Crowd model building as a collective decision support system

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Abstract: Different researchers have designed a diversity of model building methods with specific characteristics depending on various data sources, objectives and applications in the system dynamics. On one hand, the expansion of system dynamics applications has caused the development of various model building methods necessary. On the other hand, information technology advances specifically web 2.0 has led to the development of various model building methods with more capabilities. Thus, the main purpose of this paper is to introduce crowd model building based on web 2.0. To achieve this objective, first, various system dynamics modelling methods including document model building (DMB), individual model building (IMB), group model building (GMB), community model building (CoMB) and crowd model building (CMB) were compared and contrasted through a systematic literature review. Finally, crowd model building was fully explained.

Keywords: online/web surveys; collective decision support system; CDSS; System Dynamics II; SD 2.0; crowd model building; CMB.

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1 Introduction

System dynamics with a claim of recognising the main structure of determining techno-socio-economic behaviours achieved a tremendous progress in the shortest time and is regarded as the most effective and powerful problem-solving approaches to various social-economic systems problems (Fartookzadeh and Zolfagharian, 2012).

The growth of system dynamics took place in a range of three different domains that include:

1 defining in various countries and reputable universities as an academic discipline (Morecroft and Wolstenholme, 2007; Milling, 2007)

2 increasing the applications of this approach so that system dynamics has been used for various applications and industries (Elharakany et al., 2018; Omamo et al., 2018; Nikabadi and Hakaki, 2018; Soni and Chorasia, 2017; Oyo et al., 2016; Haji Gholam Saryazdi et al., 2015; Haji Gholam Saryazdi and Manteghi, 2014; Gholamrezaei, 2014)

3 advancing in methodology as well as instruments, diagrams and software (Akkermans and Vennix, 1996; Haji Gholam Saryazdi, 2014).

For system dynamics, due to various information sources, conditions, objectives and applications, researchers have designed various methods for model building with certain characteristics, strengths and weaknesses which are appropriate for specific conditions and circumstances (Richardson et al., 1989; Winz and Gary, 2007). Furthermore, as Kim (2007) said, the model building method influences on the model which is developed. In this regard, on the one hand, the expansion of system dynamics applications and its related problems has made the development of various model building methods necessary. On the other hand, the development of information technologies and capacities especially Web 2.0 and social networks has created the potential for development of various model building methods with more capabilities. So in this paper crowd model building (CMB) is introduced as a Web 2.0 and social networking-based approach. For this purpose, first, various model building methods including document model building (DMB), individual model building (IMB), group model building (GMB), community model building (CoMB) and CMB have been compared through a systematic review of literature. Then, the CMB has been explained in details.

This paper is organised as follows: the next section makes a review of related literature of various model building methods. Then, the research method used and the research is explained. Afterward, there has been an attempt to present a suitable taxonomy of various model building methods and make a comparison among them to provide a better explanation on the CMB method. Finally, the process of CMB is elucidated.

2 Review of literature

Nowadays, a variety of software is available with different applications, strengths and qualities. For instance, the AnyLogic software has the capability of using several simulation approaches simultaneously (http://www.Anylogic.com) or web-based Optisim and Forio software which can build online simulations (http://www.forio.com; http://www.optisim.org/GLENG). Also, the web-based sites such as Insight Maker can create model with multi-user interface (http://www.insightmaker.com). Insight Maker integrates three general modelling approaches (Fortmann-Roe, 2014).

Various approaches to model building have been developed. In model building methods, first, the focus was mainly on mental models of modeller and based on the available library information sources and IMB. However, since the today's problems are beyond an individual's capability and responsibility (Roos, 1997), the participatory model building method was introduced. The participatory model building can be

performed using individual or group interviews. One of the sub-categories of participatory model building method is 'GMB' (Vennix, 1999). As Winz and Gary (2007) showed that stakeholder participation in system dynamics is not a new phenomenon. However, the involvement of stakeholders in all processes of model building with the objective of improving learning and supporting the implementation and application of GMB has recently been raised and has developed within the past 20 years (Vennix et al., 1997). The GMB since its emergence has been growing quickly so that it has been applied to many researches (Antunes et al., 2006; Elias, 2008) and there have been numerous studies on model building process, guidelines and their evaluations of this method.

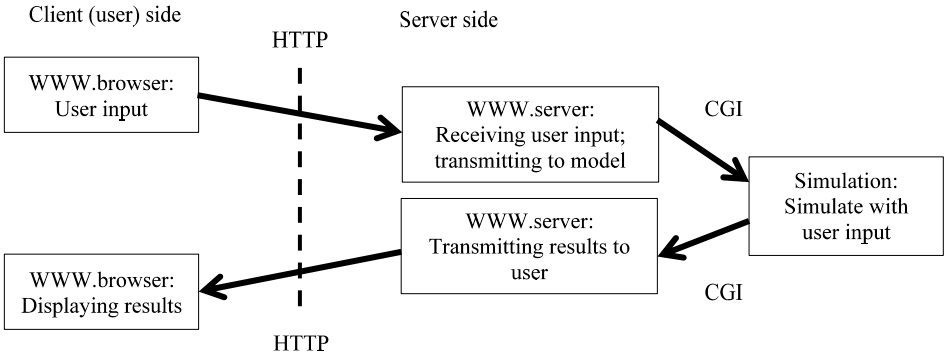
For example, Carter et al. (2013) introduced VISCONS judgmental method into GMB with a shared qualitative vision for a problem. Rather than individual interviews, VISCONS can synchronously and consensually be used for group in parameter estimation. Moreover, unlike Delphi, VISCONS is synchronous and can be used in real time in the group. VISCONS is a quick and efficient method to avoid GMB problems such as vagueness, incomplete evaluation and non-sequential participation concerning the experts demand.

In following the development of system dynamics, internet and Web 2.0 technologies has been used. Concerning the studies in which the web, transactions and its influences has been used, social computational systems have been created which is a unique interdisciplinary research for a better understanding of technical-social behaviour (Agarwal and Xu, 2011). This discipline has created open standards and has led to a collective wisdom (Surowiecki, 2004; Salerno et al., 2011).

Gary with Charyk (1996) introduced groupware technology as a tool for facilitating and reinforcing GMB through providing an electronic forum for team members to obtain and share all related information. In this method, all the relevant information is shared and discussed in one uninterrupted virtual meeting. The team members make an effort to document their mental models and ensure that their electronic discussions lead to a general consensus or alternative hypotheses. In this model building, the team members can involve anytime. The continuous virtual meetings cause the CEOs more involvement, consensus and commitment.

In conventional methods, the models were typically identified during several sessions. This was difficult for all team members to participate in meetings and put pressure on model building team to finish the work within a restricted time. This leads to project's incompletion and a merely qualitative model building (Gary and Charyk, 1996). Thus, to resolve this problem, the application of internet and Web was introduced. Groessler (1996) maintains that although system dynamics creates a shared language, access to group members and their participation can be difficult due to their physical distance. Thus, virtual places can be useful and IT having access to static data can result in a collaborative action with dynamic qualitative data. Groessler (1996) adds, the initial stages of participatory model building can be performed using collaborative tools such as video-conferences, e-mails, etc. In more advanced cases, people can work together to build the model, although they are geographically distant from each other. Figure 1 depicts structure of interactive simulations on the web.

Figure 1 Structure of interactive simulations on the WWW



Source: Groessler (1996)

Today, web-based applications and games complete the traditional group workings (Hovelynck et al. 2010). Machuca and Del Pozo (1997) state that computer games based on model building result in distant learning with lower costs and allows for comparing the results between a great numbers of persons. Milling and Lehmann (1994) point out that games reinforce three areas including decision-making, systems thinking education and shared learning. The management games can lead to the improvement of various communications and competencies and sharing values and objectives (Milling, 1996).

Akkermans (1995) says, although quantitative or digital data are more accessible and analysable using IT, they are not sufficient for making strategic decisions since most of their factors are more soft factors. These soft factors are more effective than hard factors. Hard factors lead to intellect while soft factors result in wisdom (Mintzberg, 1994). Consequently, there is a need for participative methods.

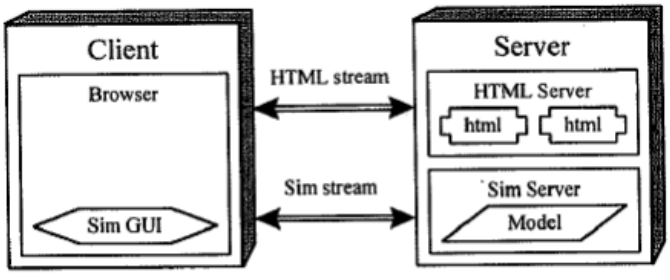
According to Azevedo-Carns (1997), the distance learning opportunity is increasing with computer's support from GMB and it is necessary to carry out further research on the method and time of its exploitation. Azevedo-Carns (1997) articulates that there are two methods for GMB. The first method is the traditional-based brainstorming (including field studies and experimental research comparing traditional brainstorming groups with face-to-face and nominal groups). The second method of GMB is electronic brainstorming (EBS) based on group decision support systems (GDSS). Azevedo-Carns (1997) writes, technology advances in sharing and viewing models on the web can create an interactive learning environment (ILE) in which groups can interact with each other to build models.

Jordao et al. (1997) suggest general multi-media tools with the objective of reinforcing understanding of causal relationships and structure/behaviour feedback. Myrtveit and Bridgeland (1997) designed the architecture of a Websim through which management simulator software can be implemented without the need for installation and using only web browser. Figure 2 illustrates the architecture of a Websim.

Alessi and Trollip (2001) assert that web is the next logical step for complementing computer-based learning which leads to expansion and dissipation of ideas for learning. Glass-Husain (2005) stated that the simulation can be carried out on the web browser and enjoy benefits such as world wide access, simple distribution and capability of monitoring simulation process. Diker and Allen (2005) proposed the XMILE language as

an exemplar interchange standard for solving the interchange problem of models among various software. According to Ikeda and Suetake (2005), groupware via the internet is appropriate for evaluation of general policy-making.

Figure 2 Architecture of a Websim



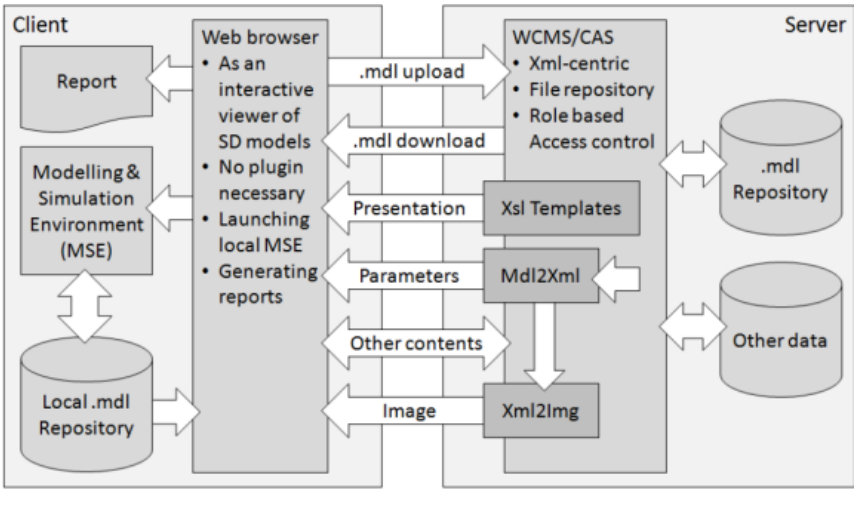
Source: Myrtveit and Bridgeland (1997)

Groesser (2006a) defines the ILE as a web-based learning environment which supports the structured interchange among the learning societies and reinforces the individuals and groups learning and removes the spatial restrictions through the internet.

Michael Bean, in recent years, has held educational workshops on online simulation and web-based games depending on system dynamics, discussions on web-based simulation (WBS) challenges and their potential solutions and providing some examples (Bean, 2007, 2008a, 2008b). He started training Forio as a web-based model building software (Bean, 2009, 2013, 2015; Bean and Schoenberg, 2010a, 2010b, 2011a, 2011b).

Powers (2008) and Schoenberg and Powers (2008) suggested two free and open source software for system dynamics, i.e., 'OpenSim' and 'Open Dialect' (Schoenberg and Powers, 2008).

