Group Model Building Using System Dynamics: An Analysis of Methodological Frameworks

Céline Bérard
University of Quebec at Montreal, Canada
Université Paris-Dauphine, France
University of Savoie, France
Celine.berard@univ-savoie.fr

Abstract: The main objective of this paper is to study existing methodological frameworks on group modelling projects using system dynamics. Such projects are more and more applied in organizations in order to support their strategic decisions. In this research, key frameworks were first identified and then classified allowing for an in-depth analysis. The results of this analysis indicate that existing frameworks proposing a global vision of projects are scarce. Moreover, few of them consider both aspects of structure and process simultaneously. In addition, three crucial issues are highlighted: the elicitation of participants' knowledge, the establishment of a consensus among participants, and the aspects of facilitation.

Keywords: system dynamics, group model building, modelling process, methodological frameworks, systematic analysis

1. Introduction

A system is defined as a complex set of interacting elements. The notion of system underlies the concept of totality, according to which "the whole is greater than the sum of parts" (von Bertalanffy, 1968). A system is said to be complex due to the multiplicity of its elements (natural, technical, economic and social) and of their interactions, but also because of the diversity of behaviours and properties it can exhibit (dynamic, emergent, etc.). A complex system is dynamic when characterized by: (1) strong interactions between the various actors of the system, (2) a strong dependency on time, (3) an internal complex causal structure subjected to feedbacks, and (4) delayed behavioural reactions, which are counterintuitive and difficult to predict (Sterman, 2000).

In such systems, actions often result in effects that differ from expected results and desired outcomes, even though decision-makers try to implement "rational" decisions according to set objectives (Friedman, 2004; Sterman, 2000; Forrester, 1975). Indeed, because of systems' characteristics, decision-making processes are carried within difficult contexts: they are affected by both complex structures of systems and cognitive limits of decision-makers (Rouwette, Gröfsler and Vennix, 2004). In this context, modelling approaches are particularly useful to better understand and analyze complex systems (Lyons et al., 2003; Friedman, 2004). For instance, systemic modelling is a methodological tradition that involves the use of formal or simulation models to analyze a complex system and to favour its understanding, and consequently it helps to improve the effectiveness of the actions that are conducted by the system's actors (Trochim et al., 2006).

In 1958, Forrester developed a discipline that is cast in this strand of systemic modelling and is mostly inspired by cybernetic systems: industrial dynamics. This approach leads to a modelling and simulation technique, known as system dynamics, which can be applied to any type of complex systems that emphasize behavioural dynamics over time (von Bertalanffy, 1968). Allowing a better understanding of the behavioural dynamics of a system, the system dynamics approach aims at supporting the decision-making processes that should lead to the improvement of the system (Sterman, 2000) and was hence applied to complex managerial problems, such as: the development of inter-organizational networks (Akkermans, 2001), the strategies of international alliances (Kumar and Nti, 2004), the prevention and management of crises in organizations (Rudolph and Repenning, 2002), the process of innovation management (Milling, 2002), to name but a few.

Many conceptual frameworks were developed in order to support the process of modelling using system dynamics (Luna-Reyes and Andersen, 2003). This process can be entirely managed by one or more modellers who are experts in the system dynamics field. Nevertheless, the system dynamics literature has highlighted the value of directly involving many participants in the modelling process (Rouwette, Vennix and van Mullekom, 2002), such as researchers specialized in part(s) of the system

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and/or its key actors. Consequently, an increasing number of projects in system dynamics modelling are carried out collectively (Andersen and Richardson, 1997) and such group modelling projects are more and more applied in organizations in order to guide their strategic decisions (Akkermans and Vennix, 1997). However, involving many participants during the model design process presents a number of methodological challenges (e.g. Luna-Reyes et al., 2006). Research relative to the application of group modelling using system dynamics is developing (Andersen and Richardson, 1997), and many techniques have been elaborated to guide such projects (Rouwette, Vennix and van Mullekom, 2002; Akkermans and Vennix, 1997). Nevertheless, research related to the application of this type of modelling rarely puts the emphasis on the course of the modelling project itself: the accent is mainly put on the results and not on the means (Visser, 2007; Morecroft and Sterman, 1994; Richardson and Andersen, 1995). For instance, Andersen, Richardson and Vennix (1997: 187) note that "*group model building is still more art than science*" and highlight the problem of improvisation that concerns the majority of group modelling projects. In fact, it is difficult to obtain a global vision of the procedures to follow to carry out such a group project, in order to model a system using system dynamics. Moreover, the documentation of group modelling projects remains basic in the system dynamics literature (Andersen and Richardson, 1997). Thus, the realization of these projects can be seen as a perilous adventure, and the question is to know how to proceed to carry them out.

