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Stirling Revisited: Practical Approaches to Merging Two Systems Thinking Streams

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Abstract

The 1994 International System Dynamics Conference, held in Stirling, reviewed a range of related Systems Thinking approaches. This paper focuses on the specific approach described by Eden in Stirling and proposes a number of guidelines that can be used to explicitly and formally link Eden's Systems Thinking approaches to formal simulation models. The specific case presented involves linking semantically rich scenario maps to a formal causal influence diagram that was in turn used as the basis for a formal simulation model. While the case reported on is quite specific, we suggest that a broader range of complementary systems thinking approaches can and should be integrated with more traditional SD simulation methods. The specific case study reported on examines a scenario-based simulation of the promotion of renewable energy sources in the UK electric power market. This work also informs on-going research in group model building, strategy modeling (especially using scenarios) and the on-going debate about qualitative vs. quantitative system dynamics.

Introduction

The last International System Dynamics conference to be held in the UK was at Stirling in 1994. During this conference, the System Dynamics community explored a range of complementary "systems thinking" and "soft systems" methodologies and their relationship to more traditional system dynamics simulation models (Richardson 1994; Eden 1994). The discussions covered issues such as how soft systems methodologies and system dynamics can inform one another, how far qualitative systems thinking can take us without using quantitative system dynamics and how complementary systems thinking approaches can support one another. One of the themes, picked up by Eden (1994), was the integration of system dynamics with another systems thinking approach. This paper builds on this work by looking at practical approaches to merging two systems thinking streams when building a formal system dynamics model.

The need to merge two systems thinking streams arises when building a formal system dynamics model because it is generally the case that a high degrees of collaboration is required between two sets of 'experts' with very different domains of technical expertise. Typically, client groups know their own substantive area and can tell the story of their system eloquently using ordinary language. On the other hand a modeler or team of modelers typically possess the special skills necessary to cast these system stories into a running model. Modelers' specialized expertises rest with the numerous technical decisions that "translate" system stories into model components such as stocks and flows, parameters, functions and run specifications.

Group oriented approaches to model building and strategy development frequently place a diverse client stakeholder group in the same room with modelers (often supported with online computing) so that a rich dialogue can occur between these two domains of expertise.

Group model building (Vennix, 1996; Vennix *et al.*, 1997) thus relies on a diverse set of mapping technologies and projected or drawn images that place easy-to-understand-and-modify images of the system before the client group so that the group can discuss, modify, and elaborate them. The maps often include stakeholder maps, causal influence diagrams, system flow diagrams, concept models, issue maps, sketches of formal non-linear mathematical relationships, workbooks of system structure, and sometimes even model equations. These various maps serve as "boundary objects" (Black, 2002; Zagonel, 2002) that facilitate discussions between clients as well as between the clients and the modeling team.

However, at some point in most, if not all, group model building efforts, modelers and clients experience a "gap" in these facilitated discussions. Although the starting point for the modeling exercise is through the use of maps that are rich in semantic content and easy for clients to interact with directly, other boundary objects that are necessary for creating formal models can often be seen as obscure or opaque. For example, most client groups find it intuitive and easy to create clusters of actors that interact within the system when completing a stakeholder map (Finn, 1996; Bryson *et al*., 2001; Ackermann and Eden, 2003). However, another form of boundary object - more formal models created following special syntactic requirements (such as making formal distinctions between stocks and flows or carefully distinguishing between the polarity of positive and negative linkages) - do not match the ordinary language of client groups.

Hence, group model building sessions must deal with this distinction between system maps with high semantic content that are easy for clients to relate to versus system models with high syntactic requirements that are relatively opaque. As most group model building projects start with qualitative maps of high semantic content and end with elaborated system views that obey all of the syntactic requirements of the simulation language modelers strive to "bring along" the client group through these stages of increasing precision and structuring of system maps. Unfortunately, most group modeling approaches eventually involve a "leap of faith" in this complicated process of translating between rich qualitative maps and system maps.

This research is focused on exploring means of managing this problem of how to create a sequence of boundary objects (maps of system issues, policies, and structures) and facilitation guidelines that allow more of the transfer from qualitative maps to highly structured models to occur out in the open and in view of client groups. We seek to gain greater client involvement in these steps of model formulation and specification. Such a process helps to provide a promising future for the integrated use of complementary systems thinking approaches as discussed in Stirling in 1994. The paper will explore some of the conceptual bases underpinning this work before discussing the methodology adopted, the case used to support our research and the insights gained.

Three Threads of Research which Inform This Work

Three distinct research areas are drawn upon to consider and develop a more transparent procedure. They are a) group model building, b) soft or qualitative systems, and c) strategy development and simulation.

With the advent of icon-oriented software that can allow models to be built rapidly and projected in front of client groups, (Vennix, 1996; Vennix *et al*., 1997; Richardson and Andersen, 1995; Andersen *et al*., 1997; Rouwette, 2003) group model building has emerged as an important way to quickly elicit model structure from a client group. Andersen and Richardson (1997) have suggested that group modelers can advance work in that field by creating "scripts" or detailed descriptions of modeler and facilitator behavior while in front of groups to both codify and exchange information on how to do this type of work. Our work continues in that line by proposing guidelines for incorporating semantically rich descriptions of scenarios into a formal simulation model.