Figure 3 Web-based architecture and XML of system dynamics viewer model



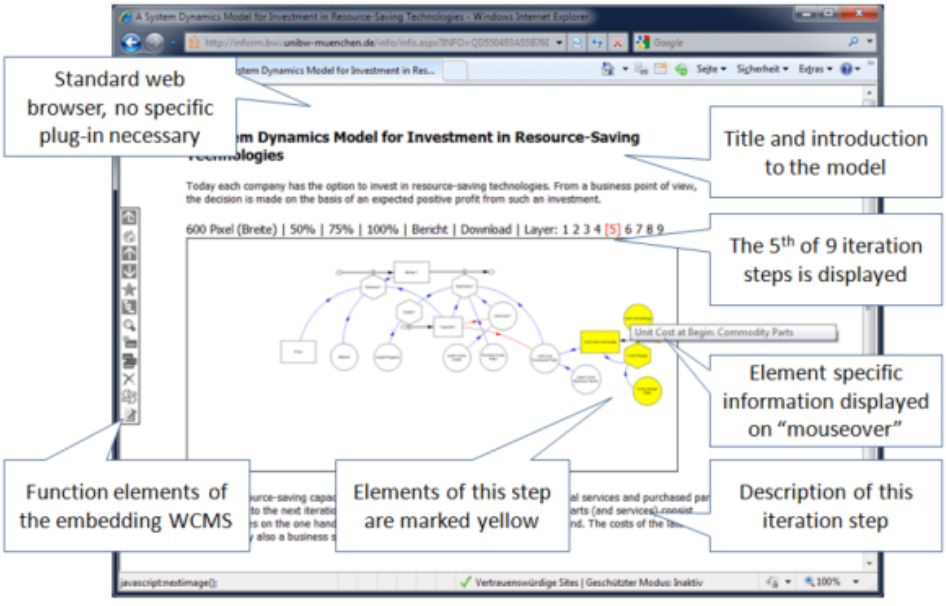
Source: Bo Hu (2011)

Schoenberg (2008) introducing the Open Dialect software, states that this software has contributed to create an ILE with an access to 1.3 billion users online.

Xue et al. (2011) describe the developed design of open source SILVER system which allows for virtual places to realise distant collaborations.

Bo Hu (2011) introduces a prototype of a web viewer of system dynamics models. A web viewer model can represent various interactive stages of modelling with the objective of providing system dynamics models as a part of simulation environment for collaborative modelling (Figures 3 and 4).

Figure 4 User relation of model viewer (see online version for colours)



Source: Bo Hu (2011)

Lempinen et al. (2011) introduced the new environment of system dynamics modelling and simulation based on open source functions, i.e., open source modelling framework semantics and simulation environment Open Modelica.

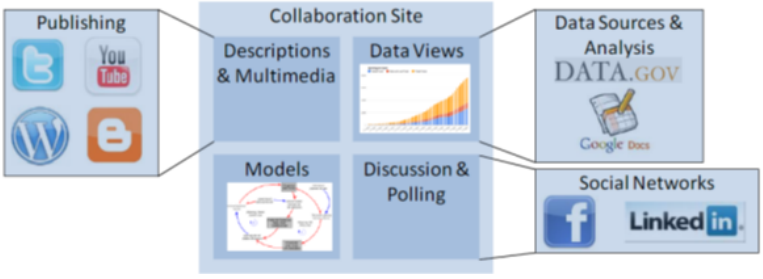
Skarin (2011) analysed the combination of system dynamics with web-based technology as part of distributed group problem-solving approach and grand problems (Figure 5).

Also, Levytskyy et al. (2009) present a model-driven approach to construction of web-based collaborative environments. Byrne et al. (2010) by reviewing of WBS, stated the advantages and disadvantages of WBS. Liu et al. (2012) introduce cloud-based computer simulation (CSim).

As we mentioned in the review of literature, on the one hand, the development of system dynamics applications has led to a growth of model building methods and applications and on the other hand, the emergence of web and internet has caused that system dynamics scientists are driven towards the use of these capabilities (Pruyt, 2016). Next, we try to introduce various model building methods and compare these methods

with CMB method which is based on Web 2.0 and social networks taking the research methodology into consideration.

Figure 5 System architecture (see online version for colours)



Source: Skarin (2011)

3 Methodology

In the present article, various system dynamics modelling methods were compared and contrasted through a systematic review of related literature. At this step, all the papers accepted at two preliminary rounds of research conference on system dynamics in 1976 and 1981 and 33 rounds of system dynamics conference since 1983 until 2015 available at system dynamics website society (http://conference.systemdynamics.org/past_conferences/) along with papers available on Elsevier and Wiley scientific database were reviewed.

In other words, there has been an attempt to introduce various model building methods, make a comparison among them and answer to questions for clarify different situations and circumstances in which these building model methods are suitable to be used. These questions depend on the factors and questions raised in the review of literature. Then CMB and it steps explained through CMB architecture.

4 System dynamics model building methods

As mentioned above, the present research aims to introduce CMB method through a comparison of different system dynamics model building methods. In the following section, we introduce and explain these model building methods.

4.1 Document model building

In system dynamics model building, the written database or documents and literature is one of the major sources of knowledge (Forrester, 1980; Richardson et al., 1989). In the other words, the model needs to be based on validated theories and empirical data (Vennix et al., 1988). DMB refers to use of the written sources as the main source of system dynamics modelling. The documents are written and numerical databases (Forrester, 1980). This includes articles, various reports, books, etc. It is important to note that in DMB, there are pre-existing, repetitive and well-structured problems since there

must be sufficient literature. Also, at the times when it is impossible to have access to experts and stakeholders or there are time or financial limitations, the DMB is suitable (Richardson et al. 1989).

In DMB, the individual or model building team after searching for relevant sources and documents make a comprehensive review of documents, analyse and elicit knowledge using analytical methods such as systematic review of literature, content analysis, grounded theory, hermeneutics, critical and official analysis of documents for model building in terms of their systematic perspective (Richardson et al., 1989; Schlüter et al., 2010; Hovelynck et al., 2010).

Concerning written sources (documents), although these sources are codified and more widely accessible than mental model knowledge and facilitate the abstraction of more detailed mental model data, the model builders are incapable of testing, developing and understanding its hidden assumptions and there is the possibility of bias in the coding (Ford and Sterman, 1997). Further, since these documents have not written for model builders, Richardson et al. (1989) suggest that experts evaluate these documents. These sources have little vagueness and can be used repeatedly (Richardson et al., 1989).

The DMB can be used in all the stages of system dynamics model building. Also, since the theories and initial model based on related literature can be precondition to other model building methods (Akkermans and Vennix, 1996; Groesser, 2006b), this method is typically used along with other model building methods such as GMB (Vennix et al., 1988; Laurenti et al., 2014) or as a preliminary method for developing dynamic hypothesis or initial model. The preliminary model leads to a concentration of discussions, time management, and higher efficiency in other model building methods (Richardson et al., 1989).

4.2 Individual model building

Although written sources have applications in model building, they do not dedicate a great bulk of data source to themselves. The most important data source for model building, as Forrester (1980) points out, is the mental database. In other words, system dynamics depends on interviewing key persons of the system (Vennix et al., 1990) and need excessively to qualitative data and human judgment in all stages of model building (Luna-Reyes et al., 2005a). In IMB, the emphasis is on using the hidden knowledge of individuals' minds. IMB refers to the process of building a model through individual interviews with clients, stakeholders, experts and those who are involved in the system. In the other words, this model building method interacts with players via individual interviews, oral history or questionnaire (less structured and open) and model construction workbook. In this method, the researcher is concerned with only one individual at a time (Vennix, 1988; Richardson et al., 1989; Fey and Trimble, 1993; Luna-Reyes and Andersen, 2003).

In IMB, individual or model building team must to determine the number of interviewees and then choose right people for interview. Also interviews type (structured, semi-structured or unstructured) and the technology used (face to face interviews, by phone, e-mail, etc.) should be determined (Luna-Reyes et al., 2004). Then, the interviews need to be done at the right time and place. After the interviews or completing questionnaires, model builder analyses data using various techniques such as content analysis, extracts the available models in the interviewees' responses and prepares the

ultimate model in terms of his own systematic perspective. Then, the model will be sent back to the individuals to ensure that the interviewer has provided the interviewees responses accurately (Richardson et al., 1989; Luna-Reyes and Andersen, 2003).

Halbe et al. (2015) state that in IMB, the individual learns to build system dynamics models from his or her own perceptions and personal judgments (Halbe et al., 2015).

In participative model building, eliciting data from participants can be performed through individual interviews, cognitive mapping or workbooks or can be through small or large groups or a combination of them (Antunes et al., 2006). In other words, IMB is a sub-category of participative model building.

IMB is mostly for creating knowledge and extracting information (extracting variables) as divergent (Richardson et al., 1989; Vennix et al., 1990; Andersen and Richardson, 1994) because in the information extraction phase, there is a need to non-interacting individuals to decrease group influence on individuals (Chen et al., 2014). In other words, IMB is suitable when individual's interaction within a group leads to model building partiality or when the participants are not willing to have open discussions or there are a restricted number of problem-solving experts (Vennix et al., 1988; Akkermans and Bosker, 1994).

The interviews data can explain perceptions, processes, feedback mechanisms and causal relations. Also, this method can be used for estimating quantitative values. An oral, rich and detailed response from interviewees is one of the properties of good interviews (Luna-Reyes et al., 2005a). In individual interviews, no discussion takes place between the team members and is time-consuming (Richardson et al., 1989; Luna-Reyes et al., 2005a). Individual interviews are asynchronous, have vagueness and a lack of consensus (Carter et al., 2013).

Consequently, this method is typically used in combination with other methods (Martinez and Richardson, 2001; Groesser, 2006b; Pieters et al., Martinez-Moyano et al., 2007). For instance, Ford and Sterman (1997) initially used individual interviews and then group interviews. Vennix et al. (1990) extended their quantitative model using individual method and then group workshops (Vennix et al., 1990). Yuliani and Tasrif (2006) used deep interviews along with content analysis of relevant documents at the system conceptualisation stage. Laurenti et al. (2014), after reviewing related literature, extracted the effective variables and hold one session GMB. Finally, they held individual interviews for modifying the model.

4.3 Group model building

As mentioned above, one of the complementary procedures of system dynamics is movement towards using mental processes and participatory or group model building (P/GMB) since the man's mind is incapable of analysing all the complexities due to short-term limited capacity or false perceptions from feedback structures (Groessler, 1996; Roos, 1997). Although IMB does not have the risk of group thinking, groups have higher ability for filtering false information towards an individual. In groups different views with different expertise are gathered and discussions lead to a clarification of individuals' assumptions (Carhart and Yearworth, 2010). Further, the gathering of experts, stakeholders and researchers reduces information gap among these three groups and increases their consensus and holism (Olabisi, 2010). Thus, group knowledge sources are higher quality than individual knowledge sources in problem-solving.

Consequently, it is necessary to use GMB facing messy and ill-structured problems with complexities and numerous stakeholders and due to the limited capacity of man's mind (Vennix, 1999). There are not sufficient theories about these problems in literature. In other words, in ill-defined problems or when experts have limited knowledge of a system that this knowledge is about a part of system too, many people need to participate to share their different views. Although this great number of individuals results in dissipation of knowledge, it would be difficult to structure and organise the process of knowledge acquisition (Vennix et al., 1988). As Groesser (2006b) points out, in GMB, several groups of players need to be involved in the process. If there is only one player in the problem, the IMB is superior to GMB (Groesser, 2006b).

GMB was developed in the 1980s (Hovmand, 2014) to refer to system dynamics process through involving clients deeply in model building process. In other words, GMB is a method based on system thinking methods for involving stakeholders through numerous sessions to look for effective factors influencing complicated systems with deep levels of uncertainties and ambiguities (Elias, 2008). Vennix (1996) defines GMB as a process through which team members interchange and discuss their own perceptions of a problem. For GMB, nominal group technique, social judgmental analysis, focus groups and Delphi method (Dalkey and Helmer, 1963), hermeneutics, soft systems methodology (Checkland and Scholes, 1999) and other suitable methods are used (Richardson et al., 1989; Rich et al., 2009).

In GMB, the model can play both the role of a micro world as a tool for solving problems and a boundary object as an instrument for discussion and learning (Andersen et al., 2007). In other words, GMB reiterates both structuring problem and process (Akkermans et al., 1993; Groesser, 2006b).

The involvement of stakeholders or individuals participation can take place at any stage of GMB (Beall and Ford, 2007; Haji Gholam Saryazdi, 2014). In this method, development of model is happened through knowledge extracting of participants since there are not this knowledge in literature (Vennix et al., 1988). Also since deeper knowledge is needed.

According to Richardson et al. (1989), GMB phases including problem definition, extracting variables and model conceptualisation needs to a less structured and more divergent thinking. In these phases individual method is better than group method. But GMB is a more suitable method for analysing and selecting the best variables (Richardson et al., 1989). On the other hand, the experts need to involve in convergent thinking phases of GMB to respond to technical questions. At this stage, GMB is often during problem solving practices to come to a general consensus among expert group (Chen et al., 2014).