The objective of this paper is to analyze the key methodological frameworks which are proposed in the system dynamics literature and which enable to guide the realization of group modelling projects. A methodological framework is defined here as any organized approach, providing process and/or structural guidelines related to any aspect of group model building. The analysis of these frameworks aims at obtaining a global vision of the research that applied a group modelling project using system dynamics, and allows drawing attention to the lack of methodological supports relating to this approach.

The remainder of this article is organized as follows. The next section highlights the foundations and principles of the system dynamics approach, prior to identifying the dimensions and components of group modelling projects using system dynamics. After that, the research method, which is based on a systematic analysis of previous works that applied system dynamics principles in a group modelling project, is described. Before discussing the research results and concluding, the selected and classified methodological frameworks are analyzed.

2. System dynamics and group model building

The system dynamics approach is addressed below, before putting the emphasis on group model building projects.

2.1 Modelling using system dynamics

A system is an organized and ordered set of interrelated elements (Forrester, 1975). The complexity of systems is often defined with respect to three dimensions: (1) the number of elements involved (*quantity*), (2) the number of interrelationships between the elements (*connectivity*), and (3) the inter-functional connection between the elements of the systems (*functionality*) (Sterman, 2000). Interactions between the various elements of a system generate complex behaviours (Limburg et al., 2002) and nonlinear relationships that are responsible for the dynamic transformations that the system experiences (Morçöl, 2005). Indeed, a complex system is structured by interrelated and interacting feedback loops (Forrester, 1975): a system is deemed dynamic due to its internal causal structure and fundamentally, because of the presence of feedback loops that impact the whole system (Meadows and Robinson, 1985). There are two types of feedback loops in systems: positive loops and negative loops (Forrester, 1975; Sterman, 2000). A positive feedback loop generates a reinforcing behaviour, that is, an exponential growth behaviour. A negative feedback loop generates a balancing behaviour, that is, an equilibrating behaviour. Interactions of positive and negative loops generate complex system behaviours of growth and collapse, oscillations, logistics growth patterns, etc (Sterman, 2000).

In complex systems, decision-makers design policies that are often difficult to implement because the design fails to take into account key feedback loops that will generate unintended consequences or limit the benefits of actions (Merton, 1936; Friedman, 2004; Forrester, 1975; Sterman, 2000). This may be the case more specifically in circumstances when the system under consideration has many components that may not be easily taken into account by decision-makers' mental models. Indeed, mental models are by definition “elusive” and are often imprecise, confused, incomplete and not adapted to determine the dynamic behaviours of systems (Forrester, 1975). This reality justifies the need for using approaches such as system dynamics modelling, which helps to recognize the dynamic behaviour that a system experiences, and consequently, helps to mitigate the cognitive limits of decision-makers. The system dynamics approach is a set of principles that have been used to tackle dynamics structure problems in complex systems using both qualitative and quantitative counterparts (Morecroft and Sterman, 1994). More precisely, it includes a set of qualitative and quantitative modelling principles that can be used to conceptualize the underlying feedback loop structure, and to simulate the repercussions of potential decisions over time (Sterman, 2000). Several conceptual frameworks describing the modelling process using system dynamics were developed. The number of steps may vary from one framework to another, but they are similar in essence (Luna-Reyes and Andersen, 2003). A predominant framework was developed by Sterman (2000), to structure the sequence of the modelling process using system dynamics (see Figure 1). It divides the process of modelling into five stages: the first two steps concern qualitative modelling, that is, the system’s conceptualization, while the other three steps concern computer-based modelling for quantitative simulation.

