Challenges in Collaborative Modeling: A Literature Review

Conference Paper *in* Lecture Notes in Business Information Processing · January 2008

DOI: 10.1007/978-3-540-68644-6_5 · Source: DBLP

Gwendolyn Kolfschoten
Delft University of Technology

Gert-Jan de Vreede
University of South Florida

Challenges in Collaborative Modeling: A Literature Review

Michiel Renger[1], Gwendolyn L. Kolfschoten[1], and Gert-Jan de Vreede[1,2]

[1] Department of Systems Engineering, Faculty of Technology Policy and Management, Delft University of Technology, The Netherlands
d.r.m.renger@tudelft.nl, g.l.kolfschoten@tudelft.nl
[2] Institute for Collaboration Science, University of Nebraska at Omaha, USA
gdevreede@mail.unomaha.edu

Abstract. Modeling is a key activity in conceptual design and system design. Users as well as stakeholders, experts and entrepreneurs need to be able to create shared understanding about a system representation. In this paper we conducted a literature review to provide an overview of studies in which collaborative modeling efforts have been conducted to give first insights in the challenges of collaborative modeling, specifically with respect to group composition, collaboration & participation methods, modeling methods and quality in collaborative modeling. We found a critical challenge in dealing with the lack of modeling skills, such as having a modeler to support the group, or create the model for the group versus training to empower participants to actively participate in the modeling effort, and another critical challenge in resolving conflicting (parts of) models and integration of submodels or models from different perspectives. The overview of challenges presented in this paper will inspire the design of methods and support systems that will ultimately advance the efficiency and effectiveness of collaborative modeling tasks.

Keywords: Collaborative modeling, system analysis and design, groups, participation, modeling methods.

1 Introduction

Modeling is a key activity in conceptual design and system design. There is broad agreement that it is important to involve various experts, stakeholders and users in a development cycle [1-3]. While these parties are often interviewed or in other ways heard, they often lack the skills to actively participate in the modeling effort. If users are not involved in systems analysis tasks, their problems, solutions, and ideas are difficult to communicate to the analyst. This often results in poor requirements definition, which is the leading cause for failed IT projects [1].

Further, analysts and entrepreneurs might have mental models, visions of a solution or system design, but might lack the adequate means of articulating these in terms familiar to all stakeholders involved [4]. While there are means to verbally explain models, such as metaphors, a graphical representation is often more effective. ("A picture tells more than a thousand words"). In order to use graphical representations as a basis for discussion, it would be useful if all the stakeholders can be actively engaged in the construction and modification of such models.

J.L.G. Dietz et al. (Eds.): CIAO! 2008 and EOMAS 2008, LNBIP 10, pp. 61–77, 2008.

With increasing complexity of systems and organizations, creating shared understanding and joint representations of those systems becomes increasingly important. Analytical skills become more wanted and more important to function in these complex contexts. However, creating one's own system representation is in many ways different from creating a joint system representation. With the increasing need for collaboration among experts and knowledge workers [5], collaborative modeling becomes increasingly important.

Collaborative modeling has been a research topic since the late 70's [6]. In order to support collaborative modeling to create shared understanding and joint visions for design and solution finding it is important to gain insight in best practices and key challenges in collaborative modeling. Most articles on collaborative modeling describe case studies and practical experiences with collaborative modeling. While meta-analysis has been performed to gain insight in metrics and effects in collaborative modeling [7] and an overview of methods and role deviations has been described [8, 9], to our knowledge there is no overview of challenges and best practices in collaborative modeling. Such overview would help us to find opportunities for research and for the design of new supporting tools and methods to empower participants and facilitators for effective and efficient collaborative modeling.

In this paper we provide an overview on collaborative modeling studies that brings together the experiences and findings from literature to identify the main challenges and lessons learned in the field. This could inspire research on new and innovative collaborative modeling support systems and methods. Furthermore such overview of challenges will be a valuable resource for practitioners in collaborative modeling. The paper first defines collaborative modeling. Next we describe the different approaches in collaborative modeling. Third, we discuss the research method for the literature review, followed by the results in which we describe critical challenges and solutions for successful collaborative modeling. We end with conclusions and suggestions for further research.