A second recent trend in the field has been to more clearly distinguish between "systems thinking" versus a more traditional view of system dynamics as supported by formal computer simulation models.[1] This was also explored at the 1994 conference in Stirling. Many of the soft systems thinking approaches share in common the creation of word-and-arrow maps that capture the thinking of client groups. Most recently Wolstenholme (1999), Coyle (2000,2001), Homer and Olivia (2001), and Richardson (2001) have raised the issue of when and how it is necessary to move from qualitative to quantitative system dynamics, where quantitative system dynamics are understood to involve formal computer simulation. This research may inform these discussions in the literature because we propose and test formal methods for bridging the gap between qualitative system maps and quantitative simulation models.[2]

Finally, Warren (2002), Morecroft (1984, 1985), Morecroft and Sterman (1994) and Milling (2002) among others have demonstrated that formal system dynamics models can be powerful supports for strategic planning. Scenario analysis (Van der Heijden, 1996; Eden and Ackermann, 1998; Wack, 1985; Schwartz, 1991) is a crucial tool for strategic planning often revealing counter intuitive effects and dynamic behavior and this research demonstrates how formal scenario analysis can be explicitly linked to system dynamics simulation models using group friendly approaches.

The research discussed in this paper not only aims to integrate the three distinct research areas detailed above, but also to inform work that is being carried out in each of them. Before discussing the research methodology adopted, the next section aims to provide the reader with background knowledge of the project that provided the opportunity for the research to be undertaken.

The Modeling Context: Renewable Obligation Certificates (ROCs) in the UK Power Market

In 2002, the UK Government brought in legislation designed to encourage the development of additional renewable energy sources within the electric power market in the UK. The Renewable Obligation Certificate (ROC) plan mandated renewal energy targets for all suppliers of electricity in the UK starting at 3.0% of total generation capacity in 2002 and rising to 10.4% by 2010. Suppliers could meet these targets either by submitting ROCs certifying that a generation source met policy guidelines or by "buying-out" of their mandated obligations at a price of 30 pounds per Mega-Watt Hour (increasing with inflation). Buy-Out fees would be returned to all holders of

[1] Senge (1990) popularized "systems thinking" a non-simulation brand of system dynamics as the "Fifth Discipline" necessary to create learning organizations.
[2] Indeed, the strategy maps that we report on in this literature are based directly on the "systems thinking" approach described by Eden at the Stirling conference.

valid ROCs in direct proportion to how many ROCs each supplier had submitted. The legislation also allowed for ROCs to be traded on a free market (OFGEM, 2002; Smith and Watson, 2002).

During the winter of 2003 a consortium of Scottish investors, planners, and consultants approached the University of Strathclyde to complete an analysis of future scenarios that could impact on the success or failure of new renewal energy investments under the ROC plan. The project was seen to be a pilot project, with its output being used to gather interest in a much fuller study. The purpose of the project was to elicit a set of scenarios that might lead to unexpected outcomes in the newly created ROC market. Such scenarios could range from unexpected boosts to profit (perhaps triggered by a sudden rise in the price of fossil fuel) to possible collapses in the market due to forces such as over supply, changes in regulation, or unforeseen health and safety issues. The project envisioned that the dynamic implications of the major scenarios would be implemented within a simulation model. A system dynamics model was one of the candidate simulation approaches.

Research Methodology

The research team assembled at Strathclyde University brought a unique set of skills to this project. One member of the modeling team was expert at strategy modeling, especially the elicitation of scenarios using Group Explorer (Eden and Ackermann, 1999) as a group facilitation software support (Ackermann and Eden, 2001). The other member of the team was expert in traditional system dynamics simulation. While the members of the modeling team were relatively more expert in one of the techniques and approaches being used, both members had considerable experience with all of the modeling methods being used (through work on previous projects), thereby facilitating discussions of how to merge methods in a group setting. Thus, both modelers had an in-depth understanding of the theories supporting their particular area of expertise, an appreciation of the other's area and extensive practical experience of employing the modeling techniques in practice. From this basis, the process of developing potential guidelines was able to take place in an informed and thoughtful manner avoiding any potential conflicts in mixing methodologies (Mingers and Gill, 1997).

A second important feature of this project is that another senior modeler was assigned a strict participant-observer role for the duration of the project. His role was to serve as a process observer during all of the group meetings, producing detailed notes concerning interactions in the room during the group modeling sessions and determining whether the intended design matched that that was followed during the workshop (Argyris, 1982; Argyris and Schon, 1974). Between modeling sessions, this modeler-reflector participated in the design of the guidelines that were ultimately used to link the scenario maps with the system dynamics simulation allowing the team to tap into his knowledge of group model building. The research reported in this article results from this assignment of an independent participant observer to record and reflect on the overall process (Luna and Andersen, 2004).

The project in detail

The entire project took place within a number of overlapping phases of work. The project commenced with rapid scenario and simulation model development, arriving at a final product within four months. Periods of time were scheduled where direct contact with the client group was necessary to enable group model building to take place. Other times were reserved for interviews, phone contact, or off-line modeling and report generation.

The project as initially envisioned was budgeted for ~35 person-days. Time with the client group (or subsets of the client group) was limited to four half-day meetings. This was to accommodate the need of members of the group to travel on meeting days. Six or seven members of the client team attended the first and second meetings, while all thirteen participants attended the third and fourth meetings.

