# Group Model Validation

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*Abstract*

*In this paper we report if and how validation is integrated in the different participatory approaches in System Dynamics. After this we present an analysis of 86 case studies to create a picture of how validation is conducted and reported in the field. We found that validation is hardly described as an integrated part of any participatory modeling approach. Furthermore, the process of validation and the end-result is little reported on in any case study. We believe that there is a significant difference between validation in non-participatory and participatory approaches due to the social aspect. In this context we derive three questions as a requirement for validation. The aim is balancing individual mental models, group mental models and logic and data. Based on the tension between these three factors we developed a preliminary approach to participatory structure validation. This procedure is focused on generating a productive amount of cognitive conflict in order to confront the structure of the model with all available information. The outcome is increased structure validity, documentation of limitations and increased understanding of the reasoning underlying the model's structure.*

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## Introduction

Validation is the process of building confidence in the model (Forrester, 1961; Forrester & Senge, 1979) and building credibility in the user community (Rykiel, 1996). It leads to acceptance of the model, i.e. commitment and usage which eventually leads to implementation of the decisions derived from the model. Thus, validation of is an essential part of a model based intervention. However, debates about the nature of validity arose. For instance, Barlas and

Carpenter (1990) examine validation from two different philosophical views concluding that models *'lie on a continuum of usefulness'* (Barlas & Carpenter, 1990, p. 157) if taken a relativist philosophy. Nevertheless, researchers need to accept that an absolute validity is impossible (Sterman, 2002) and thus, a model cannot be either right or wrong (Barlas, 1996). And this leads to one of the oldest definitions of validation in System Dynamics (SD): it is the *'transferred confidence in a model's soundness and usefulness'* (Forrester & Senge, 1979, p. 8). For this reason several validation tests were developed (e.g. Forrester & Senge, 1979; Barlas, 1989; Sterman, 2000). However, since several years, researchers claim a lack of practice of validation (Barlas, 1996; Groesser & Schwaninger, 2012). Probably, this claim was initiated by the only empirical study concerning the use of validation tests which dates back to 1995. Scholl (1995) conducted a survey among the SD society members (*N*= 455). He found that even the most basic validation tests are used by a mere fraction of the respondents (Figure 1). Only structure and parameter verification are used by 80% of the respondents, extreme condition and sensitivity tests are used by 60%. These results indicate that validation tests that are considered important in the SD literature are not being used by a considerable amount of the respondents.

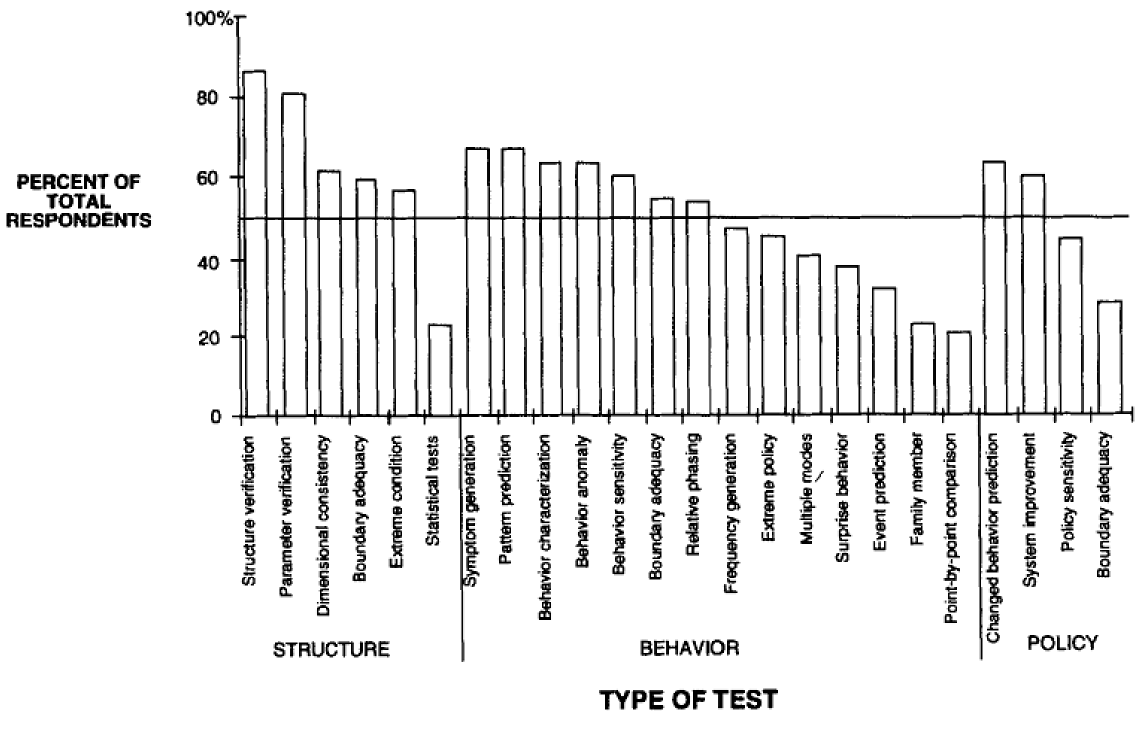


**Figure 1. Benchmark Result: Validation Tests (Scholl 1995:144)**

For that reason authors started to categorize validation procedures and providing frameworks about validation (Lane, 1995; Barlas, 1996; Sterman, 2002; Zagonel & Corbet, 2006; Groesser &

Schwaninger, 2012). These researchers succeed in categorizing validation procedures according to their functions and goals (e.g. structure validation). They provide a logic structure for usage and Scholl gives a good picture of the situation among society members. However, what most researchers forget is to pay attention to the setting, which is the environment, in which validation is taking place. Taken the tremendous importance of validation, we wonder why the setting in which validation takes place was not regarded yet. We distinguish between two settings: participatory and non-participatory in regard of the intervention. In non-participatory settings, the client's mental model is used for knowledge elicitation and confronted with data. The modeling process takes place separately and the final model is usually presented to the client. In this case, validation transfers the confidence to the client (Forrester & Senge, 1979). Participatory settings, like group model building, on the other side do not only aim on knowledge elicitation. It aims on client involvement in such a way that learning and strategic change takes place and a sustainable use of SD will be initiated. Therefore, validation plays not only a role of building confidence but also ensures that right and sound decisions can be derived.

In the following, we examine (1) how validation is treated in seven different participatory approaches of SD and survey 86 case studies to get a clear picture of the common practice of validation. After that we reflect on the (2) difference of validation in participatory and non-participatory settings. In the last part of the paper (3) we develop guidelines for validation in a participatory setting and present a procedure on how to conduct structure validation with the client.