2 Background

2.1 Collaborative Modeling Defined

For the purpose of the research presented in this paper, we define collaborative modeling as:

The joint creation of a shared graphical representation of a system.

In this definition we focus on graphical modeling of systems as opposed to physical modeling of objects or artifacts such as in architecture and industrial design. Graphical models are usually created in a conceptual design phase either for analysis or design. They are used to communicate a representation of a system in order to understand or change it. Conceptual models are used in a early phase of analysis and design and therefore are initially associated with a sketching activity. However, when they are used as a basis for design or structural analysis they need to meet various requirements with respect to precision and rigor. They also may need to be translated to computer models in order to calculate effects of the model. For this purpose, modeling languages have been developed to capture conceptual models as computer models to enable easy manipulation and automatic syntactic verifications. Using computer models also makes it easier to make changes in a model, especially when changes in one component result in changes to other components and relations between components.

Further, we focus on joint creation to indicate our interest in stakeholder participation in the modeling effort as opposed to modeling by external professionals or analysts only. Joint creation requires the exchange of perspectives among the participants. The model is a way to elicit, highlight, and communicate different perspectives and assumptions among group members.

In order to create a shared representation as opposed to an individual representation, a shared understanding of the elements and relations in the model needs to be created. Shared understanding can be defined as "the overlap of understanding and concepts among group members" [10, p. 36]. We build on this definition for the collaborative modeling domain where we define shared understanding as *the extent to which specific knowledge among group members of concepts representing system elements and their relations overlaps.* In order to create overlap in knowledge, participants need not only share information about model elements and relations. They also need to create shared meaning with respect to these elements and their relations. Creating shared meaning is often studied from a 'sensemaking' perspective. Sensemaking is described by Weick as involving "the ongoing retrospective development of plausible images that rationalize what people are doing" [11, p. 409]. Sensemaking usually requires some development of shared meaning of concepts, labels, and terms. It also includes the development of a common understanding of context and the perspective of different stakeholders with respect to the model.

2.2 Approaches in Collaborative Modeling

Within the field of system dynamics, modelers started to involve client groups in the modeling process since the late 70's [6]. Since that time, various other modeling approaches have adopted the notion of collaborative modeling and found methods to involve stakeholders in their own modeling efforts, see e.g. [8, 12, 13]. As a result various research groups performed field studies, gained experience, and eventually developed sophisticated methods for modeling efforts that have high levels of stakeholder participation. However, different modeling languages are associated with different methods for analysis and design. To accommodate different stakeholder groups, new methods had to be developed leading to different approaches and eventually different patterns in collaborative modeling. Here we describe the most important approaches in collaborative modeling.

2.2.1 Problem Structuring Methods

Problem Structuring Methods refer to a broad variety of methods and tools that have developed mainly in the UK to cope with complexity, uncertainty and conflict [14]. The most well known of these methods are Soft Systems Methodology, Strategic Choice, and Strategic Options Development and Analysis (SODA), of which the last has further developed into Jointly Understanding Reflecting and Negotiating Strategy Making (JoURNeY Making) [15]. These methods have the following similarities in approach: use of a model as a transitional object, increasing the overall productivity of group processes, attention to the facilitation of effective group processes, and significance of facilitation skills in enabling effective model building [16]. Especially the first of these is characteristic for Problem Structuring Methods: models are seen as instrumental to strategic decision making and problem solving in complex settings, so the approach typically focuses on the overall decision making process which often includes simulation for scenario explorations. In Problem Structuring Methods, a group's shared understanding is created by switching between the views of individual participants and the entire group, and focus on the differences in view to resolve these [17, 18].

2.2.2 Group Model Building

Group Model Building is considered a special case of Problem Structuring Methods for hard modeling, and has been developed by researchers of the University at Albany in New York, and the University of Nijmegen in the Netherlands. According to Andersen et al, Group Model Building refers to "a bundle of techniques used to construct system dynamics models working directly with client groups on key strategic decisions [19, p. 1]". Group Model Building always has a system dynamics approach, and usually extends the conceptual model to simulation models to explore diverse strategic options. The flexible outlines of the method, the so-called scripts, are presented in [8].

The more applied and specific approach called Mediated Modeling is largely based on these scripts and is developed mainly for complex problems of ecological nature. Shared Vision Modeling provides a similar approach to handle water resource management problems [20].