The project involved 3 major phases of work. The first phase, surfacing and structuring of material, commenced with the elicitation of key events that would define possible future ROC scenarios. The focus question was straightforward: "What future events could have an important impact on the financial performance of ROCs". The two sessions (involving subgroups of the client group) used a Group Decision Support System called Group Explorer to rapidly collect these events (Ackermann and Eden, 2001). Working with a skilled facilitator, each session sorted approximately 100 events into major themes and sought important consequences for these clusters of events – essentially building up a cause map illustrating possible scenarios (see Eden and Ackermann, 1999;Eden and Ackermann 1998 for more details).

Phase two involved the integration of the material gathered in the first phase. Following a process of integration and analysis of the cause maps (Eden and Ackermann, 1998) the next workshop involved the client team first reviewing and confirming the integrated scenarios, and then taking away a workbook of "homework" from the meeting and returning the workbooks for further analysis by the modelling team. This work represented an application of approaches worked out and routinely used by Vennix (1996), Richardson and Andersen (1995) and others in group model building projects. The third and final phase then moved onto classic model building, mostly done "in the back room" with frequent consultation with experts nominated by the group and the scenarios. The final scenarios along with their impact on the possible future of the ROC market were then presented back to the entire client group for reflection and review of next steps.

Artefacts created in the Modeling Process

Figure 1 illustrates the sequence of artefacts that were created during the 3 major phases of the modeling intervention. Some artefacts were created directly by group process in group meetings—these are underlined. The modeling team created other artefacts while working "in the back room" and not in view of the client group—these are in standard text that is non italic/underlined. Finally, some artefacts created during one of the meetings were subsequently brought into subsequent meetings and were discussed and modified (but not initially created) by the client group—these are in italic.

Figure 1: Sequence of Boundary Objects Created During the Project

The objects in Figure 1 are organized in rough temporal sequence working from left to right. The timing of the various group meetings is indicated at the bottom of the figure. The arrows connecting the various products indicate that the object at the tail of the arrow was created in time before the object at the head. In general the object at the tail of the arrow was used as a basis to create the object at the head of the arrow. The heavy lines without arrowheads indicate that the two objects at each end of these lines were crafted with significant amounts of interaction.

Three sequences of interconnected activity are also illustrated in Figure 1. Along the top of the diagram is a sequence of products mainly associated with creating scenarios for the future of ROCs. This sequence of products begins with the "Raw Scenario" maps elicited in the first meeting and ends with the final definition of scenarios presented at the last meeting. Along the bottom of the diagram is a sequence of objects associated with the creation of a formal model. This begins with prior theory (relating to power markets and commodity cycles) and ends with the final running model. In-between are objects whose purpose was to "traverse" between the scenario building effort and the formal modeling project.

The key story that we want to tell in the rest of this paper is how the research team was able to get the client group from the upper left hand corner where the project started with a Group Explorer elicitation of scenario events down to the lower right hand corner. At the end of this chain, an elaborated causal influence diagram was used to create a formal simulation model. These beginning, middle and end points for our story are boxes with bold lines. Below, we proceed to describe in brief detail the work processes and group facilitation techniques and modeling guidelines that we used along this critical pathway.

Phase 1: Elicitation of Material

The initial meetings used Group Explorer to elicit participants' perceptions of key events that would have an important future impact on the price of ROCs. The process commenced with each of the client team anonymously and simultaneously entering into the system possible events that could trigger alternative futures. This allowed a wide range of contributions to be gathered very quickly and ensured all had an equal share of airtime – ensuring that the procedure felt just (Kim and Mauborgne, 1995) and enabling a wide range of perspectives to be elicited. The next stage was spent sorting these events into major themes – essentially adopting a form of crude content analysis. The final, and longest stage saw participants working together to build the events into a means ends network (using cause mapping) – illustrating how major clusters of activity linked to one another and what were their important consequences.

Figure 2: Photograph of one of the groups working on generating scenario events

Phase II: Integration of Material

(i) Integrating the Scenario maps to create one single semantically rich qualitative model

The "raw" scenario maps elicited in the first two meetings needed to be merged. Not surprisingly there were common themes across the two workshops, for example local governmental policies or newly emerging policies of the EU but there were also differences due to the different compositions of the subgroups. The common themes provided an obvious starting point for the integration with the remaining material being woven into the resultant structure (informed through the observations of both the modelers and the participant observer). This process involved working off line, whereby the modeling team focused on identifying scenario events and where these were identical in meaning merging them (Eden and Ackermann, 1998). Where there was some dispute over the exact meaning, causal links were drawn between the two events illustrating potential connections but not reducing the richness and variety – the group would check these new links during the next workshop. Once complete, various analytical routines could be executed to determine particular model structures, for example the emergence of new dominant themes or feedback loops.