## Part I: The practice of validation in participatory approaches

The importance of client involvement in the SD modeling processes has been recognized as early as the first work in SD (Forrester, 1961). Forrester emphasized that the 'mental models' of clients provide a rich basis of information that is indispensable when constructing a model. Starting from this premise, system dynamicists have involved clients and experts in the modeling process and different approaches emerged. These participatory approaches involve clients both in similar and in varying ways for a diversity of purposes. Many of them move beyond merely eliciting mental models, they seek to create a feeling of ownership and commitment (Lane 1992, Vennix 1996, Wolstenholme 1992), a sustainable use of SD (Lane 1992) and foster consensus among the participants (Vennix, 1996). Andersen et al. (2007) identify seven different approaches for client involvement (see Table 1). The aim of the analysis of the participatory approaches is to examine if validation is conducted, i.e. is there a distinct place for validation in the approach? A more elaborate analysis of the approaches can be found in appendix I.

| Approach | **Client's involvement** | **Report on Validation as distinct part** | **Validation types mentioned** |
|---|---|---|---|
| **Reference Group** (Randers, 1977; Stenberg, 1980) | Conceptualization Behavioral Analysis | No | Parameter Behavior |
| **Stepwise Approach** (Wolstenholme, 1992) | All | No | Behavior |
| **Modeling as Learning** (Lane, 1992) | All | No | No |
| **Strategic Forum** (Richmond, 1997) | Conceptualization Behavioral and Structural Analysis | No | Behavior Structure |
| **Strategy Dynamics** (Warren, 1999) | All | No | No |
| **Hine's Standard Approach** (Otto & Struben, 2004) | Conceptualization Behavioral Analysis | Yes | Behavior |
| **Group Model-Building** (Andersen & Richardson, 1997; Vennix, 1996) | All | Yes | Behavior |

**Table 1. Approaches to GMB, validation and tests performed (adapted from Rouwette 2003: 48)**

As can be seen client involvement is high in all seven approaches but only two of the approaches refer to validation as a distinct part of the modeling process. In contrast, not mentioning validation as a distinct part of an approach does not mean that it is not conducted. For instance, validation can play a role in every section of the modeling process without being mentioned as a distinct phase. In the last column of Table 1 you can see that some approaches report on different types of validation but do not refer to them as a distinct phase. Consequently, the analysis of the participatory approaches per se is not enough. For that reason, we conducted a literature study of 86 case studies of one of the participatory approaches mentioned above. Most of the cases were taken from Rouwette et al. (2002). The complete list can be found in appendix II.

We counted how often various validation tests were mentioned in the case studies. We used a generous coding scheme, for instance: workbooks concerning the relationship between variables counted as structure assessment and decision rule verification. "What-if" analysis, in contrast, is very ambiguous and could refer to sensitivity, extreme condition tests, cutting the loop or scenario testing. If no further explanation was given, we did not count ambiguous terms as a test.

There is no exhaustive list of validation tests. In our research, 14 distinct tests were identified, which formed the basis of the analysis. The tests and results are summarized in table 2. To allow easy comparison to Scholl's figure (figure 1), figure 2 shows the percentage of case studies reporting the test.

| **Validation Test** | **Number of mentions** | **Validation Test** | **Number of mentions** |
|---|---|---|---|
| Face Validity Test | **34** | Basic-behavior reproduction | **27** |
| Validity of decision rules | **17** | Endogenous behavior reproduction | **0** |
| Physical conservation | **1** | Boundary adequacy | **2** |
| Dimensional consistency | **2** | Sensitivity Analysis | **15** |
| Integration error | **0** | Behavior prediction | **1** |
| Extreme condition test | **3** | Shock Test | **1** |
| Parameter assessment | **18** | Statistical Tests | **2** |

**Table 2. Frequency table of reported validation tests**

It is rather surprising that we find that not even one test is used in 50% of the cases. While validation in general is mentioned in about 60% of all cases, the tests most often mentioned are face validity (34 cases; 39,5%), basic behavior reproduction (27 cases, 31.4%) and parameter assessment (18 cases, 20.9%). This is very low. Moreover, we find that the test of endogenous behavior reproduction is not mentioned once. We regard this test as the most important validation test in SD. It examines the model's nature and checks if the behavior is endogenously produced or if the behavior is due to external data. It also identifies the most influential loops which are responsible for the model's and therefore system's behavior.

Further, the integration error was not once examined. This test examines the stability of a system and analyzes whether or not the time step is appropriate for the pace of the changes of the dynamics of the system (Sterman, 2000). The use of other tests are also low, however we do not intend to explain the test rather to discuss why these results occur.

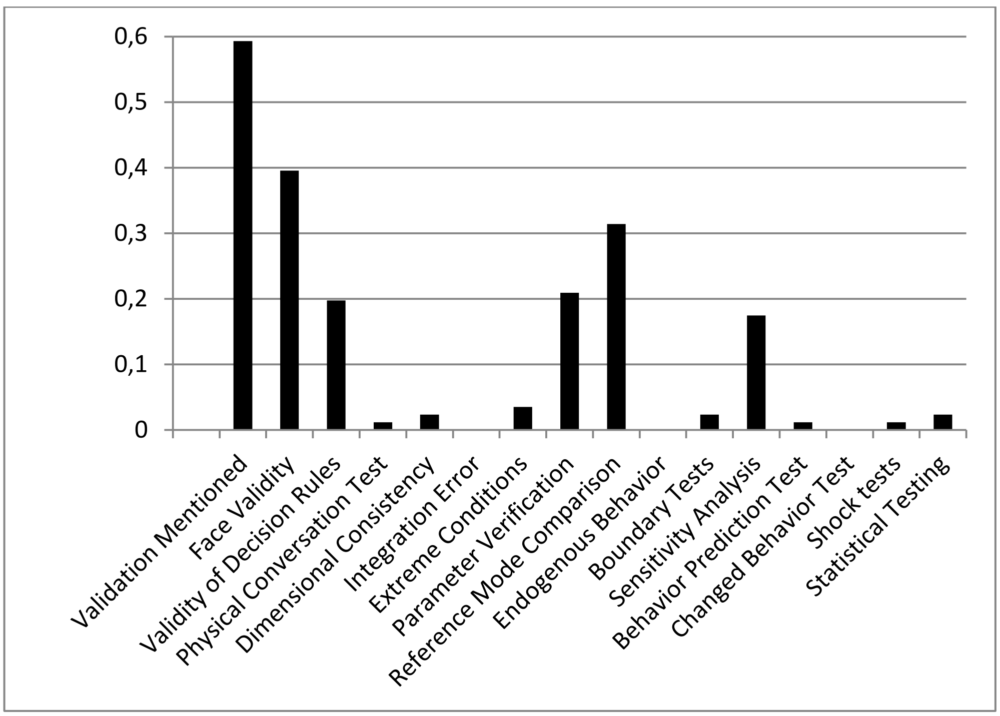


**Figure 2. Validation tests conducted in 86 case studies**

## Summary and Discussion of Part I

In the first analysis, we found that only two participatory approaches mention validation as a distinct part. The second analysis found that out of 86 case studies only 51 (~60%) mention validation and only 5 validation tests were reported on in 15-39% of all cases. We did not find any procedures that describe how validation is conducted. In addition, we believe that some of the tests are useful to conduct with the client. As shown in the case of the test of endogenous reproduction, the tests do not only examine the soundness and reasonable behavior of the model but also provide insights into how the system works.