The major problem in GMB is the numbers of individuals who need to participate in the model building session. Elias et al. (2004) reiterate that, the group members need to be selected that cover a diversity of views. However, the size of groups cannot be very large; although this causes a larger organisational database for commitment to implement a decision and increases model quality, on the other hand, reduces individuals' participation and satisfaction and creates tensions among group members (Richardson et al., 1989). Consequently, the size of group must not be too large or too small. Vennix (1996) and Richardson et al. (1989) regard 10–12 members in a group as an ideal group and a group with 25 members a large one (Vennix, 1996; Anderson and Richardson, 1995). There are usually two methods for GMB. In the first method, GMB involves small

groups of 3–5 individuals. The second GMB allows for participation of 25 individuals or more (Winz and Gary, 2007). In large groups, there are typically five roles for model building team to manage the sessions efficiently. These roles include facilitator, moderator-recorder, content coach/modeller, process coach and gatekeeper (Luna-Reyes et al., 2005b; Esensoy and Carter, 2015).

The second challenge after determining the number of members is to select appropriate members (Groesser, 2006b). The participating members need to be selected using purposive sampling (Yuliani and Tasrif, 2006) and involve experts, stakeholders and clients and those who are directly involved in the problem.

The reason for selecting a small number of members is the accessibility restrictions and gathering the individuals in one physical location. To overcome this problem, there are two methods.

One solution to this problem is using a combination of model building methods (Martinez-Moyano et al., 2007; Chaloupka, 2007; Richards et al., 2013). For instance, Vennix et al. (1988), first, tried to develop a preliminary model through a review of literature and model builders' insights. Then, they made an attempt to try out policies and discuss the results using experts' views via Delphi technique panel. They also extended their model using workbook, IMB as well as group workshops of quantitative model.

Ford and Sterman (1997) initially used individual interviews and then moved towards group interviews. Luna-Reyes et al. (2005a) used observational data and interviews for their preliminary analysis. Then they used GMB. Carhart and Yearworth (2010) used nuclear industry documents and GMB for evaluating non-military nuclear industry. Wagle (2014) suggests rapid participatory system dynamics modelling (RPSDM) for tacking time, resources and expert's limitations in GMB which is based on a combination of individual and GMB methods. Also, Laurenti et al. (2014), after reviewing related literature, extracted effective variables, boundary and functions in the life cycle assessment. Then, they held a GMB session. Finally, they performed individual interviews to modify the model. Vugteveen et al. (2015), first, prepared and sent an online questionnaire to extract related variables. Afterward, they extracted relationships between variables in workshops through identifying the participants.

The second solution to tackle this problem is using community or CMBs. In the next section, we introduce community and CMBs.

4.4 Community model building

CoMB refers to an extended, but certain group of experts, stakeholders, and clients who are related to the problem and involved in it. The group members are mainly 25 to 100, but may exceed this estimate as circumstances dictate. Such individuals are often first identified by the model building team and then invited for the purpose of building models. New participants may also be introduced and invited to the team through these newly added members, which requires new members to be engaged with the problem.

In the CoMB, an online community is first established and then, members initiate model building through this community. In this model building procedure, participants attempt to perceive the problem and clarify it, analyse and recognise the structure causing the problem and ultimately, build a model based on it and propose solutions.

The CoMB can be accomplished through platforms of internet, Web 2.0 and social networks. The CoMB leads to greater involvement of members as well as to independence of place and time; however, responses suffer a lower validity and reliability

than those in GMB, since in the latter, a smaller number of people are gathered together at a certain point in time who eventually produce more accurate and reliable output based on some challenging and accurate debate.

Peter Hovmand proposed community-based system dynamics (CBSD). He states that a community-based model building is a participatory approach to engage and work with associations and organisations to develop GMB (Hovmand, 2014; Yadama et al., 2010). In this regard, Bridgewater et al. (2011) attempted to strengthen understanding and develop a strategy to improve crime prevention among teenagers in Boston, using the community-based model building. Such communities, other than specialised, expert and guild members, can include rural population, outcasts, the poor, etc. (Yadama et al., 2010; Hovmand et al., 2010, 2014).

It is important to note that CoMB according to Hovmand is model building through communities, while the CoMB in this study refers to online model building via internet and social networks through involvement of communities. In other words, members selected for the CoMB must be experts, stakeholders and clients involved in the problem. This type of model building, in which problem are generally novel and researches are exploratory in nature, is suited to consider problems for which there are sufficient specialists who are far apart or it is difficult to gather them around at a certain time and place.

By the term 'community', it is meant a group of individuals with some points in common, such as location, experience or interest (cited in community tool box website).

Model building in a community leads the whole system toward better understanding of perspectives of different experts and stakeholders in that particular community. The isee system company has initiated a model building program on its website by organising an online webinar on freelance training with 70 participants. This company has also conducted a webinar on the topic of drought in California through the CoMB by establishing an online community with the aim of building models and discussing them, in which nearly 160 people enrolled (isee system company website).

The CoMB approach is appropriate to initiate GMB phases which mostly need divergent thinking (Richardson et al., 1989). Divergent tasks involve obtaining different ideas about reference mode or model boundary and deriving different variables (Anderson and Richardson, 1994).

In this method, since the information is recorded by the community members at the time of receiving and the members are free in time and space, only the modeller is required to act. In other words, the quintuple roles required for GMB can be accomplished by one person.

Haji Gholam Saryazdi and Purserajian (2015) investigated barriers to technology development in Yazd Province through the CoMB. Their study comprised of two stages: at the first stage, they initiated their CoMB program by establishing an online community in telegram messaging service and registering the target population in the community (managers of state agencies, university authorities and professors, managers and industry experts, entrepreneurs and managers of tech firms, members of Yazd Science and Technology Park). Accordingly, they posed their research question (what are the barriers to technology development in Yazd Province?) in the community and members' information and opinions were collected within one month. Then, the overall conclusion was presented to the group after integrating and moderating ideas, revisions were obtained and ultimately, the output was approved by all the members. Then at the second

stage, by holding two meeting sessions on GMB including people with expertise and responsibilities related to technology development, the output resulting from the CoMB was scrutinised and the final model was extracted.

4.5 Crowd model building

Expansion of internet access along with borderless, interactive communication via Web 2.0 and social networks has provided grounds for problem solving, acquiring and sharing knowledge. Using of crowd for performing various tasks such as sharing of knowledge and ideas through crowdsourcing, sharing financial resources through crowd funding, labour supply through labour cloud, etc. is increasing.

Adoption of social media has altered methods of production and consumption of information towards the use of the phenomenon of creating intelligent and collective data. Social media are inexpensive, easy to use, and almost everywhere available platforms which provide a dynamic, participative (collaboration-driven), democratic and non-regulated environment to internet users to express views and opinions, share notions, and participate in debates (Agarwal and Xu, 2011). Internet provides opportunity for the global model simulation by establishing infrastructure, especially web-based services. Simulations run in a web browser possess advantages such as global access, easy distribution, and ability to monitor simulation stages (Bean, 2007).

Therefore, since IT and internet provide researchers with an environment to collect massive datasets and also, to conduct web-scale experiments (Liu et al., 2010), behavioural model building is facilitated for generation of social behaviour, implementation of scenario planning, advanced perception of social behaviour, patterns and its potential consequences (Agarwal and Liu, 2009). In this regard, various methods and systems have been created for study of interactions among individuals, groups and even nations (Agarwal and Xu, 2011).

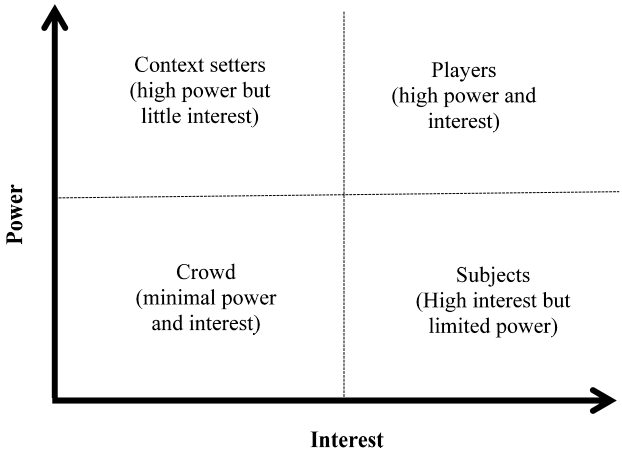
In this paper, we used this platform for system dynamics and introduced CMB approach as a collective decision support system (CDSS). The CMB here refers to the use of Web 2.0 and social networks to gather a large number of people for identifying new, exploratory dynamic problems and collecting different opinions, as well as analysing, model building and presenting its results.

Winz and Gary (2007) believe that participation can occur at individual, organisational or social level. Thus, the CMB emphasises social participation as it involves very large, infinite and uncertain group of all people who can be either expert to the problem and involved in it or have no particular relation to the target problem. As previously mentioned, the number of people is infinite in this type of model building and the team usually holds a public call to invite people for model building. Moreover, the core participants, including experts, stakeholders, and clients related to the problem and involved in it are identified by the model building team and invited to build models. In this approach, new participants are also introduced to the procedure and participate in model building through the members.

This perspective in this approach is diverging in nature and the approach functions for new, exploratory research issues in need of collecting great number of opinions. However, this method is commonly used for certain topics for which no specific experts are available. Here involvement of users is important for two reasons of knowledge acquisition and diffusion (Vennix et al., 1988).

According to the classification of the problem's audiences or stakeholders based on power and interest proposed by Bryson (2007), a crowd usually demonstrates low power and low interest over the problem (Bryson, 2007; Butler and Adamowski, 2015). That is why new phenomena and exploratory researches are performed CMB.

Figure 6 Classification of stakeholders based on power and interest



Source: Bryson (2007)

4.6 Comparison of different model building methods

In that follows model building methods are compared according to influential factors on the selection of such approaches as well as characteristics of each approach. With literature review factors affecting the choice of model building approaches are identifies that include: type of problem, purpose of model building, type of used data source, type of output, place-form processing continuum, type of work to perform (dominant perspective), number of participants, number of roles and model building team members, type of participants, methods and techniques of data collection, phases of model building, accessible space and time, cost, and used technology (Richardson et al., 1989; Vennix et al., 1994; Azevedo-Carns, 1997; Ford and Sterman, 1997, Luna-Reyes et al., 2005a; Ford et al., 2006; Elliot et al., 2005; Kim, 2007; Winz and Gary, 2007; Rouwette and Hoppenbrouwers, 2008). These methods are compared based on the above 13 criteria as follows.

4.6.1 Type of problem

One important factor in the selection of type of model building is type of problem. The problem can be viewed as a continuum of well-structured and repetitive to messy and new (Vennix, 1999). The problem is well-structured and repetitive in document and IMB. In other words, the problem is properly defined and addressed by the relevant literature in these two types of model building. Moreover, related experts and stakeholders have sufficient knowledge of the problem. Therefore, these problems can be modelled by reviewing the literature relevant to each problem and using experts' opinions.

However, in GMB, the problem is generally ill-structured and messy, has many stakeholders, but often little previous theories on it and also, human mind alone is limited in understanding such problems and thus, a team of individuals knowledgeable to the problem or interested in it is required to build and analyse models (Vennix, 1999).

In community and CMB, the problem is mainly novel and research approach is more of an exploratory type. The CoMB approach is suitable to use if the problem is in a particular domain and its experts are recognisable, whereas CMB should be applied if experts in the field are not sufficient in number and the problem is a new social phenomenon, in need of engaging the society.

Table 1 Comparison of model building methods based on type of problem

Document model building	*Individual model building*	*Group model building*	*Community model building*	*Crowd model building*
Well-structured, repetitive problems	Well-structured, repetitive problems	Ill-structured, messy problems with numerous stakeholders	New problems and exploratory research for which many experts exist	New problems and exploratory research for which not sufficient experts exist

4.6.2 Purpose of model building

The purpose of model building can be solving a real problem (applied and practical approach), learning, discovering structure of a phenomenon and theory building. In document and IMB, it is mainly intended to solve a practical problem, whereas in GMB, in addition to solving a problem, promoting group's learning, upgrading members' mental models and in some cases, theory building is intended.

Accordingly, the CoMB, like GMB, is intended for problem solving, learning and theory building through engaging individual's mental models. However, CMB seeks to understand and discover new phenomena as well as to extract affecting variables and identify their basic structure. This method, in addition to identifying the intended social phenomenon and its sociotechnical effects, aims to develop appropriate theories to understand its structure and behaviour. Furthermore, designing basic structure and initial theories of new phenomena through public and social participation is effective in resolving related problems and even, preventing its occurrence and diffusing and information providing about the phenomenon.

Table 2 Comparison of model building methods based on purpose of model building

Document model building	*Individual model building*	*Group model building*	*Community model building*	*Crowd model building*
The use of available information and resources in the form of a systematic approach to better solve problems	The use of mental models in the form of a systematic approach to better solve problems	The use of mental models in the form of a systematic approach for better problem solving, learning, or theory building	The use of mental models in the form of a systematic approach for better problem solving, learning, or theory building	Use of collective intelligence for initial understanding and discovering structure of a new phenomenon and better problem solving, learning, or theory building

4.6.3 Type of used databases

In different model building methods, various databases mentioned by Forrester (1980) are used. Since, according to classification of research strategies by Bleijenbergh et al. (2009), DMB is among data-driven research strategies. In DMB, the focus is on written and numerical databases. This is while in IMB, the focus is on individual mental models, and in GMB, individual mental models interacting together in a group are emphasised. According to the same classification by Bleijenbergh et al. (2009), types of model building from individual to crowd are among participatory strategies. Moreover, this classification demonstrates that if research is to solve real problems, participatory strategy becomes practical and participants are mainly stakeholders; however, if the research is for theory building, expert-driven participatory strategy and participants are experts in various fields (Bleijenbergh et al., 2009).