(ii) Detecting feedback loops to highlight potentially dynamic behavior

As noted above, using the built in analytic features of the software, the modeling team was able to identify any feedback loops. The next stage was to check whether the feedback loops were genuine i.e. not a result of incorrect linking of scenario events. Each loop was subsequently checked to determine whether the chain of argument 'made sense' followed by checking any doubtful links or loops with experts in the field. Those feedback loops that remained were then examined in detail. One area of interest was determining whether they comprised events from only one workshop or whether they encompassed contributions from both of the workshops. In addition, did they appear to contain contributions from different perspectives e.g. finance, generation, supply etc. Finally consideration was given to reflecting on how detailed or nested[3] they were. Feedback loops, which although focusing on a particular theme or process have a number of different paths contributing towards the dynamic behavior, may have more impact or likelihood of occurring than those relatively sparsely linked structures. The loops thus identified were candidates for inclusion in the formal quantitative model structure. Due to the limited time of the pilot project, these candidates were not incorporated into the simulation model, but their impact on the behavior of the ROC market was discussed with the client group.

(iii) Building the Preliminary Causal Influence Diagram

In working to create a system dynamics model to simulate the scenarios that were being produced, the team decided to construct a causal influence diagram to capture the main structure of the ROC market. The literature suggests that there are a number of ways in which to get a preliminary causal model. For example, a concept model (Richardson and Andersen, 1995) could be produced early in the process or published models on markets which are believed to have a similar structure could be used or a structure could be developed from the ground-up by interviewing players in the market (Ackermann *et al*., 1997). For this project, the modelers had been present at and had participated in the conversations in meetings one and two. Based on those discussions, the modeling team believed that published work on electric power markets and general commodity markets (for example, Larsen *et al*., 2001; Sterman, 2000; Ford, 1997) shared features in common with the ROC market and therefore provided a good source from which to construct a preliminary causal influence diagram. The preliminary causal influence diagram was then modified through one-to-one discussions with experts in the ROC market. The resulting diagram obeyed all the syntactic requirements of a formal causal influence diagram—indeed early on in the project this causal influence diagram was recast as a preliminary running simulation model (Saeed, 1998a, 1998b).

(iv) Working with Reference Mode Sketches

Before the third meeting, as part of building the causal influence diagram the modeling team also had focused in on the price of ROCs and the relative supply versus demand of renewable generation capacity as key variables that would be central to any reference mode for a final system dynamics model. To get some feel for the values of these variables, at the third meeting, the client team drew the reference modes for these two key variables using standard group modeling scripts (Andersen and Richardson, 1997; Saeed, 1998a, 1998b)

(v) Reviewing the scenarios

The third meeting commenced with a review of the merged scenarios. This was to ensure that the links integrating material from both workshops were valid as well as to develop further

[3] Nested feedback loops occur when there are many different routes making up and consolidating a single feedback loop

integrating links and material. One of the insights gained from the analysis stage had been that the scenarios tended to be very focused around one specific theme rather than built up of a series of interacting events – the notion of interacting improbabilities (van der Heijden, 1996). Effort was therefore spent eliciting how the events captured impacted not just the theme they were currently supporting but also others – thus building a set of scenarios that addressed a broader spectrum.

(vi) Quantifying the key relationships

The final substantive portion of the third meeting centred on quantification of key relationships necessary to complete a formal simulation model. Prior to the third meeting, the modelling team had worked extensively with the preliminary causal mechanism and had identified 3 key relationships that would need to be quantified before a running model could be constructed. The modelling team used small group techniques to elicit these relationships from the client team (Ford and Sterman, 1998; Lee at al, 1998)

(vii) Gaining Group Feedback – filling in a workbook

As the participant group left the third meeting, each member of the group was given a 'workbook' comprising five tasks. The first task requested that members reviewed the scenarios checking further to ensure that they were 'correct' in terms of the links (and therefore suggesting deletions and additions if need be). The second task requested a review of the causal influence diagram, aiming to validate its structure. The third task was to take each scenario and suggest 3-5 links where the scenario impacted upon the causal influence diagram (this process is described in more detail in the next section). For task 4 members were then asked to explain the importance of the links made in task 3. The final task was a review of the quantification processes carried out in the workshop (the above step). This material was then used to refine both the scenarios and the causal influence diagram.

(viii) Determining the impact of the scenarios on the Causal Influence Diagram.

Merging the refined scenario event maps with a preliminary causal influence diagram created the central boundary object used to organize much of the conversation during the third meeting. ***The details of how this step took place represent the key product of this research effort.***

By this stage in the modeling process, a coherent set of scenario maps had been produced along with a causal influence diagram that captured the main dynamics that both the modeling and client team believed to exist in the ROC market. The modeling process then focused on how the various scenarios that had been developed would impact upon the causal influence diagram and hence a resulting system dynamics model.

For this project the modeling team were keen to develop a replicable process that would clearly demonstrate how they had moved from the qualitative scenario maps to their quantitative implications. The team developed a set of guidelines that captured the process of linking the scenarios to the causal influence diagram. We used these guidelines in working to link the scenario maps with the causal influence diagram.

The main focus of the guidelines was to categorize each of the scenario events, in each of the scenario maps, in one of the following categories:

a) **Explanatory**: the event was seen to be detailed material, that comprises examples or elaboration for its consequences in the scenario map

b) **Input to causal influence diagram**: an event that directly impacts one or more of the causal influence diagram variables (often supported by explanatory material)
c) **Output from causal influence diagram**: an event that is triggered by one or more of the causal influence diagram variables
d) **Aggregate: a less elaborated form of the full causal influence diagram structure**: in this case one or more of the linked scenario events provide an aggregated form of a more elaborated structure in the causal influence diagram.
e) **Causal influence diagram variable addition**: the event suggests a structural change to the causal influence diagram extending and elaborating it.