For the second analysis two assumptions were taken which need to be discussed. Firstly, the case studies chosen were taken from another paper (Rouwette et al, 2002). Not all case studies have the same purpose, some of them focused on a certain technique, method or problem rather than discussing the modeling process (e.g. Richardson & Anderson, 1995). Consequently, it seems logical that those case studies do not necessarily report on validation. Further, it was not analyzed whether the case study concerned a boundary object or micro-world (Zagonel, 2002) or if it was qualitative or quantitative in nature. Secondly, inferences about how some case specific action could be related to a certain test had to be made.

Nevertheless, the combination of both analysis let us conclude that only little validation is conducted or reported on. However, we cannot conclude whether it is a problem of reporting or indeed the lack of usage but we believe that the answer lies in between. In case of the first we want to refer to Rouwette et al. (2002) suggestion to introduce a fact sheet concerning implementation and effectiveness of group model-building interventions. We suggest adding an overview about client's involvement in the modeling process, whether the model was qualitative or quantitative and which tests were performed. Such an overview would help transfer confidence, foster future research and help pinpoint potential weak points in practice. It is however only a solution to the problem of not reporting on validation.

If validation is not conducted, we need to refer back to its tremendous importance in the participatory setting. Group model-building aims on strategic change retrieved from the model output. Thus, if the logic, soundness and usefulness are not examined, the model can lead to wrong decision. To foster the use of validation with the client, we first need to understand, what makes validation in a participatory setting different from non-participatory settings. This issue, we examine in the next part and conclude a procedure which takes the differences into account.

## Part II: The difference of validation in a participatory setting

We follow the definition that validity is transferred confidence in the soundness and usefulness of the model related to its purpose (Forrester & Senge, 1979) whereby we want to focus on the word "transferred". Why and from where to where do we transfer confidence? This definition is a good example of traditional validation, i.e. non-participatory settings. As Forrester (1987) states, the biggest source of information is held in mental models. Only few data is available as written or numerical sources. These two sources will be combined, aligned and sometimes altered in or through a SD model which leads to understanding of the system. Thus, the modeler triangulates between three sources of information: The mental model of the client, the data and logic and the SD model. This relationship is shown in figure 3. In this setting, the client is not involved in the modeling process. The modeler tests the soundness and usefulness of the model by his/her own and presents some of the validation procedures to the client. A walkthrough, for instance, examines the relationship between the mental model and the SD model. The basic behavior reproduction shows the interaction of the SD model and the logic and data. Through simulation and sensitivity analysis, mental models are altered, and stimulate for example the relationship of logic and data and the mental models since the client will better understand the underlying dynamics of the system in question. Consequently, a simple triangle can describe the how validation procedures take into account and influence the different sources of information.

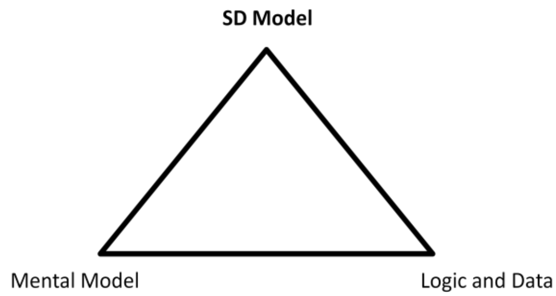


**Figure 3. The triangular of relationships of validation in non-participatory settings**

This relationship changes in case of involving the client in the modeling process. The integration of the client into the whole process leads to more possibilities of transferring confidence. As Vennix (1996) points out that the social aspect, e.g. how participants respond to the modeling process, influences the effectiveness of the intervention which is not determined by the model validity. In this context, we want to refer to procedural justice (Korsgaard, Schweiger & Sapienza 1995) which is a way of facilitation which affects the perception of fairness within the decision process and leads to commitment of the group member even though the outcome is unfavorable for them. While consenting with Vennix' statement, we fear that practitioners in the field of participatory modeling rather focus on building confidence, thus on process effectiveness, without examining the soundness of the model for reasonable behavior and logic. One example is the argument that group model-building automatically leads to a valid model due to the fact that the model is a result of consensus (or at least consideration) of initially many conflicting viewpoints. We believe this assumption to be naïve. It is unlikely that the modeling team can judge if the model is sufficiently valid due to the inherent lack of understanding and information they will have about the system. Homer (1996, p. 16) emphasized that *'the refinement process will not come to a natural halt ... there will rather be a trade-off toward the end of the project'*. Thus, the modeling team will have to decide on how much effort they and the client wishes to invest to obtain an adequate level of confidence that the model reflects different sources of information correctly. This also means making a trade off on which sources of information to base their assumptions if different sources conflict. Since this is not a straightforward matter, testing the consistency of a model, its acceptance by participants and their confidence in it becomes essential. A framework for validation should thus encompass the different sources of information which consists of the social as well as technical aspects of validation.

Thus, the social aspect is added: There is the individual who faces, and at the same time is part of, the group. Hence, the social aspect is to be divided into two distinct sources of information. As Phillips and Phillips (1993) describe it, groups have a personality and a character which does not necessary needs to mirror the individuals. Further, literature often talks about the group who decides (e.g. Reagan & Rohrbaugh, 1990; Weisband, 1992; Nutt, 2010). However, when talking about implementation it comes back to the group member, i.e. the individual (e.g. Korsgaard et al, 1995; Eden et al. 2009; Hamilton & Gioia, 2010). Consequently, there is the interaction between the individual and the group and the logic and data which lead to a distinction of three separate but intertwined sources of information which are connected with the SD model. These sources form both, the input to the model as well as the benchmark compared to which the model validity is judged by every individual. Related to the social part of validation, and the hallmark of group model building, is the triangular relation between the model, individual mental models and group mental models. Kim (2009) points out that a group level mental model is a blurry term since it sometimes refers to a process and other times to the knowledge held by the individuals. We refer to it as the mental map of the problem agreed on by every individual in the client group – the collective consciousness (Eden & Ackermann, 2010: 239).