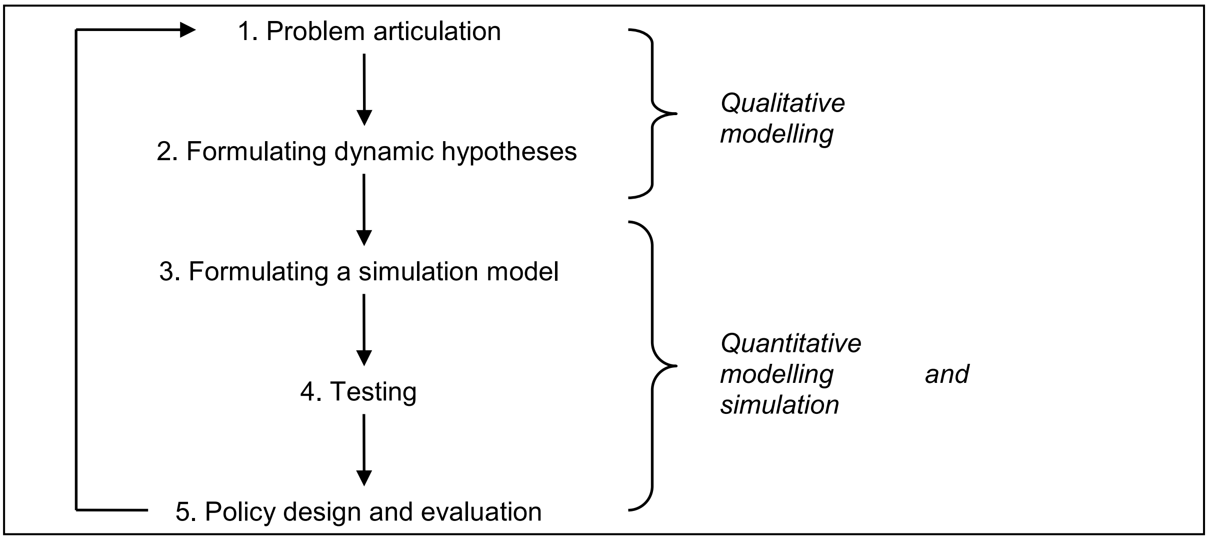

Figure 1: Modelling process using system dynamics according to Sterman (2000)

The first step consists in articulating the problem: it aims at defining the problem to be solved and the objective of the model. The second step, related to dynamic assumptions, leads to the development of an influence diagram. Influence diagrams make it possible to conceptualize the dynamics of a complex system, to exchange mental models between individuals and groups, and to communicate assumed important feedback loops at the source of the problem(s) (Sterman, 2000). Such a diagram highlights both the variables of a system and the links between these variables (Diffenbach, 1982). Moreover, it indicates the polarity associated with causal links in order to distinguish between positive feedback loops and negative feedback loops (Sterman, 2000). In other words, an influence diagram represents a hypothesis of the feedback structure of the system under consideration (Diffenbach, 1982), but it also serves as a tool for the creation of a shared mental model amongst members of a group or of an organization.

The third step aims at formulating a simulation model, that is, a level-rate diagram. Level-rate diagrams are quantitative models that represent a system with stocks and flows. Stocks are accumulators of money, goods and information, calibrated so as to characterize the state of a system at a point in time and to generate the information on which decisions and actions rest. Flows correspond to the change per period of time that increases or decreases levels in the system. This third step also includes the development of decision rules (i.e. mathematical equations), the quantification of variables, and the model calibration using parameters to define initial conditions (Sterman, 2000). The fourth step consists in making sure the model is appropriate for the task at hand. Typically, this step involves a series of tests to obtain the confidence in the model based on both internal and external consistency tests (Martis, 2006). For example, the objective of “behaviour reproduction tests” is to make sure the behaviour of the simulated system corresponds to and reproduces, to a certain extent, its real behaviour. However, the reality is that no model can be entirely "exact" (Sterman, 2000), and no model can be expected to be valid in an absolute sense (Forrester, 1975). The question that one should ask about a model does not concern its accuracy, but its usefulness in meeting a set of objectives (Sterman, 2000). Finally, the fifth step relates to the formulation of new potential strategies and the evaluation of simulated results. This last step requires on the one hand the identification of scenarios, i.e. alternative strategies, and on the other hand, the analysis of the simulated results generated by the model for each scenario over time. Thus, the simulation model aims at testing and comparing different scenarios of "fictive" actions, to predict the future behaviours of the system under consideration (Sterman, 2000): a simulation model works as a decision-support system.