2.2.3 Enterprise Analysis

Originally, collaborative modeling research at the University of Arizona has a stronger focus on the development of software tools as well as facilitation techniques for the support of collaborative modeling efforts [21, 22]. This approach concentrates more on collaboratively built models as a goal in itself rather than as a transitional object. The models to be built are often of the IDEF0 type, and many techniques are especially meant to deal with IDEF0-standard models [23, 24].

Apart from these above described approaches, the term Participatory Modeling is loosely used for collaborative modeling across different approaches. Companion Modeling (ComMod) uses multi agent systems or role playing games to elicit information needed to construct the model [25]. The used methods are designed to build different types of models in different contexts with different purposes. In this article we focus on the similarities between modeling methods and challenges in the collaborative modeling effort.

3 Method

In this paper we focused on the challenges that groups encounter when they engage in a collaborative modeling effort. As a research method we used a literature analysis. Because the data collected in collaborative modeling is often of a qualitative nature, a quantitative meta-analysis was not feasible. Moreover, a structural survey among key journals would have been highly inefficient as collaborative modeling research can be found in journals concerning modeling and collaboration as well as in domain specific journals such as “Water Resources Update”. While the resulting set of articles might not be a complete set, the interdisciplinary nature suggests that a more qualitative approach is most efficient and effective to create an overview of existing literature on collaborative modeling. In total we found 46 papers.

We analyzed papers that studied collaborative modeling in which the deliverable is a graphical model of a system, as discussed in the definition. We searched for articles in which the modeling method was the central topic. We did not discriminate among research methods or approaches [21, 26, 27]. To identify articles we searched in various research databases such as Google Scholar, Elsevier’s Scopus, IEEE Explorer, the ACM Portal and Science Direct on: collaborative modeling/ modelling, participatory modeling, group model building, shared vision modeling, and mediated modeling. Further, we searched for articles on collaborative modeling within the context of the related subjects such as: facilitation, G(D)SS, Collaboration Engineering, (Information) Systems and Software Engineering, Business Process Modeling, collaborative design, and collaborative learning. From the papers we found we searched the bibliography for additional references, and we looked at papers that cited the papers we found [28].

For each article we searched for challenges and lessons learned. We captured these in a database and compared the different findings from different perspectives. We based these perspectives on the framework used by Nunamaker et al. to study the effects of electronic meeting systems [29] (see figure 1).

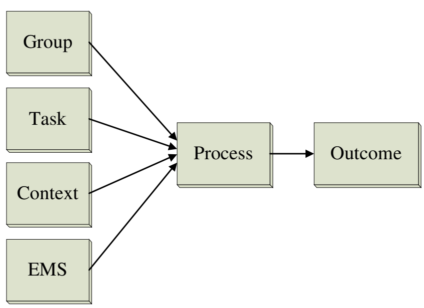

Fig. 1. Framework used by Nunamaker et al. (1991) to study effects of EMS

We adapted this framework as to reflect the most relevant factors of collaborative modeling as found in the literature:

- Group. We focused on the composition of the group and the different roles that can be present during a modeling effort.
- Task and Context. We found papers in a wide variety of (possibly overlapping) domains, including Systems Theory (15), technological support and Software Engineering (14), collaboration and facilitation (11), Business Process Modeling (5) and environment management (3). We also found that the collaborative modeling occurred in various organizational settings such as public (7), military (4), insurance (2), health

care (2), and software engineering (2). Due to this broad scope, we chose to perform our analysis independently of the task and contextual factors like domain and organizational setting in which the modeling method is used.

- EMS. We found several studies in which specific tools were used to support collaborative modeling and in which this technology was the central topic. However, this paper focuses on the modeling effort, not on the technological design of supporting tools. Therefore, we study the technological aspect in terms of its functionalities only, and how they relate to other aspects.
- Process. Since we are interested in the interaction challenges of participants and the role of facilitation support in collaborative modeling efforts, we studied the process from two perspectives: the interactive process and the modeling method.
- Outcome. For collaborative modeling, the model quality is of specific interest. Factors like efficiency and buy-in are considered in relation to other aspects.

Our tailored framework thus consists of four key aspects of collaborative modeling, as shown in figure 2. The results are described and compared in the next section.