Based on this categorization of the scenario events, the modeling team undertook the following steps:

Step 1: Begin at the Bottom of a Scenario Chain[4]: In order to take a systematic approach to the categorization of the events, commence with the event at the 'bottom' of a scenario map i.e. identify the longest chain of argument and begin with the most subordinate scenario event.

Step 2: Code the Scenario Variable*:* Determine which of the above 5 categories is the most appropriate for the chosen event. Then, if the event is:

a) **Explanatory**, move up the next step in the chain of causality until reaching an event that has more than one event leading into it. Consider the next most elaborated chain supporting this event so as to address the entire portfolio.
b) **An input to the causal influence diagram**, link the event into the appropriate causal influence diagram variable
c) **An output from the causal influence diagram**, link the appropriate causal influence diagram variable to the event
d) **A less elaborated form of the causal influence diagram**, then simply make a note of this
e) A **causal influence diagram variable addition**, alter the causal influence diagram structure appropriately and link the scenario event to the new causal influence diagram variable

Step 3: Repeat the Process*:* Start with the next most subordinate event chain and repeat step 2.

Steps 2 and 3 should be repeated until all events in the scenario map have been categorized and the appropriate links made between the scenario map and the causal influence diagram.

An example illustrating how the above guidelines were used in practice is detailed below.

Figure 3 shows an excerpt from one of the scenario maps produced for the ROC project. The scenario map is taken from the artefact 'Merged and Refined Scenario Maps' shown in Figure 1, which is the result of merging the material elicited during the initial two meetings. Overall, 8 scenario maps were produced during the project and Figure 3 below shows only a small section of one of these maps.

Figure 3 includes some of the events that the client group raised as contributing to a 'General reluctance to invest in power in the UK'. When reviewing this figure, please note the following:

- The numbers at the beginning of each event are simply reference numbers.

[4] a scenario chain is the chain of argumentation linking events together in a causal manner. Thus the bottom of the chain is the most sub-ordinate event.

- An arrow from event A to event B should be read as 'event A may lead to event B'
- If a negative sign appears at an arrow head, then this should be read as 'event A may not lead to event B'
- The unbroken arrows shown in figure 3 only represent a small number of the links in and out of each event. The dotted arrows with attached numbers represent links to further events that are not displayed in this small excerpt.
- The different fonts used for the events relate to different categories of events that were used as part of the analysis of the scenario maps, but are of no real significance to the focus of this paper

Figure 3: Scenario events leading to a 'General reluctance to invest in power in the UK'.

The results of the categorisation process for each of the events in Figure 3 is included in Appendix I.

For the pilot project, it was agreed that the focus of the simulation model would be on those events that acted as inputs to the causal influence diagram. The categorization process highlighted 3 events that acted as inputs for the scenario excerpt shown in Figure 3. Therefore, this led to the scenario events being linked to the causal influence diagram as shown in Figure 4 below. In this figure, the bold arrows represent the links between the scenario map and the causal influence diagram. The top 5 concepts (i.e. those above the dotted line) are variables in the causal influence diagram, whereas the bottom 4 concepts (i.e. those below the dotted line) are events from the scenario map.

Figure 4: Links between scenario events and the causal influence diagram.

Although the process of coding the moves from the scenario maps to the quantitative model structure was mainly carried out "in the backroom", not in view of the client group, this was mostly due to time pressures. However, the modeling team did lead the client group step-by-step through the process for one of the scenarios. Prior to linking the two models the client group had spent time discussing and modifying both the scenario map and the causal influence diagram in order to enhance their understanding and ownership of both. The facilitators thus were able to take each scenario event in turn and explain how they would be categorized in terms of the guidelines discussed above. When a category was chosen for a scenario event, the appropriate link to the causal influence diagram was made. This process led the client group to become engaged in the linking process and resulted in them confirming the linkages and making suggestions for other links that could be made between the scenario maps and the causal influence diagram. This process of refining the linked maps also continued after the group session as participants took a workbook of printed maps away with them to review and send back more detailed comments. In addition, during the group session, the modeling group observed the client group using both the scenario event names and variable names from the causal influence diagram relatively comfortably in their discussions. The group appeared to move between the two sets of concepts seamlessly.

The process aided the client group to observe a clear path from the original information gathered from them at group sessions to the output from the system dynamics model. This was possible via the scenario maps (built-up in a group session using events suggested by the group) to the links between these events and the causal influence diagram, to a quantification of that model and finally the results from simulating the quantitative model.

Phase III: Modeling

(i) Running Model

The modeling team working "in the back room" rather than with the client group constructed the final running simulation model. As shown in Figure 1, in constructing the final running simulation model, the modeling team made use of the updated scenarios, the reference mode exercise, the results of the key quantification exercises, the refined causal mechanism, and the "pearls of wisdom[5]" generated by the client group. In addition, the collective workbooks contained detailed comments, modifications, and insights on most all of the material generated in the three group meetings. Because such an extensive amount of material had been collected from the client group, constructing the running simulation model to demonstrate project feasibility was not a conceptually complicated process.

The running model was a system dynamics model that simulated the impact of different possible future scenarios. The output from the model included time plots of major variables that demonstrated the future behavior of the ROC market based on each of the scenarios. The pilot project had created a preliminary proprietary model that could be used by investors to investigate risk in the ROC market.