2.2 Group model building using system dynamics

The modelling process using system dynamics can be carried out through two types of projects: modelling projects versus group modelling projects. The first type is managed by one or more modellers, who themselves design models and gain the expertise and required data from many sources, and often from experts on the modelled system. For the second type of project, experts on the system are not the only source of information, but are invited to elaborate models with the help of an expert or a team of experts in the system dynamics field. Research on group modelling has highlighted the importance of involving many participants in the modelling process, with the aim of increasing the relevance and usefulness of the model (Vennix, 1996). Moreover, group modelling projects help to develop a comprehensive understanding of the scope of the system and to guide the actions that are conducted, while giving advantages at individual and collective levels. At the individual level, the approach improves the mental models of participants. At the collective level, it allows the alignment of the mental models, the achievement of a consensus with respect to decisions, and the involvement of the group with respect to these decisions (Andersen, Richardson and Vennix, 1997).

In a group modelling project, the participants develop one or many models during structured sessions with the help of a facilitator, who must favour the elucidation of knowledge within the group (Rouwette, Vennix and Thijssen, 2000). These sessions are typically referred to as group modelling workshops, work sessions or conferences. The participants are the "clients" for whom the model is developed, and can be researchers specialized in part(s) of the system, and/or practitioners who are themselves actors of the system. Basically, any project of group model building is articulated around a number of common components that encompass three stages of activities: pre-meeting activities, activities during the modelling sessions, and after-care or follow-up activities (see Table 1).

Table 1: Components of group model building

Components	Description
Pre-project client-consultant relationship	- Who initiated the contact, modeller or client? - Type of problem being addressed and goals of project
Participants	- Size and composition of team - Level of top management support
Contacts with participants	- Were pre-meeting interviews scheduled? - What introduction to system dynamics is given?
Sessions and participants	- Participants (number and characteristics of attendees) at each session - Sessions: numbers and average duration - How much work was done off site and how much with the group? - Participation satisfaction with process and outcome
Modelling procedure	- What type and process of modelling was used? - Support: supporting techniques used in the process - Was a preliminary model used or did the meeting start from scratch? - Were questionnaires/workbooks used?
Facilitation aspects	- Number of facilitators and their roles - Degree to which facilitator steers the discussions
Sessions logistics	- Were meetings held away from the office? - Room design and layout

Adapted from Andersen, Richardson and Vennix, 1997: 192-193

2.3 Dimensions of group modelling projects

Group modelling projects can be described according to two dimensions: the structural and process dimensions. Each of them includes several components.

On the one hand, Andersen, Richardson and Vennix (1997) took into consideration some components that are mainly linked to some structural aspects of group modelling projects. More precisely, two structural components were identified based on their study: (1) the group structure, which takes the participants, the composition of groups and sub-groups involved in each session, and the facilitation aspects into account; (2) the logistic component, which includes all the aspects related to the location, fitting and equipment of the room. On the other hand, these authors were also interested in the process aspects of group modelling projects, that is, the modelling activities. However, these activities are relevant only through the realization of the modelling process steps using system dynamics. Consequently, five process components were identified to describe each step of the modelling process, as defined by Sterman (2000): (1) problem articulation; (2) formulation of dynamic hypotheses; (3) formulation of the simulation model; (4) testing of the model; (5) formulation of potential strategies and evaluation.

Hence, the analysis of the studies conducted by Andersen, Richardson and Vennix (1997) and Sterman (2000), permitted to define seven components that are used in this present research to characterize group modelling projects using system dynamics (see Table 2).

Table 2: Dimensions and components of group modelling projects

Dimension	Components	
Structure	Group structure	S1
	Logistics	S2
Process	Problem articulation	P1
	Dynamic hypotheses	P2
	Simulation model formulation	P3
	Testing	P4
	Formulation of potential strategies and evaluation	P5

3. Selection method of methodological frameworks

A systematic analysis of the literature was conducted in order to identify key methodological frameworks that enable to guide the implementation of a group modelling project. A systematic review rests on a rigorous, scientific and transparent process, and is based on two fundamental elements: the identification of inclusion criteria and the selection strategy of relevant works (Alderson, Green and Higgins, 2004).