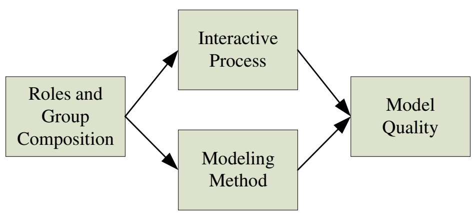

Fig. 2. Adapted framework with four key aspects of collaborative modeling

4 Results

As discussed in the Method section, we study the challenges and lessons learned found in the literature within four topics that represent critical choices in the design of a collaborative modeling activity:

1. The roles and group composition
2. The interactive process; collaboration and participation
3. The modeling method, activities and modeling rules to support the modeling effort
4. The model quality, both from an objective and a subjective perspective.

4.1 Roles and Group Composition

Collaborative modeling requires expertise in two distinct area's; facilitation of the group process and expertise in modeling, and the modeling semantics. Such expertise is generally not available in organizations and is therefore often outsourced. On the other hand, participants can also fulfill different roles in the collaborative modeling process to coordinate tasks and responsibilities in the modeling effort.

4.1.1 Facilitation Roles

Richardson and Andersen have described five essential roles that should be present in a Group Model Building session: the facilitator, the modeler/ reflector, the process coach, the recorder and the gatekeeper [9]. Roles can be allocated to different people in the group, which can effect the workload of those participants and therewith the effectiveness and the efficiency of collaboration support [30]. Furthermore, some roles can be combined, or even (partly) assigned to group members. Having an outside facilitator is considered very useful, especially if technology is used [31, 32]. Vennix et al. note that facilitated groups get less frustrated, have strongly improved group performance, less social-hierarchical domination in discussions and focus on a broader spectrum of approaches to the problem [6].

In traditional modeling methods, the input of stakeholders is processed into a model by the analyst/ modeler. But also in more collaborative settings the role of modeler is mentioned in the literature. However, a modeler/ reflector will not only support the process of collaborative modeling, but will also interfere with the content to help groups to understand the system or process under discussion. There is a discussion among scholars about the effect and ethics involved in content interference by outside facilitators [33]. Also, there is no consensus among scholars about whether the roles of facilitator and modeler should be represented by separate persons. Especially when the task is complex, a large cognitive load is imposed on a person that serves both [9]. Separated roles of modeler and facilitator are found to save time and increase model quality [9, 34, 35]. A facilitator and modeler need to work together seamlessly and be careful not to create conflict between each other. Van den Belt suggests that these roles are therefore inseparately intertwined, and a combined role of facilitator and modeler is equally or even more efficient because it allows a stronger focus on conflict resolving tasks [36]. Moreover, a larger supporting team is more expensive. A third possibility would be to assign the modeler role to the group of participants as a whole, which would increase the participation of group members, but would also pose great challenges for the facilitation. Little explicit research is found with the use of this approach.

The recorder, also known as chauffeur provides the technical support to the group by processing the input of the group directly into a modeling tool and by operating any additional technology such as group support systems [9, 30]. The role of the chauffeur is closely related to the role of modeler, but the chauffeur functions more as a scribe, whereas the modeler also interprets and reflects on the group's input. Both roles can be executed by one person.

The process coach focuses solely on the dynamics of individuals and subgroups and serves as an assistant to the facilitator to decrease cognitive load. The role of the process coach is to detect conflict, uneasiness, dissatisfaction, a lack of motivation and other signs of the group that require action from the facilitator. It is the task of the process coach to not only identify these needs, but also to suggest remedies [9]. Little literature is found that explicitly mentions this role.

Finally, the gatekeeper is the medium between the facilitation and the participation roles. This role is a twofold representative: for the participants he represents the supporting team and vice versa. Usually this is a person within the organization who initiates and carries responsibility for the project. The gatekeeper can help the facilitation team in preparation tasks and in assigning participation roles [9].

4.1.2 Participation Roles

One of the main reasons for failure of business process re-engineering projects is the involvement of the wrong people at the wrong time for the wrong reasons [34]. Within all approaches the importance of selecting the right participants is acknowledged [8, 37]. There are several factors that should be kept in mind when composing the group. Critical choices should be made with respect to the involvement of experts (professionals or people with experience) and the involvement of stakeholders. Sometimes both experts and stakeholders are involved to achieve both model quality as well as support for the resulting representation of the system or process.