There is also a more technical part of validation which relates more closely to comparing the model to data and logic from the real world system. The former relates, for example, to time series while the latter relates to such statements as ‘inventory cannot go below 0’. These different sources of information are not isolated from one another, instead they are closely connected. For example: data shapes our own mental models and individual mental models shape group mental models. In fact, the process of group model building itself changes these sources of information (Vennix, 1996).

Social processes take place especially when messy problems occur, when “soft” concepts need to be defined and no empirical measures are available. That is the case when the SD intervention is used as a boundary object (Zagonel, 2002). In such an intervention, the initial problem is ill-defined. Each group member has an own mental model, which will lead to conflicting viewpoints. Through exchanging information, negotiation and alteration a shared reality is created and thus consensus and agreement is built – the group mental model. For participants and modelers alike this is a process of learning. Through the exchange of information knowledge is shared and new knowledge is created, which leads to changes in mental maps. The SD model can be a medium in this as well as an end product, i.e. a boundary object (Zagonel, 2002). In an ideal situation the individual mental models will agree with each other and with the model. Such kind of unanimous agreement among individuals is referred to as consensus. Consensus fosters commitment to the decision and its implementation (Schein, 1969). It therefore leads to a higher effectiveness of the intervention (Dooley, Fryxell, & Judge, 2000). However, research has shown that concurrence seeking groups produce lower quality decisions than groups in which conflict is encouraged; premature consensus leads to a lower decision quality (Cosier & Rose, 1977). Consequently, when involving the client, a certain level of conflict, frustration and anxiety needs to be stimulated by the facilitator (Phillips & Phillips, 1993). So in short, a facilitator should focus on the alignment of individual mental models with the group mental model in to the SD model while stimulating discussion on basis of the conflicting perspectives. Thus, the exchange between individuals with the group which is rather direct and does not involve the SD model directly. In doing so, the facilitator is not only confronting the model with available information but also confront different information sources with new information.

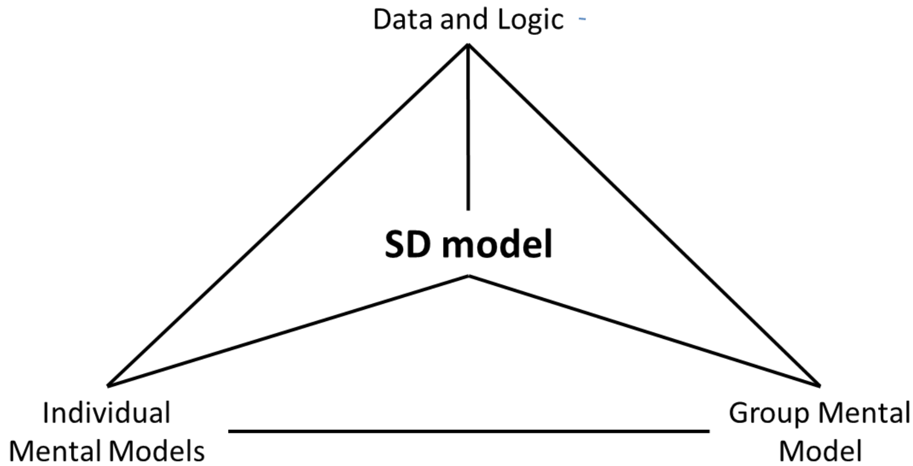


**Figure 4. A myriad of relationships surrounding validation in participatory SD approaches**

In the discussion above, we have showed that the involvement of a client group into the process leads to a distinction between individual and group mental models. Thus, taken the relationship from figure 3, we can now identify what makes validation in a participatory setting different in comparison to the non-participatory setting. By adding one more source of information, the number of interrelations between the sources of information has doubled. That leads to a myriad of relationships shown in figure 4. Each line indicates exchange of information. The lower part of figure 4 shows the social aspects. The individual mental model is on the left corner. Through the social process within a group, these mental models will be shared, criticized and adjusted. That leads to the collective consciousness – the group mental model. On the top we display the third source of information: data and logic. Each source of information affects the model and the other sources of information. This makes validation about finding an appropriate balance between logic and data, the individual's mental models and the group mental model. This is done not only by confronting the model with the available information but also confronting the other different sources of information with each other to encourage learning. In the case of using an SD model as a boundary object this might emphasize the bottom triangle, connecting individual and group mental models with a SD model while quantitative models might emphasize the relation between data and the SD model more. Hence, the importance of each of the six relationships in the framework depends on the purpose of the model.

Knowing about the intertwined sources of information, we can now derive three questions which need to be answered with "yes" in order to validate the model:

1. *Do the group and every group member can define the problem and thus the model's purpose?*
2. *Does the group agree on the model, the boundaries and its behavior?*
3. *Do the group members agree individually on the model, the boundaries and its behavior?*

These questions are connected to the myriad in figure 4. The first one examines the relationship between the three sources of information. The different perspectives of the group members need to be aligned and everyone needs to be able to describe the problem with the available logic and data in order to know about the model's purpose in which its validity needs to be examined. The second questions checks, if the modeler team succeeded to transfer the problem description into the model. Thus, it checks the interrelation of the SD model, logic and data and the group mental model. Since the model emerged from a participatory modeling process, this question is most likely answered with "yes". What follows is now the question to every group member individually which should be done in anonymity. Asking the group members individually can lead to critique, doubts and not mentioned ideas (Postmes & Lea 2000). Thus, individual agreement needs to be explored since the decision is made in the group, the strategic change, however, is carried out by the individual. With the third question, the relationship of the SD model, data and logic and the individual mental model is examined.

In the following we want to present a procedure that answers those three questions in a participatory and facilitated way. However, this procedure is derived from the discussion and is not tested yet.

## Part III: A procedure for validating a system dynamic model structure

The procedure should be done at the end of the intervention. That means that the modeling team already spent some time with the group and has a good picture about the life of the group and the characters of the group members. The model should be in a mode of presentation and the procedure should be seen as the final step to clarify the use, the findings and foster commitment.

As preparation, the modeling team should identify the main loops or leverage points of the model. In case of a quantitative model, that is done by the test of endogenous behavior reproduction. By cutting the feedback loops its influences will be examined and the most influential loops can be derived. In case of qualitative models, the central variables can be identified by counting the loops that involve the variable or the connections that go into and out of the variable. At the end the modeling team should have subdivided the model into an appropriate amount of parts fitting to step 4 of the procedure (mentioned later).

The second step of the procedure is to introduce the role of validation. That is actually the task description. It needs to be clear what every member needs to do, thus it align the goals of the participants for the session and creates commitment to the task ahead. Further, it needs to be stated which benefits the validation process is bringing: it provides more useful results, builds confidence in the results and a better understanding of the model structure. At this point, some members might say they understand the model. However, it is good to check it and challenge the model again. In case the participants fully understood the model, the procedure will not take long and verifies whether the intervention was successful in aligning the different mental models.