The previous works proposing a methodological framework in group model building were selected according to three criteria. First, only the articles using system dynamics approach were retained. Second, only the articles published in scientific journals or in research books were included to ensure the “validity” of the selected frameworks. Third, given that a published framework could be updated and improved by it(s) “creator(s)” or by the researchers’ community, only the articles describing the last “version” of a framework were analyzed. On this basis, sixteen methodological frameworks were selected.

4. Classification and analysis of methodological frameworks

The sixteen methodological frameworks were analyzed and classified. This classification (see Table 3) rests on the principal and substantial components of each framework.

4.1 Structural dimension

Even if the structural dimension of group modelling projects is a crucial factor of success (e.g. Andersen and Richardson, 1997), only seven methodological frameworks enlighten this dimension.

Component S1: group structure. Six methodological frameworks stress the group structure component.

The frameworks highlighted by Richardson and Andersen (1995) and Andersen and Richardson (1997) identify five roles to be represented within the group modelling support team: (1) the facilitator, who acts as a group guide and knowledge elicitor; (2) the modeller, or reflector, who focuses on the model that is being formulated by the group and the facilitator; (3) the process coach, who focuses on the dynamics of individuals and subgroups within the team; (4) the recorder, whose task is to write down or sketch the important elements of the group proceedings; (5) the gatekeeper, who is usually a person within the "client" group who carries responsibility for the modelling project and initiates it. These five roles that have to be represented in any group modelling support team are well accepted in the system dynamics literature. They can either be distributed amongst several participants, or combined (Richardson and Andersen, 1995), and generally, the trend is to include two to five members taking on the roles of facilitator, modeller, process coach, recorder and gatekeeper. However, some authors prefer to duplicate certain roles, and this may be the case more specifically for the facilitator role. For example, Canava, Boyd and Taylor (2007) involved two facilitators per modelling session in their application of group model building.

Table 3: Frameworks classification according to the two-dimensional scale

Methodological frameworks	Structure		Process				
	S1	S2	P1	P2	P3	P4	P5
Vennix et al. (1992)	✓		✓	✓	✓	✓	✓
Vennix and Gubbels (1992)				✓			
Wolstenholme and Corben (1994)				✓			
Richardson and Andersen (1995)	✓						
Vennix (1996)				✓			
Vennix, Akkermans and Rouwette (1996)			✓	✓			
Andersen and Richardson (1997)	✓	✓	✓	✓	✓		✓
Richmond (1997)							✓
Ford and Sterman (1998)					✓		
Cavana et al. (1999)			✓				
Vennix (1999)	✓		✓				
Rouwette, Vennix and Thijssen (2000)		✓					
Stave (2002)			✓	✓	✓		✓
Howick, Ackermann and Andersen (2006)				✓	✓		
Cavana, Boyd and Taylor (2007)	✓			✓			
Visser (2007)	✓						
Number of frameworks per component	6	2	6	9	5	1	4
Number of frameworks per dimension	7		13				

Indeed, an important aspect of the process of group model building is facilitation (Rouwette, Vennix and van Mullekom, 2002). Given that the facilitator's attitude has an impact on the quality of communication and on the establishment of a consensus among participants (Akkermans and Vennix, 1997), this role is relatively well explained in previous works. For example, Visser (2007) proposes an application of the communication theory to the facilitator's behaviour. In the same vein, Vennix (1999) was interested in the characteristics that are essential for this actor: he must adopt the "right" attitudes (such as mutual aid, neutrality, investigation, curiosity, integrity and authenticity), have a sufficient knowledge of the system dynamics approach, and have process structuring skills, conflict handling skills and communication skills.

As well as the group modelling support team, the groups and subgroups involved in each modelling session should include stakeholders and/or experts on the system or part of the system. The gatekeeper plays an active role for the selection of these participants (Andersen and Richardson, 1997). On the one hand, it is suggested that the number and diversity of participants may have a positive effect on the usefulness of the model designed (Richardson and Andersen, 1995). On the other hand, however, it is recognized that communication among group participants decreases as the group size increases (Vennix et al., 1992), and that the management of large groups underlies issues in terms of interpersonal relations and conflicts, which add an inhibition risk to the process (Richardson and Andersen, 1995). The underlying intricacy may be more apparent in groups that include various stakeholders with conflicting interests: it may justify the need for creating a sub-group per group of stakeholders involved in the modelling project, as recommended by Cavana, Boyd and Taylor (2007).