According to various databases, large group mental database of professionals and members of a particular community is mostly used in the CoMB. Also, the main emphasis in CMB is on public mental database (collective intelligence) as well as on engagement of the community and society in a newly emergent phenomenon.

Table 3 Comparison of model building methods based on type of database

Document model building	*Individual model building*	*Group model building*	*Community model building*	*Crowd model building*
Written and numerical database	Written, numerical and mental database, and here the focus is on individual mental database	Written, numerical and mental database, and here the focus is on group mental database	Written, numerical and mental database, and here the focus is on relatively large group mental database	Written, numerical and mental database, and here the focus is on public mental database (collective intelligence)

4.6.4 Type of output

The output of model building sessions can be in two forms:

1 model as micro world (Zagonel, 2002, 2004), representative objects (Bayer et al., 2010) or virtual world (Sterman, 2000), which is a presentation of reality of foreign policy making environment. In other words, micro world models are used as the actual presentation of decision-making situation to test results of selection of policies (Zagonel, 2002, 2004; Eden and Ackermann, 2006; Bayer et al., 2010; Esensoy and Carter, 2015; Scott et al., 2016)

2 model as boundary object or socially constructed artefact, which is a tool for common discussion, trust building, agreement and understanding (Zagonel, 2002, 2004; Eden and Ackermann, 2006; Esensoy and Carter, 2015; Scott et al., 2016).

Moreover, models, either as boundary object or micro world, can be epistemic or technical objects. Epistemic objects help to create new knowledge and are dynamic, whereas technical objects are static and available as a means to make knowledge accessible (Bayer et al., 2010).

Table 4 Comparison of model building methods based on type of output

Document model building	*Individual model building*	*Group model building*	*Community model building*	*Crowd model building*
Micro world	Micro world	Micro world or boundary object	Micro world both more boundary object	Micro world both more boundary object

4.6.5 Comparison on the basis of place-form processing continuum

Based on the place-form processing continuum framework by Kim (2007), various model building techniques are as follows. This framework consists of two continuums of place of process and form of process. Here, location of the processor continuum is defined as level of involvement of individuals in receiving information, processing it, and taking measures on its basis, ranging from individual to collective (group, organisation or industry) level. The Form of the processor continuum indicates the output form of the model building which includes a range of static objects such as memory and knowledge to a process that changes with the group dynamics such as communication and interaction (Kim, 2007).

As clearly shown in Table 5, document and IMB emphasises knowledge acquisition and analysis from individuals and mainly intends to solve problems and build an artefact (dynamic model). GMB is in the middle of these two continuums. In this type of model building, providing a specific output similar to a model is also mainly intended and the model building process and changing attitudes, as well as increasing participants' commitment and learning during the process are emphasised.

Table 5 Comparison of model building methods based on Kim's place-form processing continuum framework (2007)

Location of the processor	*Form of the processor*		
	Product		*Process*
Individual	Document model building		
	Individual model building		
		Group model building	
Collectivity			*Community model building*
			Crowd model building

Community and CMB make sense by large-scale involvement of highly collaborative people. These types of model building are mainly attempt to create a mentality on a new phenomenon, discover and understand it and diffuse knowledge about it. In other words, these two methods are at the end of each continuum and focus in the location of the processor on collectivity and in the Form of the processor on process. As a result, CMB is CDSSs.

4.6.6 Type of work to perform (dominant perspective)

There are three types of works in the dynamic model building process (Richardson et al., 1989; Château et al., 2012):

1 Works that require divergent thinking to elicit information (Type A). This type of work is a part of production phase specifications such as problem definition, model conceptualisation, model validation and formulation.

2 Exploring course of action that requires convergent thinking and is a part of problem solving phase specifications including the definition of causal relations, feedback loops and rate equations (Type B).

3 Assessment conditions works which refers to the judgment and selections such as choosing the parameters, policy scenarios and model assessment methods (Type C).

Each dynamic model building step requires these three. Problem identification and definition, and system conceptualisation are mostly Type A since they require a database of relevant information and different ideas. In model formulation step, the modeller is focused on system performance which is more associated with Type B. Model use, implementation and dissemination, and model testing and evaluation are type C (Château et al., 2012).

Calhoun et al. (2010) suggest that divergent actions include activities which lead to the production of ideas and different interpretations and convergent actions refer to those activities that integrate different ideas and interpretations as well as evaluation actions that lead to the assessment and selection between the options and ideas (Calhoun et al., 2010).

Richardson et al. (1989) stated that initiating GMB phases requires divergent thinking and should be less structured (Richardson et al., 1989). Convergent thinking phases should be subject to the intervention of specialists to respond to technical questions. Their comments are used to reach consensus during these actions (Chen et al., 2014).

Finally, we can say that divergent actions are used in any model building method to collect ideas and variables and then convergent actions are used to create a model as focal object or artefact. And again divergent actions are used the model testing and using it. Figure 7 illustrates this concept (Slinger et al., 2009).

Accordingly, it can be mentioned that divergent and convergent actions with different focus points and volumes are used in all model building methods.

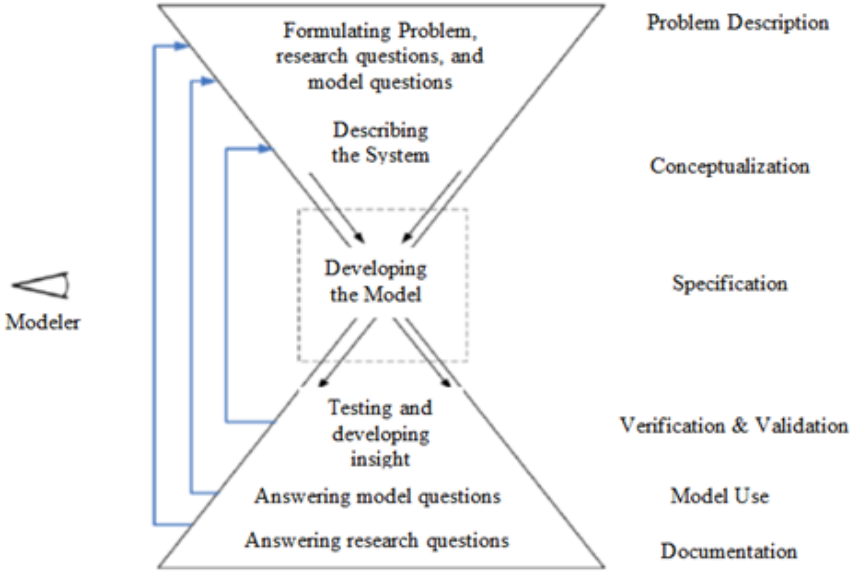
As Table 6 shows, the modeller acts as a person in charge of converging various documents and studies in DMB. In other words, although the modeller has a divergent attitude towards collecting literature and documents, most of his actions are to further consolidate and converges different findings based on a holistic and systemic approach.

In IMB, the focus is on divergent works so that the modeller is to collect different views of different individuals and this action constitutes the major part of the work and is of significance in building an appropriate model. After collecting information and reviewing mental models of different persons, the modeller should perform convergent actions to build a model.

GMB contains a relatively equal combination of these two types of work. In the first phases, the modeller is to gather different people to participate in the group and acquire the members' different perspectives. During and after each meeting, the modeller should

integrate the discussions of the team members into the model. Both these actions are important and of high volumes.

Figure 7 Type of work during different phases of dynamic model building (see online version for colours)



In community and CMB, all actions are divergent since the purpose and philosophy of these methods are understanding and discovery of a new phenomenon through investigating the public mental models. Furthermore, because non-interacting individuals are more needed in the information elicitation phase in order to reduce the group's influence on individuals, the nominal group technique (Chen et al., 2014) or community and CMB methods are highly effective.

Table 6 Comparison of model building methods based on the type of work

Document model building	*Individual model building*	*Group model building*	*Community model building*	*Crowd model building*
Convergent	Divergent	Divergent and Convergent	Divergent	Divergent and more in initial steps to explore and identify variables.

4.6.7 Number of participants

One of the important factors is the number of people participating in different model building methods. In DMB, the modeller or the model building team usually conduct research and build the model and no participation exists in practice. In IMB, people are usually interviewed individually and there is no communication between people. The number of participants may vary based on the problem. There are two types of meetings in the GMB: Small group meetings and large group meetings.

Vennix (1996) asserts that all stakeholders and clients shall be covered in the GMB because the lack of a stakeholder enhances the risk of non-commitment in the implementation of the final decision. On the other hand, large groups (more than 10 to 12 persons) cause lower satisfaction level, greater waste of time and interpersonal communication troubles (Vennix, 1996; Yahril et al., 2006). Hence, when the number of stakeholders is high (more than 25 persons), small group meetings (with 3–5 persons) are used to collect data. Then in a general meeting, all participants convene and the results of the small meetings are expressed and sum up.

Stave (2002) introduces three challenges to engage the stakeholders in the public model building projects:

1 since stakeholder participate voluntarily, the problem is forcing them to attend in meetings

2 volunteers spend less time than those who their task (clients)

3 public participants tend to self-select; this mean that they participate in meetings when they wish (Stave, 2002; Yahril et al., 2006).

The community and CMB methods can solve these challenges so that there is no need for concurrency and a same place and participation and its time is according to their will. In CoMB, the online forum consists of 100 persons and more collaborating in the model building process. There is no size limit in the CMB and there is a need for public and society participation to understand new phenomena and enhance awareness.

Table 7 Comparison of model building methods based on the number of participants

Document model building	*Individual model building*	*Group model building*	*Community model building*	*Crowd model building*
There is no collaboration in model building.	One person is interviewed individually. The total number of participants usually reaches up to 25 persons and more.	Small groups usually with 3 to 5 persons and large groups up to 25 persons.	Online forums up to 100 persons and more.	Unlimited number.

4.6.8 Number of roles and model building team members

There are different roles for the modeller in model building methods (Esensoy and Carter, 2015). In document and IMB, the modeller is required and he is in charge of tasks such as coordinating with people to interview, holding meetings and facilitating the discussions. In GMB, five roles are of essence: facilitator, moderator/recorder, content coach/modeller, process coach and gatekeeper (Luna-Reyes et al., 2005b; Yahril et al., 2006; Andersen and Richardson, 2010; Esensoy and Carter, 2015; Richardson et al., 1992). In meetings with large groups, five different persons should play these roles; however, one person can play these roles in small groups (Richardson et al., 1992).

As it can be seen in Table 8, although community and CMB deal with a large number of participants, only modeller is sufficient because in this model building methods information are recorded simultaneously with the members' log in and members are not bound with time and space. In other words, one person suffices to play these five roles.

Table 8 Comparison of model building methods based on the number of roles

Document model building	*Individual model building*	*Group model building*	*Community model building*	*Crowd model building*
Only modeller is sufficient.	Only modeller is sufficient.	There are usually five different roles and these roles can be played by a same individual in small group.	Only modeller is sufficient.	Only modeller is sufficient.

4.6.9 Type of participants

In document and IMB, the modelling is performed by an individual modeller or a team who are specialised in the dynamic system model building and specialists in problem field. In the participative model building (individual, group, community and crowd), three distinctive groups are involved: The first groups are the core modelling group or model building team who perform project management, data collection and analysis, and simulation, etc. The relevant process and their size were explained in previous section. The second group consists of clients and stakeholders who are the same institutions and departments that are responsible for the problem. And the third group contains the experts who are knowledgeable about the problem (Richardson et al., 1992; Anderson and Richardson, 1994). However, the remarkable point in the CMB is that the second and third groups are not usually significant; therefore, the emphasis in the CMB is on social involvement such that the model building contains large, unlimited and unspecified groups of all people who can be a problem expert and get involved in it or those who have nothing to do with a concerned problem. In this type of model building, the size is unlimited.

Table 9 Comparison of model building methods based on type of participants

Document model building	*Individual model building*	*Group model building*	*Community model building*	*Crowd model building*
Only the model building team which can contain only one person builds models based on the literature. The members are both model building and problem experts.	They are usually experts related to the problem.	Experts, stakeholders and clients who are associated with the problem as well as the model building team with 5 different roles.	Experts, stakeholders and clients who are associated with the problem.	A combination of related and unrelated people.