With respect to expert involvement a trade-off emerges between quality of the model and shared understanding. First of all, the richness of the expertise in the group should be considered in order to produce a complete model that covers the scope of the system. However, when experts have non-overlapping expertise, it might become more difficult to create shared understanding.

A similar trade-off occurs when inviting stakeholders. When critical stakeholders are not invited, the group can have insufficient decision power, and there can be a lack of support for solutions and decision by non-invited or insufficiently heard stakeholders [34, 38]. Dean, Lee et al. note that the presence of both process designers and process owners is important in process analysis [22]. In other methods user involvement might be critical. On the other hand, more stakeholders can result in more conflict, which will require more consensus building activities. For the same reason it is found more difficult to maintain motivation among participants in a freestanding project with non-professional interests [36].

In general, in a large group participants have less average speaking time in “live” discussions [35]. Further, a large group produces a lot of information, which in its turn puts a strain on the cognitive load of individual participants with the danger of information overload [23, 24].

Although there are means to overcome the challenges of large groups, e.g. by working in parallel by the use of group support systems, group discussions are found to be at the heart of Group Model Building processes [35]. In some cases, different stakeholders or experts are involved at different steps in the modeling process to reduce the burden on the costly time of professionals. However, stakeholders that are involved later can put earlier made decisions back on the agenda, or even reject these [34, 38]. Simultaneously involved participants are found to increase pace and buy-in [34].

4.2 Collaboration and Participation

As mentioned above, the presence of a modeler or chauffeur has a large impact on the group processes. When using a scribe/ modeler role individual group members have less direct access and power to influence the model. The rules for scribe/ chauffeur and modeler are different. In a chauffeured setting changes made to the model will have to be agreed upon by the group before the chauffeur effectuates the change. Another rule, more associated to the modeler role is that the modeler can freely interpret the group discussion, and based on this, change or extend the model [9].

Another effect of the presence of the chauffeur or modeler is that participants have less access and ability to modify the model, and therewith to explain their perception to the group. This lack of access can lead to less interactivity because of more indirect communication among group members via the chauffeur [35]. This can decrease the feeling of data ownership or group contribution to the model. Also, some cases in which a modeler carried out the steps were identified as time-consuming [34]. In some cases a modeler interpreted and made changes to the model in between sessions which resulted in feelings that the model no longer captured the group's original intent [13]. A problem with inability to change the model is that on one hand, participants are asked to 'translate' their perceptions and ideas to the modeling language, but on the other hand they do not get the opportunity to verify this translation, or to express their perception in the common modeling language. This lack of ability to express and the lack of feedback can cause a feeling of not being understood, and not being able to express a vision or perspective.

Experiments with a modeler making changes simultaneously with the group were less successful because the modeler could not keep up with the pace of the group. Another possibility is that the group can directly make changes to the model, while the facilitator or a separate modeler is present to give modeling guidance to the group [13, 22]. In most cases of unchauffeured modeling, group members were given a modeling training in advance of the session, which is acknowledged to be critical [23].

A critical enabler of full group participation is the ability to work in parallel. In all cases were the model was built in parallel, the group divided into subgroups and subgroups were assigned parts of the model corresponding to the subgroups' expertise. Dennis et al. found that parallel built models are built ten times as fast as models built with the plenary group [23]. While in general facilitation with group support systems individual parallel work is common, little literature is found on individual parallel model building. In both cases a key challenge lies in change management and change awareness among parallel working individuals or groups. Andersen and Richardson found that convergent thinking requires the input of the group as a whole [6, 8].

Group processes of collaborative modeling efforts can be strongly affected by social factors that are apparent among group members, e.g. organization-hierarchical factors, and conformism. Conformism is the phenomenon that persons tend to align opinions to the group opinion, especially when speaking in front of the group, which is also called groupthink [39]. Groupthink is a negative form of convergence, where confirmation is not rational but based on social pressure. These factors can be effectively dealt with by the use of anonymity in the electronic modeling tool [35]. A downside of anonymity is that changes cannot be attributed to experts or stakeholders.