Anyway, the team size does influence the management of the project (Vennix et al., 1992), and has to be taken into account. First, the roles of facilitator and of modeller have to be necessarily separated in projects involving a large group (Richardson and Andersen, 1995). Second, the fewer the participants involved, the more unstructured the techniques can be. Third, if a large number of people are involved, labour-saving techniques have to be used (such as questionnaires, workbooks, structured workshops, and software support) (Vennix et al., 1992).

Component S2: logistics. Existing frameworks investigating the logistics are scarce: only two articles are concerned with this component.

The framework proposed by Andersen and Richardson (1997) provides recommendations regarding the room layout and the technical supports, given that a room with a top notch set up and appropriate technical supports facilitates the communication and the implementation of tasks. First, concerning the room layout where modelling sessions take place, chairs must be placed in a semicircle, and one should preferably use swivel chairs. Indeed, as these authors explain, swivel chairs allow participants to turn easily to address each other and/or to create small subgroups. Moreover, whereas small tables can be useful for the occasional writing tasks that may arise during the workshop, tables are often absent from plenary group meeting sites given that tables might interfere with group dynamics. Second, it could be useful to combine technical supports such as whiteboards and projection equipment. The framework suggested by Rouwette, Vennix and Thijssen (2000) also puts the emphasis on technical supports, and more exactly, on electronic equipments. These authors show that electronic communication could be used to avoid the direct costs of convening groups, given that it enables to reduce conformism thanks to the use of anonymity, and to increase the number of participants involved in a modelling session.
In short, the visual coherence and synergy must be maintained during the modelling sessions, and the logistics – in terms of room layout, visual aids and communication channels – are presented as a critical success factor of the group modelling sessions. In particular, the logistics component plays a primary role with respect to the facilitation process.

4.2 Process dimension

The majority of methodological frameworks stress the process dimension of a group modelling project. The group modelling process in system dynamics involves cognitive tasks that can be divergent, convergent or evaluative (judgment and choice). Each activity of this process emphasizes different combinations of these types of cognitive tasks (Vennix et al., 1992). Some techniques can support process activities, but they depend on the type of tasks they involve: whereas divergent tasks have to lean on an individual application of techniques or on small nominal groups, convergent and evaluation tasks require plenary sessions, which can be completed by sub-group workshops (Andersen and Richardson, 1997). Hence, each step of the group modelling process can include a succession of individual activities, sub-group workshops and plenary sessions. Nevertheless, each possesses its own issues and requires its own techniques.

Component P1: problem articulation. The first step of the group modelling process using system dynamics is addressed by six frameworks. This step is crucial for any modelling project, given that it aims at identifying the objective and the scope of the model to be designed.

The problem articulation activities are mainly based on individual meetings with participants, that is, preparatory interviews (Stave, 2002; Vennix et al., 1992), or on small nominal groups (Vennix et al., 1992). Diverse techniques can be used to structure the problem to be solved, such as: the combination of system dynamics modelling techniques and of brainstorming tools (Vennix, Akkermans and Rouwette, 1996); the tool of reference modes sketched as graphs of problematic and preferred behaviour over time (Andersen and Richardson, 1997); the tool of coloured hexagons to identify the stakes and key variables of the system under consideration (Cavana et al., 1999). Whatever the techniques used, this first step mainly relies on divergent tasks in order to increase the quantity and diversity of ideas (for example, about the system boundaries) (Vennix et al., 1992), and on visual aids such as graphs, maps, or diagrams, in order to support the process of eliciting information.

However, opinions in a group can differ considerably regarding the problem to be solved. Two main factors explain the existence of ill-defined or messy problems: the deficiencies in group interaction and the construction of multiple realities in groups (Vennix, 1999). Hence, in the case of messy problems, the role of facilitator is even more crucial to create consensus and commitment within the group.