4.6.10 Methods and techniques of data collection

In each method, data collection and analysis tools are different. Like other library methods, text analysis tools and techniques such as content analysis, data mining, text mining, grounded theory, and so on are used in the DMB method. In the IMB method, the focus is mostly on interviews and questionnaires as well as work book, which are usually semi-structured. After the interviews, content analysis such as DMB is usually conducted for the generated content. In the GMB, the brainstorming and simulation during meetings

and workshops are emphasised; however, the use of workbooks and unstructured questionnaires is also common. When these tools are employed, content analysis techniques are also used. Brainstorming is the only tool used in CoMB because the discussions are concise, accurate and relevant to the problem and findings convert into a model or a variable affecting the problem in the same session. Other tools such as content analysis or workbooks are less required.

Table 10 Comparison of model building methods based on methods and techniques of data collection

Document model building	*Individual model building*	*Group model building*	*Community model building*	*Crowd model building*
Content analysis and other text analysis methods	Interviews, questionnaires and work book	Brainstorming and structured workbooks	Brainstorming	Brainstorming (qualitative research)

4.6.11 Model building phases

Any of the model building methods can be used in different dynamic system phases (Winz and Gray, 2007). In the DMB, the focus is on the initial steps (dynamic hypothesis formulation and primary model conceptualisation). In individual and GMB, all model building phases are involved; however, in some cases depending on the type of objectives and subject of the study, these methods may be used in one of these phases.

Although all model building phases can be performed in community and CMB methods, the emphasis is on the first steps (extracting variables) in order to discover new phenomena and collect divergent views in this regard in order to understand the basic structure of the phenomenon.

Table 11 Comparison of model building methods based on model building phases

Document model building	*Individual model building*	*Group model building*	*Community model building*	*Crowd model building*
All phases of model building with an emphasis on initial steps (dynamic hypothesis formulation and establishment of a basic conceptual model)	All phases of model building (from problem definition to model testing and policy analysis).	All phases of model building.	All phases of model building with an emphasis on initial steps (eliciting affecting variables).	All phases of model building with an emphasis on initial steps (eliciting affecting variables).

4.6.12 Accessible space, time, and cost

Each method has specific place, time and cost specifications. There is no specific spatial and temporal dependence in the DMB method and the modeller only looks for various sources related to the subject and performs the research process without excessive cost. In IMB method, a proper place is needed for interviews and the interviewee is asked to express his favoured interview place and time. Accordingly, the interview meeting is held. The cost of these meetings is not high; however, it is more costly in comparison with the DMB. In GMB method, planning workshops and workshop activities including procurement, scheduling and developing exact schedule for the workshop day,

appropriate place and necessary facilities (including whiteboard, white wall, video projector with computers having model building software, proper layout of seats and other furniture) should be done in advance (Anderson and Richardson, 1994; Luna-Reyes et al., 2005b; Groesser, 2006b; Hernantes et al., 2013; Butler and Adamowski, 2015). Hence, there is spatial and temporal dependence in this method and it is usually costly.

Table 12 Comparison of modelling based on accessible space, time, and cost

Document model building	*Individual model building*	*Group model building*	*Community model building*	*Crowd model building*
There is no spatial and temporal dependence and the cost is low.	The spatial and temporal dependence is usually in the form that the most suitable place is where the interviewee is comfortable. The cost is moderate.	The spatial and temporal dependence is usually in the form that a same place and time is preferred. The cost is high.	There is no spatial and temporal dependence and the cost is low.	There is no spatial and temporal dependence and the cost is low.

In the community and CMB, individuals sign in via the internet, web and social networks from different locations and from different countries and at various times during the model building interval and build the model (Gary and Charyk, 1996; Groessler, 1996). Hence, there is no spatial and temporal dependence in this method. Moreover, web-based tools simply and inexpensively provide model building platform and the need for other expenses such as transportation, meeting place and the like is eliminated.

4.6.13 Technology used in data collection

Each method uses different technologies. In the DMB methods, different tools and technologies associated with searching documents and resources as well as text analysis software such as data mining and text mining software are used. In addition to face-to-face interviews in the IMB, other tools such as phone, e-mail and videoconferencing can be used for interviews and collecting the data. In the GMB, model building sessions and workshops are held with the presence of all members in person and in some cases via videoconferencing. However, recording software and technologies, software, video projector, white walls, and the like can also be used during the sessions.

Table 13 Comparison of model building methods based on the used technology

Document model building	*Individual model building*	*Group model building*	*Community model building*	*Crowd model building*
Technology and related software associated with analysing the documents are used.	Face to face or via phone, e-mail and videoconferencing.	Mostly face to face and in some cases via videoconferencing.	Via the internet and Web 2.0 platforms and social networks (online/web survey).	Via the internet and Web 2.0 platforms and social networks (online/web survey).

Table 14 Summary of system dynamics model building comparisons

	Document model building	*Individual model building*	*Group model building*	*Community model building*	*Crowd model building*
Type of problem	Well-structured, repetitive problems	Well-structured, repetitive problems	Ill-structured, messy problems with numerous stakeholders	New problems and exploratory research for which many experts exist	New problems and exploratory research for which not sufficient experts exist
Purpose of model building	Problem solving	Problem solving	Problem solving, learning, or theory building.	Problem solving, learning, or theory building.	Discovering structure of a new phenomenon and problem solving, learning, or theory building.
Type of used data source	Written and numerical database	Written, numerical and mental database, and focus on individual mental database	Written, numerical and mental database, and focus on group mental database	Written, numerical and mental database, and focus on relatively large group mental database	Written, numerical and mental database, and focus on collective intelligence
Type of output	Micro world	Micro world	Micro world or boundary object	Micro world both more boundary object	Micro world both more boundary object
Place-form processing continuum	Product-individual	Product-Individual	Middle of product-process and middle of individual-collectivity	Process-collectivity	Process-collectivity
Type of work to perform (dominant perspective)	Convergent	Divergent	Divergent and convergent	Divergent	Divergent
Number of participants	Not participation	Individual participation	Small groups: 3 to 5 person large groups: up to 25 persons.	Online forums up to 100 persons and more.	Unlimited number.

Table 14 Summary of system dynamics model building comparisons (continued)

	Document model building	*Individual model building*	*Group model building*	*Community model building*	*Crowd model building*
Number of roles and model building team members	Only modeller is sufficient.	Only modeller is sufficient.	There are usually five different roles.	Only modeller is sufficient.	Only modeller is sufficient.
Type of participants	Individual or model building team.	Experts related to the problem.	Experts, stakeholders and clients.	Community members (experts, stakeholders and clients).	A combination of related and unrelated people.
Methods and techniques of data collection	Content analysis and other text analysis methods	Interviews, questionnaires and work book	Brainstorming and structured workbooks	Brainstorming	Brainstorming (qualitative research)
Phases of model building	All phases of model building with an emphasis on initial steps.	All phases of model building with an emphasis on initial steps.	All phases of model building.	All phases of model building with an emphasis on eliciting affecting variables.	All phases of model building with an emphasis on eliciting affecting variables.
Accessible space and time, cost	No spatial and temporal dependence and low cost.	The spatial and temporal dependence and moderate cost.	The intensive spatial and temporal dependence and high cost.	No spatial and temporal dependence and low cost.	No spatial and temporal dependence and low cost.
Technology used	Software associated with text analysing.	Face to face or via phone, e-mail and videoconferencing.	Face to face and via videoconferencing.	Via the internet and Web 2.0 platforms and social networks (online/web survey).	Via the internet and Web 2.0 platforms and social networks (online/web survey).

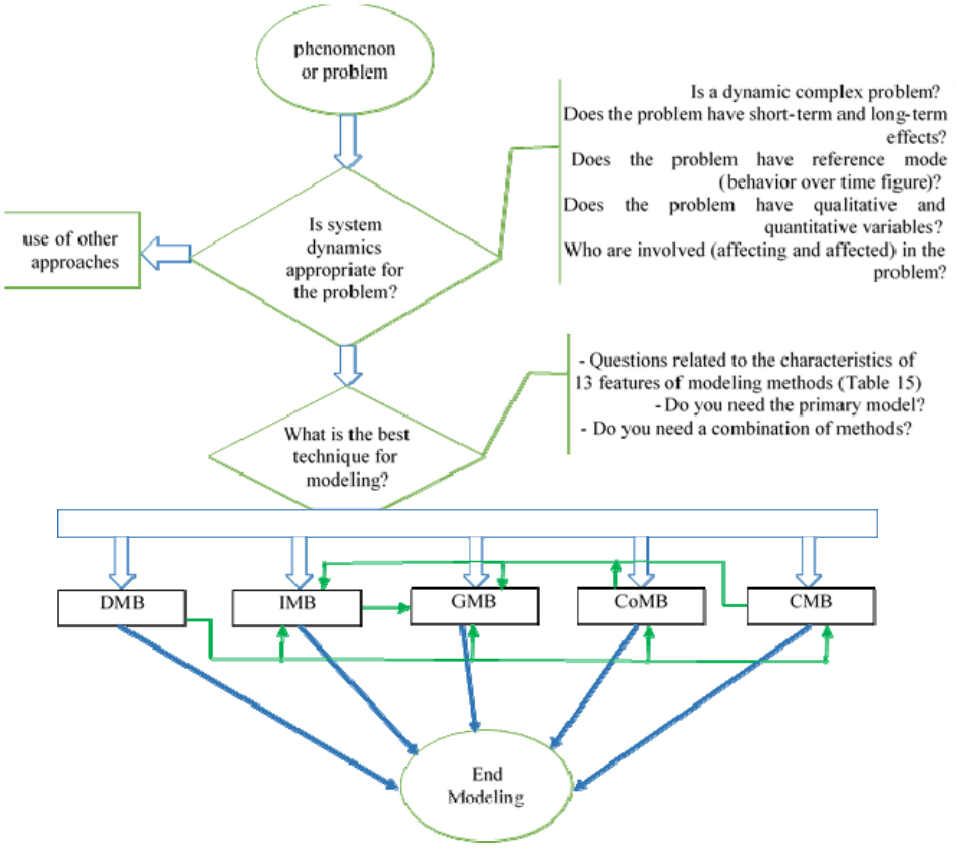
In the community and CMB, model building is performed via the internet, Web 2.0 platforms and social networking. In this type of model building, popular social networks such as telegram, Facebook, etc. can be useful tools for collecting the people, providing information, and model building. Internet with infrastructures, especially web, provides an opportunity for the online/web surveys and the global model simulations. Simulations run in a web browser have advantages such as speeding survey (Conrad et al., 2017), universal access, easy distribution, and potentials for simulation process to be monitored (Bean, 2007).

Table 14 summarises the comparison of these five model building methods.

5 Explaining CMB

In this section, the CMB and its steps are explained in the form of CMB architecture. Figure 8 shows the revised version of the framework developed by Vennix (1996).

Figure 8 The system dynamics model building architecture (see online version for colours)



Source: Revised of the Vennix (1996) framework

Table 15 The relevant questions to determine the model building methods

No.	*Characteristics of model building methods*	*Related questions*
1	Type of problem	• What type is the problem or phenomenon?
		• Is the problem well-structured and repetitive or chaotic, ill-structured and new?
		• Are there experts or associations relevant to the problem or phenomenon?
2	Purpose of model building	• Does model building aim at solving a real problem (applied and practical approach), learning, discovering a phenomenon or building a theory?
		• Does model building aim at enhancing awareness and consensus or discovering new structures?
		• How important is the accuracy of the model and its results in comparison with collecting different results?
3	Type of used data source	• Are there valid theories and empirical data on the concerned problem or phenomenon?
		• What data and how much is available?
		• Are there studies on the problem or phenomenon?
		• Are there experts or associations relevant to the problem or phenomenon?
		• Is the main source the mental models of individuals, groups, organisation, or society?
		• Is the main focus on individual or collective intelligence?
4	Type of output	• Is the model a boundary object or micro world?
		• Is the model a knowledge object or a technical object?
		• Is the focus on model building process and individual learning or on building a model to solve the problem?
		• Is the model quantitative or qualitative?
5	Place-form processing continuum	• Is processing a product or process?
		• Does processing takes place at an individual or collective level?
6	Type of work to perform (dominant perspective)	• What kind of work is considered in model building? (Extracting information or periodic review of the action or evaluation)
		• Does discovering the problem or phenomenon aim at data mining and identifying factors associated with it?
		• Does it need divergent tasks?
		• Is the purpose integrating different views on the problem or phenomenon?
		• Does it need convergent tasks?
7	Number of participants	• Is there any access to experts, stakeholders and customers involved in the problem or phenomenon?