4.3 Modeling Method

One of the main challenges of collaborative modeling is to design the process for the modeling effort, i.e. a sequence of modeling steps [6, 8]. In [8], Andersen and Richardson plea for a flexible approach, where the structure of each modeling effort is adapted to the context and may even be adapted during the sessions. Dean et al. examine modeling methods from a less flexible perspective [13].

A key question in the design of the collaborative modeling process is whether to start from scratch or with a preliminary model that is created by the supporting team based on interviews or documents [40]. Vennix reports that the use of a preliminary model is most suitable for cases where time is costly or where the supporting team is less experienced, because it can increase efficiency an encourage a lively discussion right from the start [8, 40]. On the other hand, there is a danger of perceived lack of ownership of the preliminary model which could result in low commitment, putting the process on the agenda, or rejection of the model [15, 40]. The process may be thwarted if the preliminary model is based on unknown assumptions or outdated [34].

When starting from scratch, several approaches are available. In most approaches the first step consists of a brainstorm or "gathering" to elicit the relevant concepts [12, 13, 35]. In approaches for Enterprise Analysis [13] an initial model is often created during the beginning of the modeling effort, often after a brainstorm about the most relevant high-level concepts. This initial model acts as a starting point for the further development, but differs from the preliminary models often used in Group Model Building [6, 8] in that it is built in-session with the plenary group rather than by the supporting team in advance. Furthermore, although both starting models can change considerably during the overall process (and it is stressed that they will), initial models (built with the group) will probably determine the structure of the final model more than preliminary models (built by the support team), because preliminary models aim to provoke an initial discussion to elicit conflicting assumptions and perspectives [13, 40]. The use of a preliminary model is extended in the so-called prototyping strategy, where for each step in the modeling process an analyst prepares the model and participants subsequently criticize and change the model [20]. Hengst and de Vreede write that this approach produces better results than when participants carry out each step, or when an analyst carries out each step [34].

In the subsequent convergence phase a different emphasis emerges among modeling approaches. Problem Structuring Methods have a stronger focus on eliciting the relations between individual mental maps as the model is considered a means to achieve consensus and shared understanding [12, 16]. The approaches for Enterprise Analysis focus more on the structure of the model itself, and are therefore more based on the grammar, and focus on correctness of individual modeling techniques, i.e. IDEF0-standards [13].

4.4 Model Quality

The importance of the model quality can differ for each case. For example, if the goal is to learn to improve collaboration and teamwork the modeling process is more important than its output [18], or when the goal is to learn the modeling method syntactic quality is critical [41]. Quality is a container concept for 'meeting criteria'. Depending on the goal of the collaborative modeling effort criteria for quality can be determined. In modeling, quality has two key classes of criteria: syntactic and a semantic quality. Syntactic quality concerns the correctness of the model according to the grammar of the modeling language, and therewith it's explanatory power. Semantic quality concerns the correctness of the model in terms of content, and whether it represents the system it describes. In collaboration quality is focused on process (e.g. participation, progress) and outcome (e.g. efficiency, effectiveness, complexity, shared understanding), and can be objective (e.g. time spend, quality according to experts) and subjective (e.g. satisfaction, usefulness).

4.4.1 Syntactic Quality

The syntactic quality of a model can be measured according to predefined model type-specific syntactic rules. These rules are most prescribed for the IDEF0 format, and most attention for syntax is found in the literature on the Enterprise Analysis. Apart from IDEF0-specific rules, model quality aspects that are important for all modeling types are the low amount of homonyms (some concepts are included in others) and synonyms (overlapping concepts), and the interconnectedness of different parts of the model, the latter being more a semantic qualifier. These aspects are especially important when the model is built by participants in a parallel setting [22, 23]. Dennis et al. found that, as would be expected, models that are built by an experienced modeler have better syntactical quality than models that are interactively built by participants [23, 24]. Therefore, approaches for parallel modeling with a high level of participation have to incorporate ways to improve syntactic quality. There are several methods at hand to this aim: training, guidance, periodic review, change awareness, and technological support. An extensive training of several days might be desired for the syntactic quality, but is often unpractical and costly. Therefore, Dean et al. suggest a combination of a small training and guidance of an experienced modeler during the sessions [13]. Model integration can also be improved through an explicit integration process step with the plenary group, whereas integration of participant built models by an external integrator can cause feelings of loss of ownership [23, 24]. Further, a modeling tool can have various change awareness functionalities, with which a subgroup can view the changes made by other subgroups or are automatically notified about these changes. Some case studies report good results where subgroups integrated their own model parts with others during the parallel process step [13, 42], but there is little evidence that supports the claim that a support team can rely on the voluntary integration by participants. Technological support can be used to avoid the appearance of homonyms and synonyms: before defining a new input a user has to go through a list of previously defined concepts. Also, built-in restrictions according to syntactic rules can improve syntactical quality, which proved very successful [13, 22].