(ii) Final Presentation and Report

The results of the project were fed back to the client group through both a final presentation and report. Both of these included an explanation of the methodology adopted, the steps involved in each of the 3 phases of the project and a discussion of the varying time plots of major variables that were output from the final running model. As the project had been planned as a pilot study, the final presentation also included a session at the end to discuss possible future research avenues and these ideas were included at the end of the final report.

Discussion

The above describes the team's first time using the process to link scenario maps to a simulation model. Since completing the project, the team has spent some time reflecting on the overall project resulting in suggestions to improve the process.

The team believes that the use of a basic concept model earlier on in the process may be advantageous. Such a model could be introduced to the client group during the initial couple of meetings. The possible benefits from this are that it would introduce the client group to the idea of what a simulation model is earlier in the process. Such an introduction may increase perceived

[5] These were important considerations that the participants felt that the modelling team should take into account and were elicited at the end of the fourth meeting.

confidence in the causal influence diagram as a bridge between the scenario discussions and a final running simulation model.

When showing the client group the links between the scenario maps and the causal influence diagram, the group appeared to move between the two sets of variable names relatively seamlessly. One reason for this may be that they were presented with the quantitative model structure in terms of language and notation with which they are already familiar. For example, if the model structure had been presented as a stock/flow diagram, then the move may not have been as smooth. The quantitative model structure was presented in form that was identical to the structure of the scenario maps that they had generated themselves. This similar visual form enhanced client ownership of the causal influence diagram, thereby making the transition between the semantically rich scenario maps and the high syntactic requirements of the causal influence diagrams much easier.

There are 3 threads of research for which the work discussed in this paper has implications:

Group model building

This work informs and builds upon the work in group model building in three specific ways. First, we present documentation of a case study that spans and merges two different ways of doing group model building work. We believe that significant progress can be made when practitioners working within different traditions have a chance to share their work procedures in detail. Most importantly, our work draws attention to the broad diversity of boundary objects (Black, 2002 and Zagonel 2002) that can come into play in a single model building intervention. Second our work adds to the literature on group model building by adding a number of scripts (Andersen and Richardson, 1997) for working with an expanded set of boundary objects as shown in Figure 1 that can enlarge the realm of current practice. Finally, the work presents a set of coding procedures that can be used between group sessions to link formal causal influence diagrams with semantically rich maps generated by client groups. We believe that this last objective may be the most important contribution of this work and additional experimentation along these lines will be necessary to fully refine the proposed coding rules.

Soft systems vs. quantitative simulation

The research presented here provides a concrete example of how and why it may not be necessary to view soft systems vs. quantitative simulation as either-or approaches. This builds directly on discussions at the 1994 Stirling conference. In the example that we discussed, we began with qualitative mapping techniques and wound up with a formal simulation model. Using the scripts and coding rules that we have described, we believe that it will become more and more common (and easier) for modelers to move back and forth between these two complementary approaches to system modeling. This extends the work done on mixing methodologies – typically spanning the qualitative/quantitative divide (Mingers and Gill, 1997) and opens up the possibility of addressing a wider range of problem domains. In addition, the work provides a concrete example that may inform the debate on mapping versus simulating (Wolstenholme, 1999; Coyle, 2000 and 2001; Homer and Olivia, 2001; Richardson, 2001)

Strategy development and simulation

With respect to the linked fields of strategy development and simulation, our major contribution has been to demonstrate techniques that explicitly link formal scenario mapping techniques into quantitative simulation modeling. Often when working in strategy arenas, scenarios are considered an appropriate and necessary part of any modeling team's work. However little work to date has been spent on quantifying scenarios elicited from groups. Hence the overall analysis may miss observing potentially critical dynamic effects. For example through using formal simulation modeling it will be possible to explore dynamic impacts of scenarios – understanding their causes and examining a range of mitigating actions. Or, through appreciating the likelihood of the company's performance decreasing following implementation of a strategy before seeing an increase – something that will help managers gain confidence in the strategy rather than making a premature U-turn (see Pettigrew *et al.,*2003 for more detail). These approaches will allow modelers to get the most out of both of these approaches in applied work.

Although this work builds upon the discussions during the 1994 Stirling conference, it should be noted that the results described in this paper still represent work in progress. The intention of this paper is to report on a process that has been developed and tested on one client group. This reported work builds upon two of the authors work as part of a team involved in the modeling of disruption and delay in complex projects as a part of litigation (Ackermann *et al*., 1997; Eden *et al*., 2000; Williams *et al*., 2003) linked to a related but similar stream of research in group model building (Richardson and Andersen, 1995; Andersen and Richardson, 1997). Such cross-fertilization of approaches was generative for this work and, as noted at Stirling, important for the field as a whole to make progress. We hope that future opportunities will arise where the process described in this paper can be refined. Such refinements will allow modelers to provide their client groups with clearer transitions between the development of qualitative models such as scenario maps and quantitative simulation models.

The discussions held at Stirling in 1994 were important to the advancement of appreciating how other systems thinking methodologies relate to the more traditional system dynamics simulation models. This paper has described a practical approach that can be used to further advance the work in this area. While the case reported on is quite specific, we believe that a broader range of complementary systems thinking approaches can and should be integrated with more traditional SD simulation methods. This area of work is an important area in the future of system dynamics and we are delighted that it is still on the system dynamics community's agenda a decade after Stirling.

