Start with major stock variables, try to impose your feedback loops Identify "essential" asset stock accumulations

Highly Rated

Set main goal to generate an endogenous dynamic hypothesis
Be sure dynamic hypothesis boundary is large enough for endogenous orientation
Identify key variables representing problematic behavior

Moderately Highly Rated

Be sure that each variable is measurable –at least in principal
Look at all available data

Appendix Table 3. - Best Practices in Model Formulation

Highest Rated

Start small / simple and build out / add complexity later Work up through a series of simple to more comprehensive models Quantify the structure a bit at a time Add detail to prototype as needed to improve realism and show policy impacts
Check dimensional consistency from the beginning Check the units of the equations Leverage the power of dimensional consistency
Support every concept with data or common experience Be sure equations make sense: All parameters must have real life meaning Be clear about what, in reality, the algebra represents

Highly Rated

Keep the model simple / not too detailed Set main goal to generate smallest model that captures dynamic hypothesis Assess carefully whether additional structure is required Require very good reasons to diverge from the simplest molecules Push back hard on demands for more and more detail
Simulate early / as soon as possible Simulate often Test even simple models extensively
Involve client in discussions about simulation outcomes Discuss model with a study team and revise as necessary

Moderately Highly Rated

Develop small (<100 equations) prototype (full scope not detailed) Use Prototype to test dynamic hypothesis and identify shortcomings
Avoid making equations unnecessarily complicated Avoid chained table functions (especially when concepts are overlapping)
Bear bounded rationality in mind (specially) in rate equation formulation (and in general)
Try always to describe truthfully what happens in real world (limited rationality / information)
Acquire experience with many types of models from the literature Take an apprenticeship (1 – 2 years) with an experienced system dynamics coach

Appendix Table 4. - Controversial Best Practices

Problem Identification and Definition

Identify the class of Systems to which the particular case belongs
Model the class to which the case belongs, not the case at hand

System Conceptualization

Iteratively sketch causal loop diagrams, identify state variables / levels, identify system boundary
Create comprehensive set of dynamic hypotheses (loop-explanations for reference modes) Identify loops and develop initial dynamic hypothesis Identify major causal loops determining development over time of the main variables Draw the structure of your dynamic hypothesis as a causal diagram Form dynamic hypothesis before modeling to depict major feedback loops across sectors Draw causal loop diagrams if stock-flow structure presents difficulties Identify feedback loops Look for a few potentially important feedback loops Concentrate first on main connections and major loops
Identify / draw stock-flow structures (resources, customers, products / services) Identify influences on flows

Model Formulation

Select a "core" loopset, add loopset operationally, analyze model; iterate select / add / analyze Never stray too far from a simulatable model
Think of extreme condition tests in writing equations, check if equation works in that condition Simulate different extreme conditions and modify model