Table 15 The relevant questions to determine the model building methods (continued)

No.	*Characteristics of model building methods*	*Related questions*
7	Number of participants	• How many people are involved in the problem or phenomenon?
8	Number of roles and model building team members	• Do those involved in the problem or phenomenon have diverse and sometimes conflicting perspectives or not?
		• What roles are needed for model building?
9	Type of participants	• Are interaction and participation important?
		• What form is the appropriate participation for individuals? What types of participation (individual, social, group or organisational) are required?
		• Are there three distinct groups of modellers, professionals and customers?
		• Is the primary model developed by model building experts or customers?
10	Methods and techniques of data collection	• Are structured, unstructured or semi-structured methods used?
		• Are different data collection tools such as questionnaire, work books, interviews, etc. required?
11	Phases of model building	• What phases of dynamic systems model building are emphasised?
12	Accessible space and time, cost	• How geographically distributed are those involved in the problem or phenomenon?
		• Is there a challenge in access to people in terms of time or space?
		• How much is the model building budget? How much is a reasonable cost for the problem or phenomenon?
		• How much time is available to perform model building?
13	Technology used	• Are new tools and technologies (internet, web and social networks) available?
		• Do the people involved use tools and new technologies (internet, web and social networks)?
		• What other model building technologies and tools are available?

Figure 8 shows system dynamics model building architecture with regard to different paths. According to this architecture in dealing with any problem or phenomenon, one first needs to examine the appropriateness of using system dynamics approach and respond the questions presented in this section (Vennix, 1996; Groesser, 2006b). The system dynamics will be appropriate if the answers provided for these questions reveal that the phenomenon is complex and dynamic with long-term and short-term effects, reference mode, qualitative and quantitative variables and different people involved in (affecting and affected) (Haji Gholam Saryazdi et al., 2017). Otherwise, other approaches should be used.

After the appropriateness of system dynamics was evaluated, the model building path should be determined based on different model building methods. To this end, the questions associated with 13 features of model building techniques as well as the questions on the necessity of having a primary model building model (Stave and Dwyer, 2005) or on the use of a combination of methods should be answered.

In Table 15, questions relevant to 13-dimensional features of model building methods are presented. Based on responses to these questions, different model building paths are selectable (Table 16).

According to Figure 8, different model building paths are shown in Table 16. Accordingly, the first group paths (single paths) should be used when primary model and a combination of methods is not required. With regard to the problem or phenomenon specifications and according to the questions mentioned in Table 15, one of 21 paths is selected.

Table 16 Different dynamic model building paths

No.	*Category name*		*Paths*
1	Single paths (without primary model)	Path 1	Dynamics problem → DMB → end modelling.
		Path 2	Dynamics problem → IMB → end modelling.
		Path 3	Dynamics problem → GMB → end modelling.
		Path 4	Dynamics problem → CoMB → end modelling.
		Path 5	Dynamics problem → CMB → end modelling.
2	Dual combined paths (with primary model)	Path 6 to 9	Dynamics problem → DMB → other methods (IMB, GMB, CoMB, CMB) → end modelling.
		Path 10	Dynamics problem → IMB → GMB → end modelling.
		Path 11	Dynamics problem → CoMB → IMB → end modelling.
		Path 12	Dynamics problem → CoMB → GMB → end modelling.
		Path 13	Dynamics problem → CMB → IMB → end modelling.
		Path 14	Dynamics problem → CMB → GMB → end modelling.
3	Triple combined paths (with primary model)	Path 15	Dynamics problem → DMB → IMB → GMB → end modelling.
		Path 16	Dynamics problem → DMB → CoMB → GMB → end modelling.
		Path 17	Dynamics problem → DMB → CoMB → IMB → end modelling.
		Path 18	Dynamics problem → DMB → CMB → GMB → end modelling.
		Path 19	Dynamics problem → DMB → CMB → IMB → end modelling.
		Path 20	Dynamics problem → CoMB → IMB → GMB → end modelling.

Regarding 13 questions listed in Table 15, CMB was employed when the phenomenon or a new problem and its investigation aimed to discover and understand based on divergent tasks and theory building, inform the society, use collective intelligence and to engage the society and when no relevant data, previous study or expert.

As it can be seen in Table 16, CMB has five paths. CMB was exclusively used for paths 5. However, it was used as a method to create a basic model prior to individual and GMB for paths 13, 14, 18 and 21. In other words, CMB in these four paths was a divergent task to further recognise a phenomenon or a problem and to collect variables affecting it. The following steps are to be taken after specifying the paths with CMB.

1 Determining the model building technology platform: In this step, the technology to be used for model building must be selected. This could include the use of a social networks such as Telegram, Twitter and so on, using a model building service provider website such insight maker, using online software such as Forio or designing a specific website or application by model building team.

2 Preparing the selected model building technology platform: After selecting the technology, it should be prepared for model building. For example, a proper group must be designed in telegram or the user account must be registered in model building service provider websites and the necessary arrangements must be provided.

3 Determining the primary target population: After creating a technology platform, various groups that are considered most relevant to the phenomenon or problem or who are favoured by the model building team to be participated should be identified as the primary target population.

4 Informing and recruiting (membership): Because the CMB requires the public participation, necessary information should be provided for both the primary target population and public through social networks, internet or other mass media as well as official correspondence.

5 Performing model building: Model building process initiates with the membership of an acceptable number of individuals in technology platform. In this step, it is important to briefly introduce and explain the system dynamics (or even primary education) and the intended problem. Then, the questions related to problem shall be discussed in public and comments should be collected. As McLauchlan and Schonlau (2016) point out, at the end of each question and the conclusion of survey, the respondents' final comments are collected. Model building ends when either the theoretical saturation is reached or the project time is terminated.

6 Summary and conclusion: The results of the discussions with the completion of model building time are summed and presented to the public to be confirmed. The results of model building can be developed in an appropriate format.

7 Implementation and use of crowd to perform the results: The final step of each model building project is the implementation of the model building results. In CMB, all participants can assist in implementing the project results. This can help in identifying volunteers or individuals interested in the implementation of the results.

6 Implementation and practical comparison

In this section, we discuss the practical implications and practical comparisons between DMB, GMB, and CMB. For this aim, we studied crowd funding as a new phenomenon with little literature by using systems dynamics. And then we compare GMB vs. CMB.

In the first step, we design a qualitative model of crowd funding through DMB (the variables that involve the drivers of growth and collapse are identified, and a model is developed by a systematic review of the literature) (Haji Gholam Saryazdi et al., 2019). Then we build cause and effect diagram, stock and flow diagram, and model simulations with GMB and CMB. Finally, we systematically evaluate and compare GMB and CMB. Results showed that CMB is more appropriate for understanding numerous aspects of crowd funding with a divergent view, released issues, and culture building practices in the society; while GMB is more useful for deepening individual knowledge of crowd funding aspects with a convergent point of view and increasing people commitment toward the crowd funding development (Haji Gholam Saryazdi, 2018). As a result, the practical results were the same as the conceptual claims associated with each method.

7 Conclusions

In system dynamics, researchers have designed different model building methods with regard to specific features because of diversity of information sources, terms and purpose of model building and field of application.

In this study, the CMB which is based on Web 2.0 and social networking was introduced. To this end and following a systematic review of the relevant literature, various model building methods, including DMB, IMB, GMB, CoMB, and CMB, were introduced and compared. Comparisons were made according to 13 dimensions and features. The results showed that CMB as an online survey and qualitative method by creating a CDSSs produce a large number of high-quality ideas to build a common understanding and decision-making about new phenomenon. Also, this method creates interactive interventions and society involvement via web surveys to reduce the effect of power relations in decision-making due to the use of non-interacting individuals.

Then, CMB architecture was displayed and explained through different model building paths. According to this architecture, the suitability of system dynamics should first be determined in dealing with any phenomenon or problem and then the proper model building path (21 different paths) and method are selected according to the different questions associated with characteristics of model building techniques. Accordingly, CMB was employed when the phenomenon or a new problem and its investigation aimed to discover and understand based on divergent tasks and theory building, inform the society, use collective intelligence and to engage the society and when no relevant data, previous study or expert. The CMB can be done through five paths described in the article. Finally, steps to conduct CMB were described.

References

Agarwal, N. and Liu, H. (2009) *Modeling and Data Mining in Blogosphere (Synthesis Lectures on Data Mining and Knowledge Discovery)*, Morgan and Claypool Publishers, San Rafael, Vol. 1, pp.1–109, doi:10.2200/S00213ED1V01Y200907DMK001.

Agarwal, N. and Xu, X. (2011) 'Social computational systems', *Journal of Computational Science*, Vol. 2, No. 3, pp.189–192.

Akkermans, H. (1995) 'Quantifying the soft issues: a case study in the banking industry', *The 13th International Conference of the System Dynamics Society*, Tokyo, Japan.

Akkermans, H. and Bosker, J. (1994) 'Design guidelines for participative business modelling projects: lessons from an unsuccessful case study', *The 12th International Conference of the System Dynamics Society*, Stirling, Scotland.

Akkermans, H. and Vennix, J. (1996) 'Clients' opinions on group model-building: an exploratory study', *The 14th International Conference of the System Dynamics Society*, Cambridge, Massachusetts, USA.

Akkermans, H., Vennix, J. and Rouwette, E. (1993) 'Participative modeling to facilitate organizational change: a case study', *The 11th International Conference of the System Dynamics Society*, Cancun, Mexico.

Alessi, S. and Trollip, S. (2001) *Multimedia for Learning*, Allyn and Bacon, New York.

Andersen, D.F. and Richardson, G.P. (2010) 'Improvised facilitation: a third leg on the group model building stool', *2010 International System Dynamics Research Conference*, Seoul, Korea.

Andersen, D.F., Vennix, J., Richardson, G. and Rouwette, E. (2007) 'Group model building: problem structuring, policy simulation and decision support', *The Journal of the Operational Research Society*, May, Vol. 58, No. 5, Special Issue: Problem Structuring Methods II, pp.691–694, https://doi.org/10.1057/palgrave.jors.2602339.

Anderson, D.F. and Richardson, G.P. (1994) 'Scripts for groups model building', *The 12th International Conference of the System Dynamics Society*, Stirling, Scotland.

Antunes, P., Santos, R. and Videira, N. (2006) 'Participatory decision making for sustainable development – the use of mediated modelling techniques', *Land Use Policy*, Vol. 23, No. 1, pp.44–52.

Azevedo-Carns, D. (1997) 'Enhancing generative task performance in group model-building efforts', *The 15th International Conference of the System Dynamics Society*, Istanbul, Turkey, 19–22 August.

Bayer, S., Bolt, T. and Brailsford, S.M.K. (2010) 'The social role of simulation models', *The 28th International Conference of the System Dynamics Society*, Seoul, Korea, 25–29 July.

Beall, A. and Ford, A. (2007) 'Participatory modeling for adaptive management: reports from the field II', *The 2007 International Conference of the System Dynamics Society and 50th Anniversay Celebration*, Boston, Massachusetts, USA, 29 July–2 August.

Bean, M. (2007) 'Methods to make your simulation run on the world-wide web', *The 25th International Conference of the System Dynamics Society and 50th Anniversay Celebration*, Boston, Massachusetts, USA, 29 July–2 August.

Bean, M. (2008a) 'Workshop – getting started at building web simulations using Forio Broadcast', *The 2008 International Conference of the System Dynamics Society*, Athens, Greece, 20–24 July.

Bean, M. (2008b) 'Workshop – creating multiplayer online simulation games', *The 2008 International Conference of the System Dynamics Society*, Athens, Greece, 20–24 July.

Bean, M. (2009) 'How to easily get your Vensim, Powersim, or iThink simulation on the web using Forio', *The 27th International Conference of the System Dynamics Society*, Albuquerque, New Mexico, USA, 26–30 July.

Bean, M. (2013) 'Getting started with Forio: turn your model into a web simulation', *The 31st International Conference of the System Dynamics Society*, Cambridge, Massachusetts USA, 21–25 July.

Bean, M. (2015) 'Creating interactive simulations on the web with Forio epicenter', *33rd International Conference of the System Dynamics Society*, Cambridge, Massachusetts, USA, 19–23 July.

Bean, M. and Schoenberg, W. (2010a) 'Create a multiplayer online simulation game', *The 28th International Conference of the System Dynamics Society*, Seoul, Korea, 25–29 July.

Bean, M. and Schoenberg, W. (2010b) 'Build your own free web simulation in 3 hours', *The 28th International Conference of the System Dynamics Society*, Seoul, Korea, 25–29 July.

Bean, M. and Schoenberg, W. (2011a) 'How to build collaborative online planning simulations for public policy and business workshop', *The 29th International Conference of the System Dynamics Society*, Washington, DC, 25–29 July.

Bean, M. and Schoenberg, W. (2011b) 'How to build online simulation games for classroom use workshop', *The 29th International Conference of the System Dynamics Society*, Washington, DC, 25–29 July.

Bleijenbergh, I., Korzilius, H. and Verschuren, P. (2009) 'The validity and utility of participatory versus databased research strategies', *The 27th International Conference of the System Dynamics Society*, Albuquerque, New Mexico, USA, 26–30 July.

Bo Hu, A.L. (2011) 'Web-based participatory system dynamics modelling – concept and prototype development', *The 29th International Conference of the System Dynamics Society*, 25–29 July, Washington, DC.