The third step tackles the first question in order to validate the model: Discuss the model's purpose. Since validity depends on purpose and '*judging the validity of a model ultimately involves judging the validity of its purpose'* (Barlas, 1996, p. 184), a shared understanding of the purpose of the model needs to be given. In a well-conducted GMB project this purpose should have been discussed from the start of the project and could have been altered during the process (Zagonel, 2002). The goal of the session itself is to establish if the client and modeling team is confided that the model contains all relevant information in a correct way in order to serve its purpose. If a new discussion starts and does not result in a clear definition, the intervention and thus the model failed.

The fourth step leads to a subdivision of the group in preferably groups of two persons. However, if the group size is that big, subgroups can exceed a membership of two persons. The subdivision aims on opposing views. At the time of using this procedure, the facilitator should have realized which persons have opposing views within the group. In other words, the facilitator should subdivide the group in such a way that conflict is stimulated and that two opposing persons are in one group. Opposing perspectives are wanted because the process leads to *'... scrutiniz[ing] one another's perspective in an effort to extract and combine the best* *elements of each'* (Amason & Schweiger, 1994, p. 246). The process of deliberation over contrasting viewpoints referred to by these authors is commonly described as 'cognitive conflict'. Cognitive conflict emerges when different conflicted sources of information are confronted with each other. Several authors (Wall, Galanes, & Love, 1987; Jehn, 2005; de Dreu; 2006) have found that the relationship between conflict and the quality of decision is curvilinear. Groups performing a task that experience a low or a high number of conflicts deliver a lower quality output than groups experiencing a moderate amount of conflict. Vennix (1996) depicts this relationship as seen in figure 5. This emphasizes the importance of information exchange between different sources and not only between a source of information and the model.

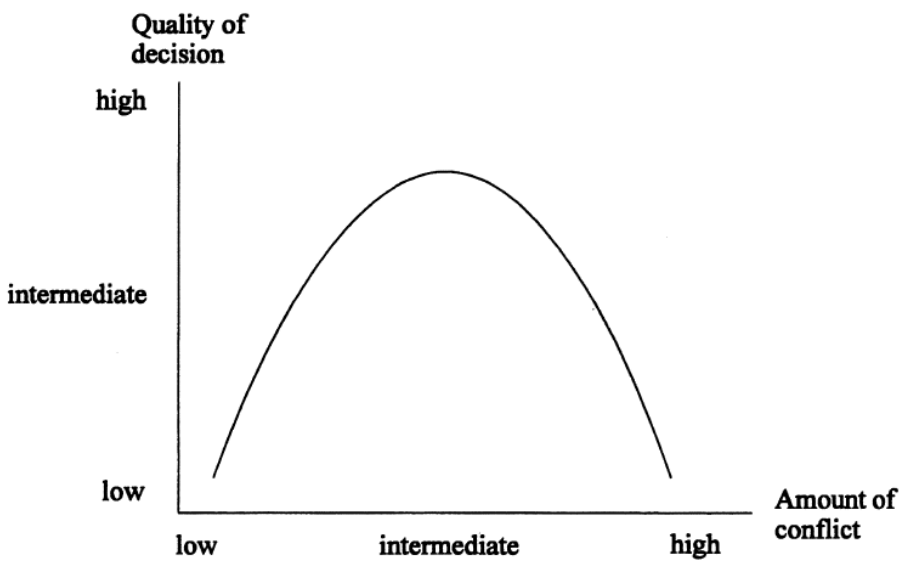


**Figure 5 Relationship between amount of cognitive conflict and quality of decisions in small groups. Adopted from Vennix (1996).**

As can be seen an optimal point of cognitive conflict exists. De Dreu (2006) found support for the inverted u-shape relationship, but finds that the effect of task conflict on decision quality is partially explained by a second inverted u-shape relationship between conflict and exchange of information and collaborative problem solving. This implies that in cases of low conflict there is too little exchange of information for the group to be able to create synergy out of each other inputs. De Dreu (2006) and Jehn (1995) found that in the case of a large number of conflicts there will be too much conflicting information. As a consequence, the quality of output drops. When there is a low amount of conflict consensus is reached. However, if information is withheld this consensus is premature. In the most extreme situation, individuals suppress conflicting information out of the desire for unanimity, this is often referred to as ‘group think’ (Janis, 1972).

After subdivision of the group, the parts of the model are distributed. For large models, these parts will be subsections or several loops. In the case of small models, that can be stocks and its flows. It is important that the group is focusing only on that part. Hence, the modeling group should pay attention that the subgroups are also concerned about and have knowledge about the submodel.

Note that putting together two opposing views together can result in the case of too much conflict. This is why the facilitator should give some basic questions about the submodel to be discussed. Those questions can be *what is the purpose of that part of the model, which process does the structure show, on what are the sections assumptions are based, what influences the submodel, what does it influence* etc. Those questions ensure the specific focus on the workings of the structure, its connection to the other sub-structures and that they reflect on the use of the substructure for meeting the purpose of the model. Of particular importance is that it is clear for participants on which assumptions the piece of structure is based. This makes every assumption in the model traceable to a source of information and allows to group to investigate if this assumption holds up to other sources of information. The idea behind these questions is to focus the discussion on the model and to examine if a group member still has doubts, ideas or comments. At this time, there is no place to park ideas. It therefore explores the third question and aligns the individual mental model with the SD model and the logic and data. It aims on ensuring commitment of the individual.

The seventh step is then to present the outcome to the entire group in order to explain the process. In such a way the findings should be shared and for every participant explained. Thus, the outcome should be that every participant understands why the boundaries are kept, why some ideas were not included and where the dynamics of the system come from. In some cases, the modeling team can even ask questions to give some input. If the explanation of the group is incomplete the facilitator might probe them for expanding it. The group should be in the position of explaining shortcomings and limitations of the model.