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Appendix I - Categorization process for each of the events included in Figure 3

Scenario event number (see Figure 3)	Categorization	Discussion
37, 95, 117, 58, 52	Explanatory	All examples of a specific situation that may cause event 115
115	Input to causal influence diagram via 258	Link to causal influence diagram via 'Availability of finance for projects'. However, also a link to this from 258 (see later). Describes the same story, therefore this direct link is not required.
89	Input to causal influence diagram	Link to causal influence diagram via 'Delay in planning permission'
123	Input to causal influence diagram (implies 2 inputs, but due to previous linkage, only 1 required)	Link to causal influence diagram via 'Delay in planning permission' (but this already linked through 89 which is an example of 123, so do not require a second link) and to 'Planning success rate'
278	Less elaborated form of existing causal influence diagram structure	Link from this to 258: High returns means more investment – causal influence diagram links already clarify this
261	Less elaborated for of existing causal influence diagram structure	Link from 261 to 258 – Too much capacity means less investment – causal influence diagram links already clarify this
258	Input to causal influence diagram	Link to causal influence diagram variable 'Availability of finance for projects'

Table 1: Categorization of the scenario events displayed in Figure 3

A fuller explanation of how the categorization process was carried out for some of the scenario events is now given:

Event 37-Change of Government: The main impact that a change in Government was believed to have on the ROC market, was that there would be uncertainty on the new Government's policies and hence their attitude to the ROC market. It was therefore not believed that this should link directly to the causal influence diagram, but instead influences it via event 115. It was therefore categorized as an *explanatory* event to event 115.

Event 258-General reluctance to invest in power in UK: If there is a general reluctance to invest in power in the UK, the direct impact of this was believed to be that there would be less finance available for power projects. This directly influences one of the causal influence diagram variables i.e. ‘availability of project finance’. Event 258 was therefore concluded to be an *input to the causal influence diagram*.

Event 278-See renewables make profit: If renewable energy projects are making a profit, then it is believed that this will encourage investors to invest in future renewable energy. Although this is captured in the scenario map extract, this argument is also captured within the existing structure of the causal influence diagram. It was therefore concluded that link between event 278 and event 258 was a *less elaborated form of existing causal influence diagram structure*.

Two categories that are not covered by the above example are an output from the causal influence diagram and a causal influence diagram variable addition. However, these categories were used to categorize events from other scenario maps – not all maps contributing to all of the categories. For example, a sequence of events that were included in the scenarios was that if the renewable energy targets were exceeded, then this might lead to ROC prices being driven down. However, the existing causal influence diagram structure would capture this event through a variable named ‘market price of ROCs’ and so the reduction in ROC market prices would be an *output from the causal influence diagram*.

An example of a *causal influence diagram variable addition* occurred through a scenario event named ‘diminished public support for renewables’. The impact of positive or negative public support had not been included in the preliminary causal influence diagram. Therefore, if the scenarios impacted by this event were to be fully explored, then additional structure would need to be added to the causal influence diagram. Due to the limited time available for the pilot project, this amendment was not made to the causal influence diagram; instead a note was made of this change for future reference when and if a more detailed second stage of the project was to be carried out.