Bridgewater, K., Peterson, S., McDevitt, J., Hemenway, D., Bass, J., Bothwell, P., ... Everdell, R. (2011) 'A community-based systems learning approach to understanding youth violence in Boston', *Progress in Community Health Partnerships: Research, Education, and Action*, Vol. 5, No. 1, pp.67–75, doi:10.1353/cpr.2011.0011.

Bryson, J.M. (2007) 'What to do when stakeholders matter', *Public Manag. Rev.*, Vol. 6, No. 1, pp.21–53.

Butler, C. and Adamowski, J. (2015) 'Empowering marginalized communities in water resources management: addressing inequitable practices in participatory model building', *Journal of Environmental Management*, 15 April, Vol. 153, pp.153–162, https://doi.org/10.1016/j.jenvman.2015.02.010.

Byrne, J., Cathal H. and Byrne, P.J. (2010) 'A review of web-based simulation and supporting tools', *Simulation Modelling Practice and Theory*, Vol. 18 pp.253–276, DOI: 10.1016/j.simpat.2009.09.013.

Calhoun, A., Hovmand, P., Andersen, D., Richardson, G., Hower, T. and Rouwette, E. (2010) 'Scriptapedia: a digital commons for documenting and sharing group model building scripts', *The 28th International Conference of the System Dynamics Society*, Seoul, Korea, 25–29 July.

Carhart, N. and Yearworth, M. (2010) 'The use of system dynamics group model building for analysing event causality within the nuclear industry', *The 28th International Conference of the System Dynamics Society*, Seoul, Korea, 25–29 July.

Carter, D., Moizer, J. and Liu, S. (2013) 'Using groups to support judgmental parameter estimation VISCONS: 'eyeballing' to capture a quantified group consensus', *Expert Systems with Applications*, Vol. 40, No. 2, pp.715–721.

Chaloupka, M. (2007) 'Using Bayesian belief networks to evaluate the relative risk of fishing gear types on sea turtle stocks', *Report of the Workshop on Assessing the Relative Importance of Sea Turtle Mortality due to Fisheries in Southeast Asia*, FAO, Bangkok, March, pp.19–23. FAO Interactions Between Sea Turtles and Fisheries within an Ecosystem Context Meeting Report 2, Food and Agriculture Organization of the United Nations and SEAFDEC, Rome and Bangkok, pp.129–140.

Château, PA., Chang, Y.C., Chen H. and Ko, T.T. (2012) 'Building a stakeholder's vision of an offshore wind-farm project: a group modeling approach', *Science of The Total Environment*, 15 March, Vol. 420, pp.43–53, https://doi.org/10.1016/j.scitotenv.2012.01.031.

Checkland, P. and Scholes, J. (1999) *Soft Systems Methodology in Action: A 30-year Retrospective*, Wiley, Chichester.

Chen, H., Chang, Y.C. and Chen, K.C. (2014) 'Integrated wetland management: an analysis with group model building based on system dynamics model', *Journal of Environmental Management*, 15 December, Vol. 146, pp.309–319, https://doi.org/10.1016/j.jenvman.2014.05.038.

Conrad, F., Tourangeau, R., Couper, M. and Zhang, C. (2017) 'Reducing speeding in web surveys by providing immediate feedback', *Survey Research Methods*, Vol. 11, No. 1, pp.45–61, DOI: 10.18148/srm/2017.v11i1.6304.

Dalkey, N. and Helmer, O. (1963) 'An experimental application of the Delphi method to the use of experts', *Management Science*, Vol. 9, No. 3, pp.458–467, http://dx.doi.org/10.1287/mnsc.9.3.458.

Diker, V. and Allen, R. (2005) 'It's about time: the why and how of using XML for developing an interchange standard for system dynamics models', *The 23rd International Conference of the System Dynamics Society*, Boston, 17–21 July.

Eden, C. and Ackermann, F. (2006) 'Where next for problem structuring methods', *J. Oper. Res. Soc.*, 19 June, Vol. 57, pp.766–768, https://doi.org/10.1057/palgrave.jors.2602090.

Elharakany, R.A., Moscardini, A., Khalifa, N.M. and Elghany, M.M.A. (2018) 'Modelling the effect on quality of information and communications technology (ICT) facilities in higher education: case study – Egyptian universities', *International Journal of System Dynamics Applications (IJSDA)*, Vol. 7, No. 3, pp.1–30.

Elias, A.A. (2008) 'Towards a shared systems model of stakeholders in environmental conflict', *International Transactions in Operational Research*, Vol. 15, No. 2, pp.239–253.

Elias, A.A., Cavana, R.Y. and Jackson, L.S. (2004) 'Analysing stakeholder dynamics in environment conflict: a new Zealand transport infrastructure project', *The 22th International Conference of The System Dynamics Society*, Keble College, Oxford, England, 25–29 July.

Elliot, J., Heesterbeek, S., Lukensmeyer, C.J. and Slocum, N. (2005) *Participatory Methods Toolkit – A Practitioner's Manual*, September, Technical Report, King Baudouin Foundation and the Flemish Institute for Science and Technology Assessment (viWTA), ISBN: 90-5130-506-0 [online] http://80.65.129.195/en/Virtual-Library/2006/294864.

Esensoy, A.V. and Carter, M.W. (2015) 'Health system modelling for policy development and evaluation: using qualitative methods to capture the whole-system perspective', *Operations Research for Health Care*, March, Vol. 4, pp.15–26, https://doi.org/10.1016/j.orhc.2014.12.002.

Fartookzadeh, H. and Zolfagharian, M. (2012) 'Explain the philosophical foundations of system dynamics using an inductive approach: paradigm classification of system dynamics', *Thoughts of Strategic Management (Andishe modiriate rahbordi)*, in Persian, Spring and Summer, Vol. 1, No. 9, pp.168–125.

Fey, W. and Trimble, J. (1993) 'An expert system to aid in model conceptualization', *The 11th International Conference of the System Dynamics Society*, Cancun, Mexico.

Ford, A., Beall, A. and Zeoli, L. (2006) 'Participatory modeling for adaptive management: reports from the field', *The 24th International Conference of the System Dynamics Society*, Nijmegen, The Netherlands, 23–27 July.

Ford, D.N. and Sterman, J.D. (1997) 'Expert knowledge elicitation to improve mental and formal models', *The 15th International Conference of the System Dynamics Society*, Istanbul, Turkey, 19–22 August.

Forrester, J. (1980) 'Information sources for modeling the national economy', *Journal of the American Statistical Association*, Vol. 75, No. 371, pp.555–574.

Fortmann-Roe, S. (2014) 'Insight maker: a general-purpose tool for web-based modeling & simulation', *Simulation Modelling Practice and Theory*, Vol. 47, pp.28–45, September [online] http://dx.doi.org/10.1016/j.simpat.2014.03.013.

Gary, S. and Charyk, C. (1996) 'Using groupware technology to facilitate team model building and learning', *The 14th International Conference of the System Dynamics Society*, Cambridge, Massachusetts, USA.

Gholamrezaei, D. (2014) *Designing of Analysis Model of Higher Education Policies using System Dynamics Approach: The Fifth Development Plan*, in Persian, Doctoral thesis of Systems Management, Faculty of Management and Economics, Tarbiat Modares University.

Glass-Husain, W. (2005) 'Workshop: making your simulation run on the world wide web', *The 23rd International Conference of the System Dynamics Society*, Boston, 17–21 July.

Groesser, S. (2006a) 'Development of a group model building framework', *The 24th International Conference of the System Dynamics Society*, Nijmegen, The Netherlands, 23–27 July.

Groesser, S. (2006b) 'Multi-perspective reflections about interactive learning environments', *The 24th International Conference of the System Dynamics Society*, Nijmegen, The Netherlands, 23–27 July.

Groessler, A. (1996) 'Providing simulation models on the internet', *The 14th International Conference of the System Dynamics Society*, Cambridge, Massachusetts, USA.

Haji Gholam Saryazdi, A. (2014) *Aviation Technology Park Designing by using System Dynamics Approach*, in Persian, Master's thesis in MBA, University of Science and culture, Tehran.

Haji Gholam Saryazdi, A. (2018) *Designing of the System Dynamics Model of Crowd funding to Support IT Knowledge based Business Startups*, Dissertation submitted in partial fulfillment of the requirements for the Degree of Doctor of Philosophy (PhD) in Information Technology Management, Tarbiat Modares University.

Haji Gholam Saryazdi, A. and Manteghi, M. (2014) 'Analyzing of Yazd Science and Technology Park policies on its tennants technology development by using system dynamics', *Journal of Innovation Management*, in Persian, Vol. 2, No. 2, pp.69–89.

Haji Gholam Saryazdi, A. and Purserajian, D. (2015) 'Pine tree model to identify the technology development barriers in Yazd', *5th International Conference and the 9th National Conference on Management of Technology*, in Persian, Tehran.

Haji Gholam Saryazdi, A., Ghatari, A.R., Mashayekhi, A.N. and Hassanzadeh, A. (2017) 'The dilemma of the dynamic problems: provide a framework for the process of problem definition', *Management Research in Iran*, in Persian, Vol. 21, No. 2, pp.1–26, Summer.

Haji Gholam Saryazdi, A., Manteghi, M. and Hashemi, S.S. (2015) 'Analyzing of NexGen aviation research and technology park policies by using system dynamics', *Journal of Technology Growth (Roshde fanavari)*, in Persian, Vol. 10, No. 40, pp.53–61.

Haji Gholam Saryazdi, A., Rajabzadeh Ghatari, A., Mashayekhi, A.N. and Hassanzadeh, A. (2019) 'Designing a qualitative system dynamics model of crowd funding by document model building', *Qualitative Research in Financial Markets* [online] https://doi.org/10.1108/QRFM-07-2018-0082.

Halbe, J., Adamowski, J. and Pahl-Wostl, C. (2015) 'The role of paradigms in engineering practice and education for sustainable development', *Journal of Cleaner Production*, DOI: 10.1016/j.jclepro.2015.01.093.

Hernantes, J., Rich, E., Leire, A., Labaka, L. and Sarriegi, J.M. (2013) 'Learning before the storm: modeling multiple stakeholder activities in support of crisis management, a practical case', *Technological Forecasting and Social Change*, Vol. 80, No. 9, pp.1742–1755.

Hovelynck, J., Dewulf, A., François, G. and Taillieu, T. (2010) 'Interdisciplinary knowledge integration through group model building: recognizing dualities and triadizing the conversation', *Environmental Science & Policy*, Vol. 13, No. 7, pp.582–591.

Hovmand, P. (2014) *Community Based System Dynamics*, Springer-Verlag New York, DOI: 10.1007/978-1-4614-8763-0.

Hovmand, P., Osgood, N., Kraus, A., Kuhlberg, J., Hammond, R., Lich, K.H., Biswas, A., Stange, K. and Rose, J. (2014) 'Extending group model building to agent based modeling: a case study on understanding the paradox of primary care', *32nd International Conference of the System Dynamics Society*, Delft, Netherlands, 20–24 July.

Hovmand, P.S., Yadama, G., Chalise, N., Calhoun, A. and Conner, D. (2010) 'Combining group model building and participatory rural appraisal in southeast rural India', *The 28th International Conference of the System Dynamics Society*, Seoul, Korea, 25–29 July.

Ikeda, M. and Suetake, T. (2005) 'Public policy evaluation using SD group modeling', *The 23rd International Conference of the System Dynamics Society*, Boston, 17–21 July.

Jordao, L., Davidsen, P. and Antunes, P. (1997) 'Multimedia and SD based interactive learning environments: increasing perception of casual and structure/behavior relationships', *The 15th International Conference of the System Dynamics Society*, Istanbul, Turkey, 19–22 August.

Kim, H. (2007) 'In search of a mental-model-like concept for group level modeling', *The 2007 International Conference of the System Dynamics Society and 50th Anniversay Celebration*, Boston, Massachusetts, USA, 29 July–2 August.

Laurenti, R., Lazarevic, D., Poulikidou, S., Montrucchio, V., Bistagnino, L. and Frostell, B. (2014) 'Group model-building to identify potential sources of environmental impacts outside the scope of LCA studies', *Journal of Cleaner Production*, 1 June, Vol. 72, pp.96–109, https://doi.org/10.1016/j.jclepro.2014.03.001.

Lempinen, T., Ruutu, S., Karhela, T. and Ylén, P. (2011) 'Open source system dynamics with Simantics and OpenModelica', *The 29th International Conference of the System Dynamics Society*, Washington, DC, 25–29 July.

Levytskyy, A., Vangheluwe, H., Rothkrantz, L.J.M. and Koppelaar, H. (2009) 'MDE and customization of modeling and simulation web applications', *Simulation Modelling Practice and Theory*, Vol. 17, No. 2, pp.408–429, February [online] http://dx.doi.org/10.1016/j.simpat.2008.10.004.

Liu, H., Yu, P.S., Agarwal, N. and Suel, T. (2010) 'Guest editors' introduction: social computing in the blogosphere', *IEEE Internet Computing*, Vol. 14, No. 2, pp.12–14.