The procedure can be summarized into the steps:

1. Identify the main loops and variables causing the dynamics of interest in the problem variable
    a. Quantitative models: Cutting the loop
    b. Qualitative models: Central variables (number of connections and/or loops)
2. Present the task of validation and present what benefits it will bring
3. Repeat the purpose of the model/project
4. Divide the group in subgroups or individuals
5. Distribute parts of the model across these groups (for large models these will be subsection, in small models this might be a single stock with its flows, for CLDs these might be loops)
6. Ask the subgroups to shortly present their sub models in the following format
    a. Our model has the purpose of...
    b. This structure shows the process of…
    c. Its assumptions are based on…
    d. It is influenced by…
    e. It influences…
    f. This structure relates to the purpose of the model because…
7. Discuss the substructure with the entire group (Under some conditions the modeling team can also input information)
8. Repeat process if necessary

This process has a number of outcomes for the model, documentation and participants. First, it validates the purpose of the model. Second, the group is confronted with the model's structure. Third, the model is scrutinized in detail and includes all available information considered relevant. Fourth, the model limitations are recorded. Fifth, all participants know the reasoning behind the structure of the model and know how it relates to different information sources, creating further ownership and confidence. Sixth, the participants and the modeling team have a good idea how well learning progressed and if different information sources are aligned. Finally it provides closure to the group of participants. The procedure thus creates interaction between individual mental models, the group mental model and real world data and logic. This procedure seeks to contribute to achieving: *'the ultimate objective of validation … [;] transferred confidence in a model's soundness and usefulness'* (Forrester & Senge, 1979 p. 8).

However, the procedure has shortcomings. When working with a client group time is a valuable asset and the procedure is time intensive. Further, the procedure is intended as a first step and is untested. We welcome use, critique and change. It is our wish that the process of validation is moved from being based on intuition and experience to publicly shared best-practices. The procedures discussed so far all focus on the tangible model. The idea that many academics and practitioners share however is that SD and GMB in particular is about more than constructing a model. How does one validate participants learning or level of consensus? And how does this relate to model validity?

## Conclusion

We found that only little information about validation is provided in descriptions of approaches and case studies. We believe that the field can benefit from practical descriptions of participatory validation techniques. For this reason we develop a myriad framework for thinking about participatory validation. To put theory into practice we proposed a procedure for structure validation. When validating a model structure we seek to compare relationships in the real world with those in our models. We compare aggregated and simplified structure to many individual perceptions of systems of near infinite complexity. Negotiating many subjective visions is vital to gain a clear as possible image of reality. The disagreement resulting from this subjectivity needs to be confronted in order to create a shared vision and gain the benefits of consensus while not losing sight of real world logic and data. Including participants in the process goes beyond a narrow definition of validation; it improves their understanding of the model and the real world system, anchors the shared vision of reality and instills confidence in the model.

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## Appendix I: Participatory Approaches

Andersen et al. (2007) identify seven different approaches of client involvement. In this section, these seven approaches are reviewed in order to determine if there is a distinct place for validation in the approach.

The first approach mentioned is "**reference groups**" (Randers 1977). Reference groups are small groups, representing a large number of people affected by a policy issue. They ensure the right direction of research, give crucial information and provide a channel of implementation (Stenberg 1980). However, the reference group is not directly involved in the modeling process. It is not mentioned if and which validation tests are conducted. At the end of the intervention, a discussion about simulation results takes place, which could be seen as a part of validation. Since the clients compare the models behavior to their perceptions or to the development of indicators.

Wolstenholme's **stepwise approach** (1992) is intended to be used by analysts and system owners together to explain problems. The client is involved in the whole process, but validation is not explicitly mentioned except for a reference mode comparison test which shall "provide some degree of confidence in the validity of the model" (Wolstenholme 1992: 129). Further, in the model analysis part, there are steps concerning logical behavior of the system, as well as steps concerning expected behavior about policies. Those steps are not formal tests and since Wolstenholme states that a digitalization of the model is not necessary (Wolstenholme 1992: 128), it can be derived that a thorough examination of the model's quality is not included in the approach.

The "**strategic forum**" (Richmond 1997) approach is designed for managers with the aim of building a shared understanding of the business in order to achieve strategic goals, as well as to build a systems thinking capacity within the firm. Richmond subdivided the process into several steps including 'exercises with the model'. Those can be seen as validation. Richmond (1997) describes a method called "putting a stake in the ground" to show how systems are misunderstood. Later this exercise was also used as a validation technique of the structure and parameters.

**Strategy dynamics** (Warren 1999) uses an own diagramming style, confronting the client with stocks, flows and the behavior of all variables in the model. The result is a model with client's estimates of reference modes. Validation can be part of the process but is not necessarily carried out (Warren 2005). A certain validation takes place by delivering a simulation model with a performance panel where the client can examine tactical changes of the strategy and test the sensitivity of the assumptions.

The "**modeling as learning**" approach uses SD as only one tool of a variety of tools to foster the client's learning process and communication (Lane 1992). The client is involved in the whole project since the underlying premise is that most learning takes place in the process. In this approach no explicit use of validation is mentioned. The focus is on learning through experimenting with the model, structuring ideas and challenging assumptions. It remains unclear if and which tests are conducted.

The sixth approach is called **Hine's standard method** (Otto & Struben 2004). This approach uses defined steps, which include problem diagnosis, boundary setting, dynamic hypothesis and scope definition. Some steps involve key stakeholders. Though the model building process is conducted only by the practitioners, the validation involves the client. Extreme condition tests, sensitivity testing as well as policy tests are included in the approach.

The **group model-building approach**, in its narrow definition, relates to two related approaches that deeply involve the client. One is a conference style approach structured by scripts (Andersen & Richardson 1997) and the other a more intuitively driven, less formally structured, approach which seems to put additional emphasis on consensus building (Vennix 1996). In both designs, validation is mentioned and seen as important. Richardson and Andersen (2010) mention testing and refinement being conducted without the client, Vennix (1996) sees validation as a flexible technique. In some cases, validation is conducted, in some not. Consequently, it can be concluded that formal validation being conducted with the client depends on the situation. However, the review of the final model, i.e. face validity, reference fit and behavior tests, is being conducted together with the client. Simply put, there is some degree of client's involvement in the validation phase.

The findings are summarized in table 1. Client's involvement is high in all seven approaches. But only two of the approaches refer to validation as a distinct part of the modeling process. In contrast, validation can play a role in every section of the modeling process without being mentioned as a distinct phase. For instance, some approaches report on different types of validation but do not refer to them as a distinct phase. Consequently, not mentioning validation in the conceptualization of an approach could be seen as an indicator that validation does not play an important role in projects with high client's involvement, but it does not provide sufficient evidence. In order to find the sufficient evidence it is necessary to study GMB cases and to analyze which tests are conducted.

| Approach | **Client's involvement** | **Report on Validation as distinct part** | **Validation types mentioned** |
|---|---|---|---|
| **Reference Group** | Conceptualization<br>Behavioral Analysis | No | Parameter<br>Behavior |
| **Stepwise Approach** | All | No | Behavior |
| **Modeling as Learning** | All | No | No |
| **Strategic Forum** | Conceptualization<br>Behavioral and Structural Analysis | No | Behavior<br>Structure |
| **Strategy Dynamics** | All | No | No |
| **Hine's Standard Approach** | Conceptualization<br>Behavioral Analysis | Yes | Behavior |
| **GMB Approach of Albany** | All | Yes | Behavior |