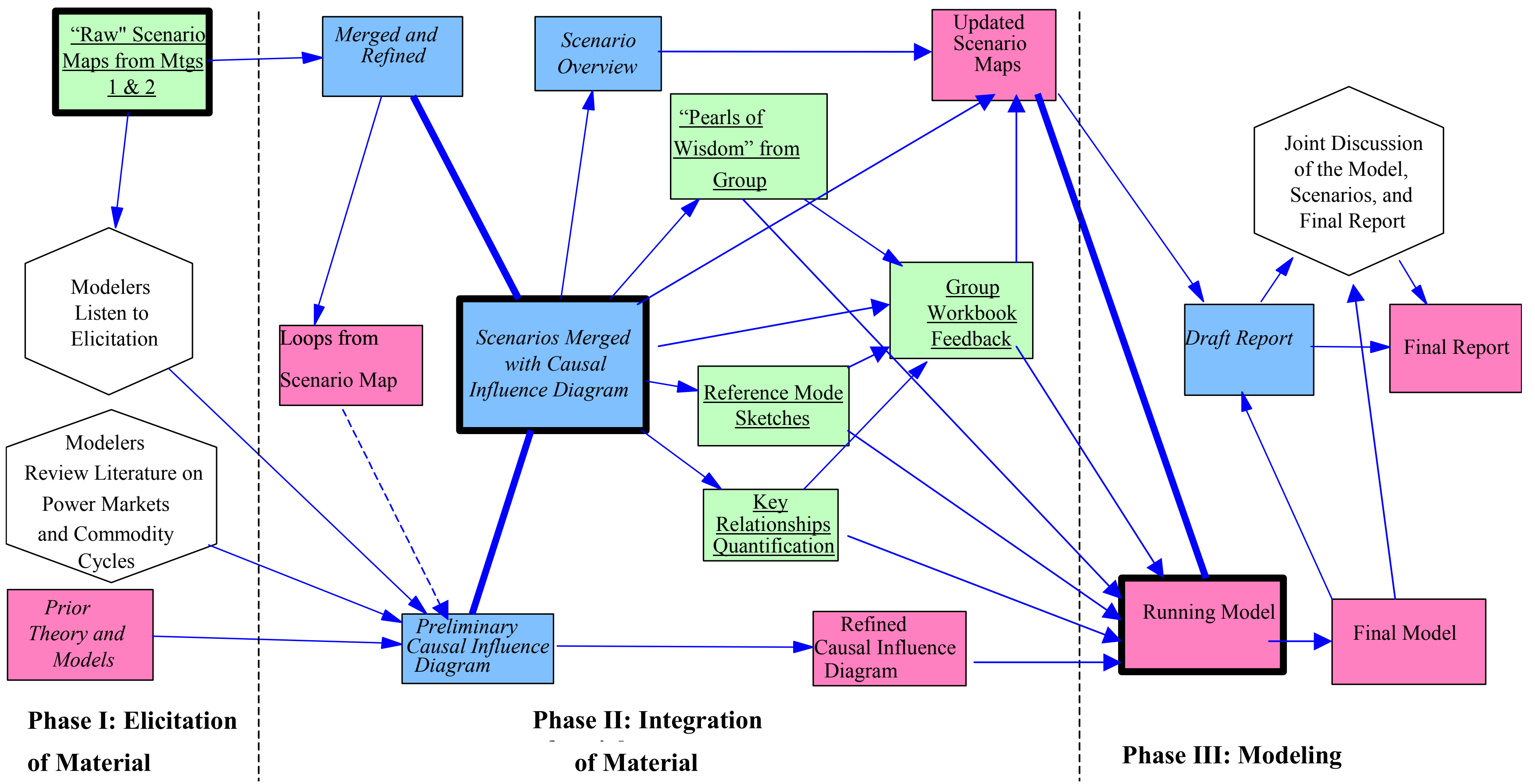

Figure 1: Sequence of Boundary Objects Created During the Project

Arrow Key:
Solid Arrows: Object at the tail used to create object at head
Dashed Arrows: Object at tail could be used to create object as head, but was not used to do so in the project discussed in the paper
Bold lines: Two connected objects created with significant interaction

Box Key:
Boxes/standard text: Artefacts created in the 'backroom'
Boxes/italics: Artefacts created in the 'backroom' but discussed and modified by client group
Boxes/underlined text: Artefacts created directly by group process
Boxes/Bold border: Focus of research
Hexagons: Processes that contribute to creation of artefacts

Figure 2: Photograph of one of the groups working on generating scenario events

Figure 3: Scenario events leading to a ‘General reluctance to invest in power in the UK’.

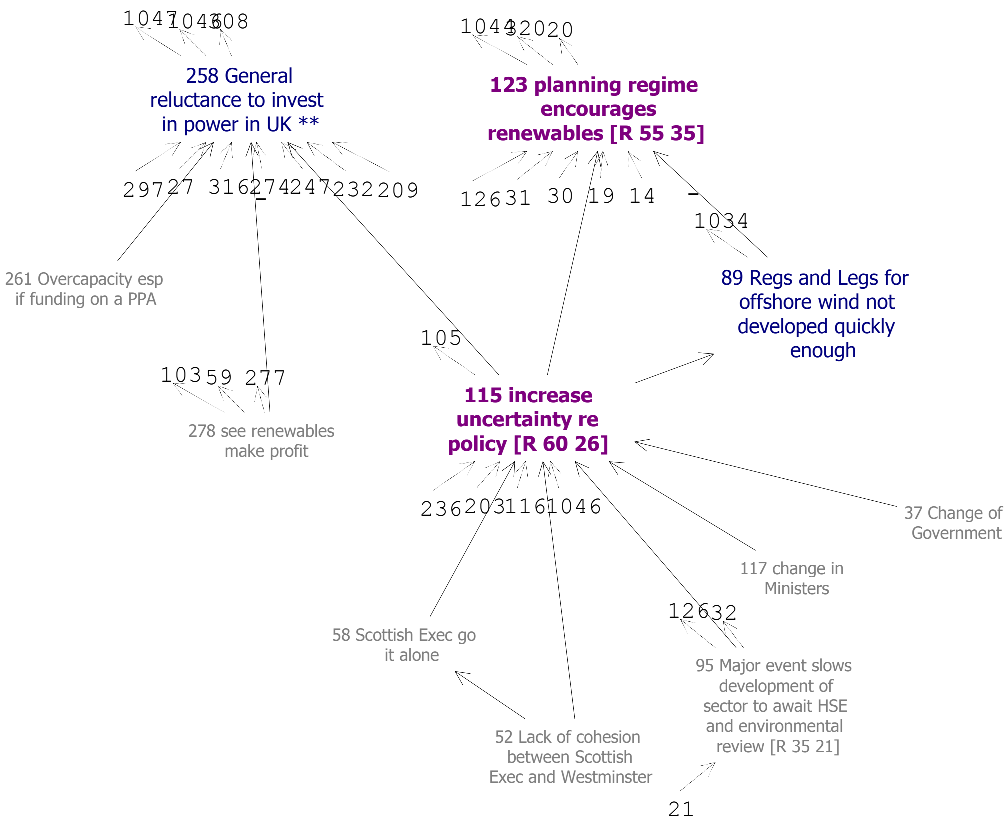

Figure 4: Links between scenario events and the causal influence diagram.