Liu, X., He, Q., Qiu, X., Chen, B. and Huang, K. (2012) 'Cloud-based computer simulation: towards planting existing simulation software into the cloud', *Simulation Modelling Practice and Theory*, Vol. 26, pp.135–150, August [online] http://dx.doi.org/10.1016/j.simpat.2012.05.001.

Luna-Reyes, L., Diker, V. and Andersen, D. (2005a) 'Interviewing as a strategy for the assessment of system dynamics models', *The 23rd International Conference of the System Dynamics Society*, Boston, 17–21 July.

Luna-Reyes, L., Martinez-Moyano, I., Pardo, T., Cresswell, A., Andersen, D. and Richardson, G. (2005b) 'Group modeling of IT-based innovations in the public sector', *The 23rd International Conference of the System Dynamics Society*, Boston, 17–21 July.

Luna-Reyes, L.F. and Andersen, D.L. (2003) 'Collecting and analyzing qualitative data for system dynamics: methods and models', *System Dynamics Review*, Vol. 19, No. 4, pp.271–296, Winter.

Luna-Reyes, L.F. et al. (2004) 'Scripts for interrupted group model building: lessons from modeling the emergence of governance structures for information integration across government agencies', *The 22th International Conference of the System Dynamics Society*, Keble College, Oxford, England, 25–29 July.

Machuca, J.A. and Del Pozo, R. (1997) 'The beer game, with the possibility of the use of EDI. Through the internet', *The 15th International Conference of the System Dynamics Society*, Istanbul, Turkey, 19–22 August.

Martinez, I.J. and Richardson, G.P. (2001) 'Best practices in system dynamics modeling', *The 19th International Conference of the System Dynamics Society*, Emory Hotel and Conference Center, Atlanta, Georgia, USA, 23–27 July.

Martinez-Moyano, I.J., Conrad, S., Cox, A. and Krahe, C. (2007) 'Modeling aviation security processes: a group model building approach', *The 2007 International Conference of the System Dynamics Society and 50th Anniversay Celebration*, Boston, Massachusetts, USA, 29 July–2 August.

McLauchlan, C. and Schonlau, M. (2016) 'Are final comments in web survey panels associated with next-wave attrition?', *Survey Research Methods*, Vol. 10, No. 3, pp.211–224, DOI: 10.18148/srm/2016.v10i3.6217.

Milling, P. (1996) 'A management stimulator to support group decision making in a corporate gaming environment', *The 14th International Conference of the System Dynamics Society*, Cambridge, Massachusetts, USA.

Milling, P. (2007) 'A brief history of system dynamics in continental Europe', *System Dynamics Review*, 30 October, Vol. 23, pp.215–218, https://doi.org/10.1002/sdr.369.

Milling, P.M. and Lehmann, F. (1994) 'Management games for group decision making in a dynamic environment', *The 12th International Conference of the System Dynamics Society*, Stirling, Scotland.

Mintzberg, H. (1994) *The Rise and Fall of Strategic Planning*, Prentice Hall, New York.

Morecroft, J. and Wolstenholme, E.F. (2007) 'System dynamics in the U.K.: a journey from Stirling to Oxford and beyond', *System Dynamics Review*, 30 October, Vol. 23, pp.205–214, https://doi.org/10.1002/sdr.368.

Myrtveit, M. and Bridgeland, D. (1997) 'An architecture for hosting management flight simulators on the World Wide Web', *The 15th International Conference of the System Dynamics Society*, Istanbul, Turkey, 19–22 August.

Nikabadi, M.S. and Hakaki, A. (2018) 'A dynamic model of effective factors on open innovation in manufacturing small and medium sized companies', *International Journal of System Dynamics Applications (IJSDA)*, Vol. 7, No. 1, pp.1–26.

Olabisi, L.S. (2010) 'The system dynamics of forest cover in the developing world: researcher vs. community perspectives', *The 28th International Conference of the System Dynamics Society*, Seoul, Korea, 25–29 July.

Omamo, O.A., Rodriguez, J.A. and Wafula Muliaro, J. (2018) 'A systems dynamics model for mobile industry governance in the context of the Kenyan Vision 2030', *International Journal of System Dynamics Applications (IJSDA)*, Vol. 7, No. 2, pp.81–100.

Oyo, B. and Mathias Kalema, B. (2016) 'A system dynamics model for subsistence farmers' food security resilience in Sub-Saharan Africa', *International Journal of System Dynamics Applications (IJSDA)*, Vol. 5, No. 1, pp.17–30.

Pieters, A., Franx, A. and Akkermans, H. (2007) 'Using group model building with many interdependent organizations to create integrated health care networks', *The 2007 International Conference of the System Dynamics Society and 50th Anniversay Celebration*, Boston, Massachusetts, USA, 29 July–2 August.

Powers, B. (2008) 'Adventures in open source: collaborative system dynamics', *The 2008 International Conference of the System Dynamics Society*, Athens, Greece, 20–24 July.

Pruyt, E. (2016) 'Integrating systems modelling and data science: the joint future of simulation and 'big data' science', *International Journal of System Dynamics Applications (IJSDA)*, Vol. 5, No. 1, pp.1–16.

Rich, E., Gonzalezb, J.J., Qian, Y., Sveen, F.O., Radianti, J. and Hillen, S. (2009) 'Emergent vulnerabilities in integrated operations: a proactive simulation study of economic risk', *International Journal of Critical Infrastructure Protection*, Vol. 2, No. 3, pp.110–123.

Richards, R., Sanó, M., Roiko, A., Carter, W.C., Bussey, M., Matthews, J. and Smith, T.F. (2013) 'Bayesian belief modeling of climate change impacts for informing regional adaptation options', *Environmental Modelling & Software*, June, Vol. 44, pp.113–121, https://doi.org/10.1016/j.envsoft.2012.07.008.

Richardson, G.P., Andersen, D.F., Rohrbaugh, J. and Steinhurst, W. (1992) 'Group model building', *The 10th International Conference of the System Dynamics Society*, Utrecht, Netherlands.

Richardson, G.P., Vennix, J.A.M., Anderson, D.M., Rohrbaugh, J. and Wallace, W.A. (1989) 'Eliciting group knowledge for model-building', *The 7th International Conference of the System Dynamics Society*, Stuttgart, Germany.

Roos, E. (1997) 'Group model building with a client using system dynamics modeling', *The 15th International Conference of the System Dynamics Society*, Istanbul, Turkey, 19–22 August.

Rouwette, E. and Hoppenbrouwers, S. (2008) 'Collaborative systems modeling and group model building: a useful combination?', *The 2008 International Conference of the System Dynamics Society*, Athens, Greece, 20–24 July.

Salerno, J., Yang, S.J., Nau, D. and Chai, S.K. (2011) 'Behavioral – cultural modeling and prediction', *Proceedings of the 4th International Conference on Social Computing*, SBP 2011, College Park, MD, USA, 29–31 March, DOI:http:/10.1007/978-3-642-19656-0.

Schlüter, M., Hirsch, D. and Pahl-Wostl, C. (2010) 'Coping with change: responses of the Uzbek water management regime to socio-economic transition and global change', *Environmental Science & Policy*, Vol. 13, No. 7, pp.620–636.

Schoenberg, W. (2008) 'The need for a system dynamics based open source, online interactive learning environment creation tool', *The 2008 International Conference of the System Dynamics Society*, Athens, Greece, 20–24 July.

Schoenberg, W. and Powers, B. (2008) 'Workshop – adventures in open source system dynamics', *The 2008 International Conference of the System Dynamics Society*, Athens, Greece, 20–24 July.

Scott, R.J., Cavana, R.Y. and Cameron, D. (2016) 'Recent evidence on the effectiveness of group model building', *European Journal of Operational Research*, 16 March, Vol. 249, pp.908–918, https://doi.org/10.1016/j.ejor.2015.06.078.

Skarin, B. (2011) 'Distributed group problem solving', *The 29th International Conference of the System Dynamics Society*, Washington, DC, 25–29 July.

Slinger, J.H., Yöcel, G. and Pruyt, E. (2009) 'Communicating model insights using interactive learning environments', *The 27th International Conference of the System Dynamics Society*, Albuquerque, New Mexico, USA, 26–30 July.

Soni, S. and Chorasia, B.K. (2017) 'Policy planning in higher technical education: a system dynamic approach', *International Journal of System Dynamics Applications (IJSDA)*, Vol. 6, No. 3, pp.87–110.

Stave, K. and Dwyer, M. (2005) 'Modeling the relationship between population and land development under changing land use policies', *The 23rd International Conference of the System Dynamics Society*, Boston, 17–21 July.

Stave, K.A. (2002) 'Using system dynamics to improve public participation in environmental decisions', *System Dynamics Review*, Vol. 18, No. 2, pp.139–167, Summer.

Sterman, J. (2000) 'Business dynamics', *Systems Thinking and Modeling for a Complex World*, McGraw-Hill Higher Education, New York.

Surowiecki, J. (2004) *The Wisdom of Crowds: Why the many are Smarter than the Few and How Collective Wisdom Shapes Business, Economies, Societies, and Nations*, 25 May, Doubleday Books, Random House Large Print.

Vennix, J.A.M. (1996) *Group Model Building: Facilitating Team Learning Using System Dynamics*, Wiley, Northwestern University.

Vennix, J.A.M. (1999) 'Group model-building: tackling messy problems', *System Dynamics Review*, Vol. 15, No. 4, pp.379–401, Winter.

Vennix, J.A.M., Anderson, D.F., Richardson, G.P. and Rohrbaugh, J. (1994) 'Model building for group decision support: issues and alternatives in knowledge elicitation', Morecroft, J. and Sterman, J. (Eds.): *Modeling for Learning Organizations*, Productivity Press, Portland OR., USA.

Vennix, J.A.M., Gubbels, J. and Doeke, L.D.V. (1990) 'Post eliciting group knowledge in a computer-based learning environment', *The 8th International Conference of the System Dynamics Society*, Chestnut Hill, Massachusetts USA.

Vennix, J.A.M., Gubbels, J.W., Post, D. and Poppen, H.J. (1988) 'A structured approach to knowledge acquisition in model development', *The 6th International Conference of the System Dynamics Society*, La Jolla, CA USA.

Vennix, J.A.M., Thijssen, C.M., Rouwette, E.A.J.A. (1997) 'Group model building: a decision room approach', *The 15th International Conference of the System Dynamics Society*, Istanbul, Turkey, 19–22 August.

Vugteveen, P., Rouwette, E., Stouten, H., Marieke, M. and van Katwijk, L.H. (2015) 'Developing social-ecological system indicators using group model building', *Ocean & Coastal Management*, June, Vol. 109, pp.29–39, https://doi.org/10.1016/j.ocecoaman.2015.02.011.

Wagle, P. (2014) 'Increasing accessibility of participatory system dynamics modeling methods: proposal for a new rapid protocol', *32nd International Conference of the System Dynamics Society*, Delft, Netherlands, 20–24 July.

Winz, I. and Gary, B. (2007) 'Participatory methods in environmental system dynamics projects', *The 2007 International Conference of the System Dynamics Society and 50th Anniversay Celebration*, Boston, Massachusetts, USA, 29 July –2 August.

Xue, Y., Osgood, N. and Gutwin, C. (2011) 'SILVERVIZ: extending SILVER for coordination in distributed collaborative modeling', *The 29th International Conference of the System Dynamics Society*, Washington, DC, 25–29 July.

Yadama, G.N. and Hovmand, P.S. (2010) 'Foundation for ecological security (Papagni Cell) and Nishesh Chalise. Community Driven Modeling of Social-Ecological Systems: Lessons from Andhra Pradesh, India, *The 28th International Conference of the System Dynamics Society*, Seoul, Korea, 25–29 July.

Yahril, S., Tasrif, M., Taufik Mukhith, A. and Napitupulu, L. (2006) 'Group model building intervention in developing country: lesson learned from developing strategies for clean air', *The 24th International Conference of the System Dynamics Society*, Nijmegen, The Netherlands, 23–27 July.

Yuliani, D. and Tasrif, M. (2006) 'Understanding community empowerment process: a case study of a rural locality in Indonesia', *The 24th International Conference of the System Dynamics Society*, Nijmegen, The Netherlands, 23–27 July.

Zagonel, A.A. (2002) 'Model conceptualization in group model building: a review of the literature exploring the tension between representing reality and negotiating a social order', *20th International Conference of the System Dynamics Society*, Grand Hotel Villa Igiea, Palermo, Italy, 28 July–1 August.

Zagonel, A.A. (2004) 'Developing an interpretive dialogue for group model building', *The 22th International Conference of the System Dynamics Society*, Keble College, Oxford, England, 25–29 July.

Websites

http://www.iseesystems.com/community/downloads/community-modeling/Community-Model-Building-drought-summary.pdf

http://www.iseesystems.com/store/training/community-free-education/default.aspx