**Table 3. Approaches to GMB, validation and tests performed (based on Rouwette 2003: 48)**

## Appendix II: Case studies

| Number | Author | Title | Published in |
|---|---|---|---|
| 1 | Alanne, P.P., Jambekar, A.B. | Putting systems thinking to use: a case study | Proceedings ISDC 1996 |
| 2 | Bentham, J.B., A.G. de Visscher | Systems thinking and its influence on operational culture | Proceedings ISDC 1994: organizational learning |
| 3 | Bronkhorst, E.M., T. Wiersma, G.J. Truin | Using complex system dynamic models: an example concerning the Dutch dental health care system | Proceedings ISDC 1991 |
| 4 | Bull, M, A. Ford, G Naill | The importance of feedback in the Pacific Northwest Electric Conservation Planning Model | Proceedings ISDC 1985 |
| 5 | Byrne, M., A. Davis | Stella modelling process for a manpower strategy | Proceedings ISDC 1991 |
| 6 | Campbell, B.R., G.M. McGrath [case 1: CSC problem] | Getting to implementation: towards a system dynamics change management framework | Proceedings ISDC 1999 |
| 7 | Campbell, B.R., G.M. McGrath [case 2: Six Seconds problem] | Getting to implementation: towards a system dynamics change management framework | Proceedings ISDC 1999 |
| 8 | Cavaleri, S., J.D. Sterman | Towards evaluation of systems thinking interventions: a case study | System Dynamics Review |
| 9 | Cavana, R.Y., P.K. Davies, R.M. Robson, K.J. Wilson | Drivers of quality in health services: different worldviews of clinicians and policy managers revealed | System Dynamics Review |
| 10 | Cooper, K.G. | Naval ship production: a claim settled and a framework build | Interfaces |
| 11 | Covert-Weiss, S., G.J. Clark, P. Odence | The development and use of the production learning environment simulation at Ford Motor Company | Proceedings ISDC 1998 |
| 12 | Coyle, R.G. [case 1] | System dynamics and defence analysis | Proceedings ISDC 1989 |
| 13 | Coyle, R.G. [case 2] | System dynamics and defence analysis | Proceedings ISDC 1989 |
| 14 | Coyle, R.G. [case 3] | System dynamics and defence analysis | Proceedings ISDC 1989 |
| 15 | Davis, A. | The application of system dynamics to re-engineering career plans | Proceedings ISDC 1994: business decision making |
| 16 | Deakins, E., G. Winch | Helping not-for-profit enterprises become more "business-like": a learning organisation approach | Proceedings ISDC 1994: microworlds |
| 17 | Delauzun, F., E. Mollona | Introducing system dynamics to the BBC World Service: an insider perspective | JORS |

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| 18 | Draper, F., M. Swanson | Learner-directed systems education. A successful example | System Dynamics Review |
| 19 | Duman, E., E. Balibek, A. Firat, Y. Barlas | A dynamic feedback model for strategic management of an insurance company | Proceedings ISDC 1997 |
| 20 | Eriksen, H.E., E.H. Nielsen | A report on the utilization of the MOSES computer as a tool in development and dissemination of system dynamics models | Proceedings ISDC 1985 |
| 21 | Genta, P.J., D.P. Kreutzer, G. Anderson, R. Hinote, W.C. Hood, K. McMillan | How to use system dynamics to create your own future: a case study of a worldwide oil and gas exploration group | Proceedings ISDC 1994: business decision making |
| 22 | Genta, P.J., N. Sokol | Applying a systems thinking approach to business process re-engineering: a case study of a Canadian oil and gas producer | Proceedings ISDC 1993 |
| 23 | Ginsberg, A., J. Morecroft | Systems thinking and the case method | Proceedings ISDC 1995 |
| 24 | Graham, A.K., R.J. Walker | Strategy modeling for top management: going beyond Modeling Orthodoxy at Bell Canada | Proceedings ISDC 1998 |
| 25 | Guthrie, S. and M. Patton | Teaching a convential class (global studies) in an unconventional manner using Stella | Proceedings ISDC 1998 |
| 26 | Hall, R.I., W.B. Menzies | A corporate system model of a sports club: using simulation as an aid to policy making in a crisis | Management Science |
| 27 | Heeb, J., C. Mauch, M. Keller, F. Huber | Planning sustainable mobility with the stakeholders - a system dynamics approach | Proceedings ISDC 1999 |
| 28 | Henderson, S.M., E.F. Wolstenholme | The application of a dynamic methodology to assess the benefit of a battlefield information system | Proceedings ISDC 1990 |
| 29 | Hines, J.J., D.W. Johnson [case 1] | Launching system dynamics | Proceedings ISDC 1994: business decision making |
| 30 | Hines, J.J., D.W. Johnson [case 2] | Launching system dynamics | Proceedings ISDC 1994: business decision making |
| 31 | Hines, J.J., D.W. Johnson [case 3] | Launching system dynamics | Proceedings ISDC 1994: business decision making |
| 32 | Hwang, L., G. Hu | Steps in conceptualizing a system for system dynamics model-building: a case study of an oil refinery of a petroleum corporation | Proceedings ISDC 1999 |

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| 33 | Jambeker, A.B. | System dynamics mapping to influence mental models: a case study | Proceedings ISDC 1990 |
| 34 | Lane, D.C. | Modelling as learning: A consultancy methodology for enhancing learning in management teams [case 1] | EJOR |
| 35 | Lane, D.C. | The road not taken: observing a process of issue selection and model conceptualization | System dynamics review |
| 36 | Lane, D.C. | From discussion to dialogue: how an interactive modeling approach was used with managers to resolve conflict and generate meaning | Proceedings ISDC 1993 |
| 37 | Lane, D.C. | Modelling as learning: A consultancy methodology for enhancing learning in management teams [case 2] | EJOR |
| 38 | Larsen, E.R., J.D.W. Morecroft, J. Murphy | Helping management teams to model: a project in the consumer electronics industry | Proceedings ISDC 1991 |
| 39 | Lee, Tsuey-Ping ; Zagonel Tsuey-Ping , David F. Andersen, John W. Rohrbaugh, George P. Richardson | A Judgment Approach to Estimating Parameter in Group Model-Building | Proceedings ISDC 1998 |
| 40 | Lyneis, J.M. [case 1: credit card industry] | System dynamics for business strategy: a phased approach | System dynamics review |
| 41 | Lyneis, J.M. [case 2: commercial aircraft industry] | System dynamics for business strategy: a phased approach | System Dynamics Review |
| 42 | Machuca, J.A.D. | Are we losing one of the best features of system dynamics? | System Dynamics Review |
| 43 | Mahmoud, M., P. Genta | Microworld of an open university: a strategic management learning laboratory | Proceedings ISDC 1993 |
| 44 | Mayberry, M., K. Hoxsey, K. McCracken, C. Rendell | Using systems thinking and dynamic simulations to reengineer manufacturing processes at Silicon Graphics | Proceedings ISDC 1996 |
| 45 | Millheim, K.K., T. Gaebler | Data-mineurs, Co. Modeling a start-up business | Proceedings ISDC 1998 |
| 46 | Morecroft, J.D.W., D.C. Lane, P.S. Viita | Modeling growth strategy in a biotechnology startup firm | System Dynamics Review |
| 47 | Morecroft, J.D.W., K.A.J.M. van der Heijden | Modelling the oil producers - Capturing oil industry knowledge in a behavioural simulation model | EJOR 1992 |
| 48 | Ramadan, N., P. Parker-Roach | Setting public policy using system dynamics and causal loop diagramming: a case study from a competitive public utility | Proceedings ISDC 1998 |
| 49 | Raynolds, P.A., G.H. Raynolds | Jog your right brain (JOG): a case study in knowledge elicitation and evaluation | Proceedings ISDC 1992 |