4.4.2 Semantic Quality

In practice, semantic model quality can be difficult to measure, so one has to rely on the subjective perceptions of participants or the support team [40]. We note that in few studies perceptions of model quality are measured from a participants' perspective. Semantic model quality concerns the completeness and correctness of the model [34]. The completeness of a model denotes to what extent the model covers all aspects of the system it represents. A high complexity can be an indication of completeness , at the same time, models are meant to offer insight in an aspect or part of a system and should therewith reduce complexity [29]. There a several ways to measure complexity, either quantitatively by the number of objects and relations in the model, or qualitatively though observation, interviewing or analysis of results. The correctness of a model denotes to what extent the aspects of a system are depicted adequately [34]. Hengst and de Vreede write that stakeholder involvement can produce more complete and correct models [34]. This may be due to more richness and diversity of expertise in the group. Also, the role of a modeler in the session may be of influence to the model quality. However, Dennis et al. found hardly any difference in semantic model quality between collaborative and analyst-built models [13, 23].

5 Discussion and Conclusions

This paper presented an overview of four critical challenges in collaborative modeling, the related findings from cases in literature and the trade-offs involved. This overview offers an overview of challenges, which provide a basis for the development of new supporting methods and systems to overcome these challenges and to empower participants and facilitators in collaborative modeling.

Within the field of collaborative modeling various different approaches use well-developed sophisticated methods which are specific for the approach. Although these approaches are designed to apply to different settings, we feel that research in collaborative modeling would benefit greatly from focusing on the similarities between them.

We found a couple of key trade-offs that have to be considered for successful collaborative modeling efforts.

- A first trade-off can be found in the choices with respect to group composition. On one hand involving stakeholders and experts can improve correctness, buy-in and completeness; on the other hand it can lead to conflict and misunderstanding due to different perspectives and non-overlapping expertise. In smaller groups, model building efficiency will be higher, participation will increase and it is generally easier to create shared understanding.
- A second important trade-off was found with respect to the level of participation. If participants are empowered to make changes to the model directly, they will have a feeling of ownership and are more likely to accept the final model and decisions derived from it. However, critical stakeholders and domain experts are not necessarily skilled modelers. To achieve syntactical quality of the model it is therefore useful to involve a chauffeur or modeler. The trade-off between quality and participation has to be evaluated in light of the scope and complexity of the system that is to be represented. Further research has to be done to evaluate whether the role of modeler can be performed by participants themselves.
- A third critical challenge is the choice of a starting point for the modeling task. The use of a preliminary model, created by an expert or analyst, outside the group process, can speed up the process and raise critical discussion topics, but can also cause detachment and even rejection of the process and the resulting model.
- A final challenge can be found when collaborative modeling effort is performed in parallel, which can also improve modeling efficiency. When separate (sub) models are created in parallel a challenge lies in the convergence and integration of these models In order to support integration of sub models or changes created in parallel, strict rules are required to ensure syntactical quality and shared understanding. An interesting research challenge lies in the development and evaluation of facilitation tools and techniques to support the integration of sub-models. Such research can benefit from the use of patterns in access control and change awareness for computer-mediated interaction [43]. Another interesting direction for further research

is to find other convergence techniques to integrate different perspectives and to resolve conflicts in semantics, perceived relations, and scope.

Concluding, the field of collaborative modeling has a rich history, but researchers have only just begun to capture and formalize best practices and methods that are known to help achieve successful outcomes. Lessons learned are numerous, but the challenges identified in this paper offer a research agenda to develop formalized methods for collaborative modeling and to design new tools to support these methods.

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