Component P2: dynamic hypotheses. This component is related to the conceptualization of the system under consideration into an influence diagram, in order to highlight its feedback structure. Nine methodological frameworks are concerned by this group modelling step. They are mainly articulated around two common issues: the process of knowledge elicitation and the establishment of a consensus among participants.

This step often requires structured and systematized group activities, with the presence of one or more experts in system dynamics modelling and one or more facilitators (Vennix et al., 1992; Cavana, Boyd and Taylor, 2007). For instance, according to Canava, Boyd and Taylor (2007), it can be useful to first perform distinct modelling sessions for each stakeholders group, to reduce the risk of limiting the points of view to one dominant stakeholders group. In fact, whereas the conceptualization of a system into influence diagrams can rely on divergent tasks for knowledge elicitation, the design of feedback structures is often performed through convergent tasks in order to explore courses of action (Vennix et al., 1992).

Various techniques can be used to facilitate these activities. For example, Vennix and Gubbels (1992) identify the Delphi method and the nominal group technique. Wolstenholme and Corben (1994) also insist on the usefulness of the Delphi method, specifically if groups of participants are large and geographically dispersed. Vennix, Akkermans and Rouwette (1996) suggest combining system dynamics modelling techniques and brainstorming tools. Andersen and Richardson (1997) put the emphasis on tools that can help participants to reason in terms of feedback, such as system archetypes. Howick, Ackermann and Andersen (2006) describe an approach that links semantically rich scenario maps to formal influence diagrams. Stave (2002) and Vennix (1996) recommend using a preliminary influence diagram, especially if participants have no system dynamics modelling experience, if the facilitator has only little experience in group model building, and if participants do not have enough time and/or are geographically dispersed. In short, the main techniques identified are referred to as information flow supports as well as cognitive aids. However, most previous works highlight the necessity of using appropriate techniques according to the team size, the time available, the localization of participants, etc. Moreover, some of them even recommend combining different techniques of cognitive aids during this second step.

Component P3: simulation model formulation. Five frameworks investigate the model formulation step, which includes the design of a level-rate model, the development of decision rules, the quantification and calibration of the model. These frameworks are mainly interested in the process of knowledge elicitation to collectively design a level-rate diagram.

On the one hand, the tasks related to the design of a level-rate diagram must be based on individual meetings with participants or on small nominal groups, as well as on structured and systematized group activities (Vennix et al., 1992). On the other hand, the tasks related to the development of mathematical equations are rarely completed with the entire group (Andersen and Richardson, 1997). Some authors account for the implementation of this third step. Andersen and Richardson (1997) describe methods that aim at quantifying model variables and refining model. Howick, Ackermann and Andersen (2006) recommend limiting the tasks to key variables and relations, using the reference modes, and trying to formally capture the participants' reactions in order to refine the model. Ford and Sterman (1998) put the emphasis on the codification of expert knowledge, in order to estimate the model's parameters, the initial conditions of the model, and the interrelationships to be specified in the level-rate model.

Nevertheless, the model formulation step is an iterative process that often requires important preparatory activities (off site) from the modelling team (Stave, 2002), in order to reduce the complexity of the task during the group modelling session. According to Rouwette, Vennix and van Mullekom (2002), in most cases, quantitative modelling tasks are not done in front of the group of participants because of their complexity. Thus, this group modelling step is seldom investigated in the literature. As Ford and Sterman (1998: 309) point out, "*the literature is comparatively silent, however, regarding methods to elicit the information required to estimate the parameters, initial conditions, and behaviour relationships*" that must be specified in quantitative modelling.

Component P4: testing. The fourth process component concerns the validation tests of the simulation model. Only one framework investigates this step in the context of group tasks.

This framework is proposed by Vennix et al. (1992). These authors identify some techniques that can be used to perform evaluation tasks that mainly aim at assessing the validity of the model's output, such as: the Delphi method, the social judgment analysis, and the nominal group technique. Nevertheless, internal and external consistency tests are mainly under the responsibility of the modelling team: this step does not require the direct implication of the participants. Hence, this component is of no great interest in group modelling research, even if it is generally recommended that the model should be validated by experts on the system.