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| 50 | Richardson, G.P., D.F. Andersen [case 1: DSS, New York State] | Teamwork in group model building | System dynamics review |
| 51 | Richardson, G.P., D.F. Andersen [case 2: Department of Social Welfare, Vermont] | Teamwork in group model building | System dynamics review |
| 52 | Richardson, G.P., D.F. Andersen [case 3, OMB, New York City] | Teamwork in group model building | System dynamics review |
| 53 | Richardson, G.P., P.M. Senge [case 1: State Insurance Department] | Corporate and statewide perspectives on the liability insurance crisis | Proceedings ISDC 1989 |
| 54 | Richardson, G.P., P.M. Senge [case 2: Hanover insurance] | Corporate and statewide perspectives on the liability insurance crisis | Proceedings ISDC 1989 |
| 55 | Rios, J.P., M. Schwaninger | Integrative systems modelling: leveraging complementarities of qualitative and quantitative methodologies | Proceedings ISDC 1996 |
| 56 | Roman Sliwa, K. | Systems thinking and organizational growth: personnel pressure and organizational equilibrium scissors. A case of the company "Beta" | Proceedings ISDC 1993 |
| 57 | Roos, E. | System dynamics modelling: a case study from the software industry | Proceedings ISDC 1996 |
| 58 | Roos, E. | Group model building with a client using system dynamics modelling | Proceedings ISDC 1997 |
| 59 | Rouwette, E.A..J.A., J.A.M. Vennix, C.M.Thijssen | Group model building: a decision room approach | Proceedings ISDC 1997 |
| 60 | Royston, G., A. Dost, J. Townshend, H. Turner | Using system dynamics to help develop and implement policies and programmes in health care in England | System Dynamics Review |
| 61 | Rufat-Latre, J. | Strategy and systems thinking through dynamic storytelling | Proceedings ISDC 1994: organisational learning |
| 62 | Rufat-Latre, J., M. Jamieson, M. Mora | Transferring systems thinking and circumscribing problems: a case study | Proceedings ISDC 1993 |
| 63 | Sancar, F.H. | Implementation of a modelling approach to community development planning [case 1] | Proceedings ISDC 1987 |
| 64 | Sancar, F.H. | Implementation of a modelling approach to community development planning [case 2] | Proceedings ISDC 1987 |
| 65 | Senge, P. | Catalyzing systems thinking within organizations | Proceedings ISDC 1987 |
| 66 | Stenberg, L. | A modeling procedure for public policy | in Randers, J. (ed.) Elements of the SD method |
| 67 | Thompson, J.P. [case 1: growing the right resources] | Consulting approaches with system dynamics: three case studies | System dynamics review |

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| 68 | Thompson, J.P. [case 2: imagining alternative futures] | Consulting approaches with system dynamics: three case studies | System dynamics review |
| 69 | Thompson, J.P. [case 3: transforming the organization] | Consulting approaches with system dynamics: three case studies | System dynamics review |
| 70 | Vennix, J.A.M. | Building consensus in strategic decision making: insights from the process of group model-building | Group decision and negotiation |
| 71 | Vennix, J.A.M. | Group model building. Facilitating team learning using system dynamics (chapter 7 and 8) | |
| 72 | Vennix, J.A.M., J.W. Gubbels, D. Post, H.J. Poppen | A structured approach to knowledge elicitation in conceptual model building | System Dynamics Review |
| 73 | Vennix, J.A.M., W. Scheper, R. Willems [case 1: Nostradamus] | Group model building: what does the client think of it? | Proceedings ISDC 1993 |
| 74 | Vennix, J.A.M., W. Scheper, R. Willems [case 3: Dutch river system] | Group model building: what does the client think of it? | Proceedings ISDC 1993 |
| 75 | Wang, S.F. | Modeling as thinking process: the leverage is thinking role, not thinking skill | Proceedings ISDC 1999 |
| 76 | Warren, K. | Designing your growth path: an interview with Charles Farqunarson | JORS |
| 77 | Watts, K.M., E.F. Wolstenholme | The application of a dynamic methodology to assess the benefit of a logistics information system in defence | Proceedings ISDC 1990 |
| 78 | Weil, H.B., K.P. Veit | Corporate strategic thinking: the role of system dynamics | Proceedings ISDC 1989 |
| 79 | Weil, H.B., R.L. Etherton | System dynamics in dispute resolution | Proceedings ISDC 1990 |
| 80 | White, L., T. Ackroyd, M. Blakeborough | Learning about modelling for learning | Proceedings ISDC 1994: education |
| 81 | Wile, K., D. Smilonich | Using dynamic simulation for resource management policy design at the Minnesota Department of Transportation | Proceedings ISDC 1996 |
| 82 | Winch, G.W. [case 1: petrochemics investment] | Consensus building in the planning process. Benefits form a 'hard' modeling approach [case 1] | System Dynamics Review |
| 83 | Winch, G.W. [case 2: petrochemics strategy] | Consensus building in the planning process. Benefits form a 'hard' modeling approach [case 2] | System Dynamics Review |
| 84 | Wolstenholme, E. | The definition and application of a stepwise approach to model conceptualisation and analysis | EJOR |
| 85 | Zagonel, J. Rohrbaugh, G.P. Richardson, and D.F. Andersen | USING SIMULATION MODELS TO ADDRESS “WHAT IF” QUESTIONS ABOUT WELFARE REFORM | Journal of Policy Analysis and Management |

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| 86 | Zazara, R., D. Fisher | Experiences in developing single-discipline and cross-curricular models for classroom use | Proceedings ISDC 1996 |