Component P5: formulation of strategies and evaluation. This component is related to the development of scenarios and the analysis of simulated results over time. Four frameworks are concerned with this group modelling step. The issue of the establishment of a consensus is omnipresent in these works, regarding the scenarios to be tested and the decision strategies to be ultimately implemented.

Group activities to be carried out in this step mainly involve tasks of judgment and choice: they are especially based on structured and systematized group activities (Vennix et al., 1992). On the one hand, the development of scenarios (i.e. potential decision alternatives) often requires group modelling sessions with a restricted number of participants. On the other hand, the debating and evaluation of simulated alternatives often involve brainstorming sessions with the entire group (Stave, 2002). Certain techniques can be used to facilitate these group activities. For example, Vennix et al. (1992) put the emphasis on using the Delphi method, the multi-attribute utility theory, the social judgment analysis, and the nominal group technique; Andersen and Richardson (1997) suggest that simple voting procedures can be used; Richmond (1997) describes an approach that aims at favouring the coherence between objectives and strategy and that mainly involves discussion and testing in a "strategic forum".

Hence, whereas the underlying evaluation tasks can be generally best performed in strongly structured group sessions (Vennix et al., 1992), the techniques used in practice range from unstructured (such as discussions, simple votes) to specific structured techniques (such as frameworks provided by the multi-attribute utility theory and used to evaluate competing alternatives on multiple criteria).

5. Conclusion

In this paper, the key methodological frameworks on group modelling project using system dynamics, were identified and classified. Their in-depth analysis indicates that existing frameworks proposing a global vision of projects are scarce.

First, few of them consider both aspects of structure and process simultaneously. Given that these two aspects are inextricably linked (e.g. Vennix, 1999), it is now time to further investigate the interrelationships between them and their successful "fit". Second, none of them covers the seven components as defined in the analysis scale used in this present study. On the one hand, the structural dimension suffers from a lack of methodological support, except for the facilitation aspects. On the other hand, while the process dimension is better investigated, the emphasis is mainly put on qualitative modelling: the group tasks for the quantitative modelling process are seldom examined, and the totality of the group modelling process is rarely taken into consideration. Consequently, previous works in system dynamics fail to give a detailed and global picture of the approaches required to implement a group modelling project. However, the framework developed by Andersen and Richardson (1997), and more recently applied by Luna-Reyes et al. (2006), represents an effort to address this gap, since it describes a set of techniques and of sub-processes, commonly referred to as "scripts", for the organization and the planning of group modelling sessions, and for the group tasks directly linked to the modelling process. These "scripts" result from ten years of experience and of literature reviews (e.g. Vennix, Andersen and Richardson, 1997) and their accumulation could be a response to the problem of improvisation that group modelling projects suffer from (e.g. Andersen, Richardson and Vennix, 1997).

A major contribution of this research is the identification of critical issues concerned with any group modelling projects. First, the elicitation of participants' knowledge is at the core of such projects. It is a question of being able to manage relevant cognitive processes and capture the mental models of the participants, in order to create a shared mental model among the entire team. However, this task is a difficult one, and it becomes more and more complex during the quantitative modelling process.

Second, the establishment of a consensus among participants is a necessary condition for making progress in the project, and plays a decisive role when the time comes to articulate the problem to be solved and to evaluate the strategic alternatives. Third, the aspects of facilitation are presented as a critical success factor of the group modelling sessions. The facilitation aspects depend not only on the attitudes and skills of the actor(s) referred to as the "facilitator(s)", but also on the choices that are made about logistics and the techniques used. The system dynamics literature highlights some guidelines that can be followed to cope with these issues, but they depend on the type of cognitive tasks to be performed.

Although this paper makes a useful contribution to the group model building literature, several potential limitations should be noted. First of all, whereas the context in which group modelling projects take place may be important (e.g. Andersen, Richardson and Vennix, 1997), contextual variables are omitted in this present study. Notably, one may suggest that factors such as the type of organization, the organizational culture, the history of participants, to name but a few, can influence the project implementation. In addition, the scope of this research is limited to the methodological frameworks using system dynamics modelling. However, the problems and issues raised by the realization of such projects also exist in other fields of research, such as: problem structuring methods of operational research, multi-criteria decision support, mind mapping, collaborative action research. Thus, these various fields of research could be used to go deeper into the analysis carried out in this article.

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