Using Cognitive Mapping to Develop a Large Forensic System Dynamics Model

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Abstract

This paper describes the use of Systems Dynamics (SD) for making a claim for Disruption and Delay. The case concerns design management of a large development project. Extensive group workshops (GDSS) with the managers, based on the cognitive mapping technique and associated software tool COPE, showed that the client-contractor interaction process had set up dynamic feedback loops creating Disruption and Delay to the project. In order to quantify the extent of the Disruption and Delay, the cognitive map was transformed into an "influence diagram" and thence through the acquisition of numeric data into a large SD model. The development of the two continued in parallel, informing and checking one another. As well as simply providing explanations of trends and behaviour, the SD model had to reproduce the planned and actual out-turns explicitly for it to be a creditable explanatory tool. The paper will draw lessons from the case study on the process of moving from a cognitive map to a SD model, and the mutual benefits of joint development, as well as more general lessons about combining soft and hard methods.

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Introduction

Operational Research, or Management Science, is traditionally associated with the application of quantitative techniques to managerial problems. It has its origins in the analysis of operations in the Second World War and, during the post-war years, these approaches were introduced, first to industry, and later to government , with some success. One definition which appeared regularly in the Journal of the Operational Research Society of Great Britain until April 1984 stated that

> "Operational Research is the application of methods of science to complex problems arising in the direction and management of large systems of men, machines and money in industry, business, government and defence. The distinctive approach is to develop a scientific model of the system, incorporating measurements of factors such as chance and risk, with which to predict and compare the outcomes of alternative decisions, strategies or controls. The purpose is to help management determine its policy and actions scientifically".

As such the term OR has been traditionally associated with techniques such as linear and non-linear programming, critical path analysis, queuing theory and so on. However more recently, particularly within the last decade, a move towards 'soft' methods has emerged (Rosenhead 1989, Eden and Radford 1990). These softer methods were and are continuing to be developed to try to resolve some of the limitations of the quantitative methods and provide further benefit to managers by focusing on predominantly qualitative data and unstructured problems. As a result they aimed to support managers working on messy, complex, wicked (Ackoff 1974) problems through adding structure and helping the process of explication. Group decision support systems were developed such as SODA (Eden 1989, Eden and Ackermann 1992), Strategic Choice (Friend and Hickling 1987) and Decision Conferencing (Phillips 1989) which provided groups with the facility to begin to explore issues, negotiate an understanding and from this, work towards a solution which was more grounded in the organisational context and therefore more likely to be implemented successfully.

However, the introduction of 'softer' approaches, whilst extending the use of OR, did not meet all the needs of managers - particularly those struggling with problems which contained elements of both hard and soft OR. To begin to address this omission, and further promote OR, some research was carried out into exploring means of mixing methods without causing substantial theoretical ramifications and conflicts (Cropper et al 1990), but even this research appears to have concentrated on one end of the spectrum - that of the softer aspects of OR. Whilst methods that incorporate aspects, or techniques, of both soft and hard OR, intuitively suggest a powerful means of resolving complex problems, their absence is not surprising. Very few practioners or academics become experienced in using both. Although courses are increasing exposing students to techniques from both 'camps', when it comes to using them in practice, those approaches that fit the style of the practioner, or those which are championed in the organisation, dominate. It appears that the majority of OR departments in organisations focus on one or two particular, and more often than not, quantitative, techniques, whilst the majority of the work carried out with the softer techniques remains within the Universities - SODA at the University of Strathclyde, SSM at Lancaster University, Robustness Analysis at LSE etc.

This paper however, reports on a Mega project (Fraser, 1984) which, by its very nature, forced the use of both hard and soft methods to be employed. As a result, practioners experienced with hard OR were brought together with those more familiar with softer methods and, in order to work together successfully, communication and mutual understanding were necessary. The paper, therefore, reflects on the project and some of its learning points to try to help those faced with such projects. As such, the paper commences with a brief outline of the project itself, in order to provide some context, which is followed by a detailed description of how the research team tackled the research project. From this experience, a number of insights were elicited and are described before the paper concludes by suggesting how weaving together soft and hard techniques can provide new and powerful methods of working .

The research project

The research project focused around developing a sustainable and quantified model of the impact of delay and disruption upon a Mega Project (Williams et al 1994). This model was to be used alongside a direct claim[1] put together by a legal team also working for the client group. The modelling technique which was required by the client was System Dynamics (Coyle, 1977). This was largely due to the fact that it had been used already in a similar case in the United States (Weil and Etherton 1990) (although the case had been settled out of court). In addition, the System Dynamics modelling approach was believed to produce models which are more transparent to the examiners than the obvious alternative - discrete event simulation modelling. A model which could easily be audited by external analysts provide a stronger legal argument than an equivalent 'black box' model.

In recent years, the System Dynamics community has placed increasing emphasis on the qualitative aspects of their chosen methodology (Lane, 1992). Traditionally, System Dynamics models were constructed with the goal of obtaining a fully quantified model, but today many practitioners choose to focus on the systemic *structures* within the system being studied, and the actual *process* of modelling, rather than 'the numbers' - they tend to use the methodology to construct learning models.

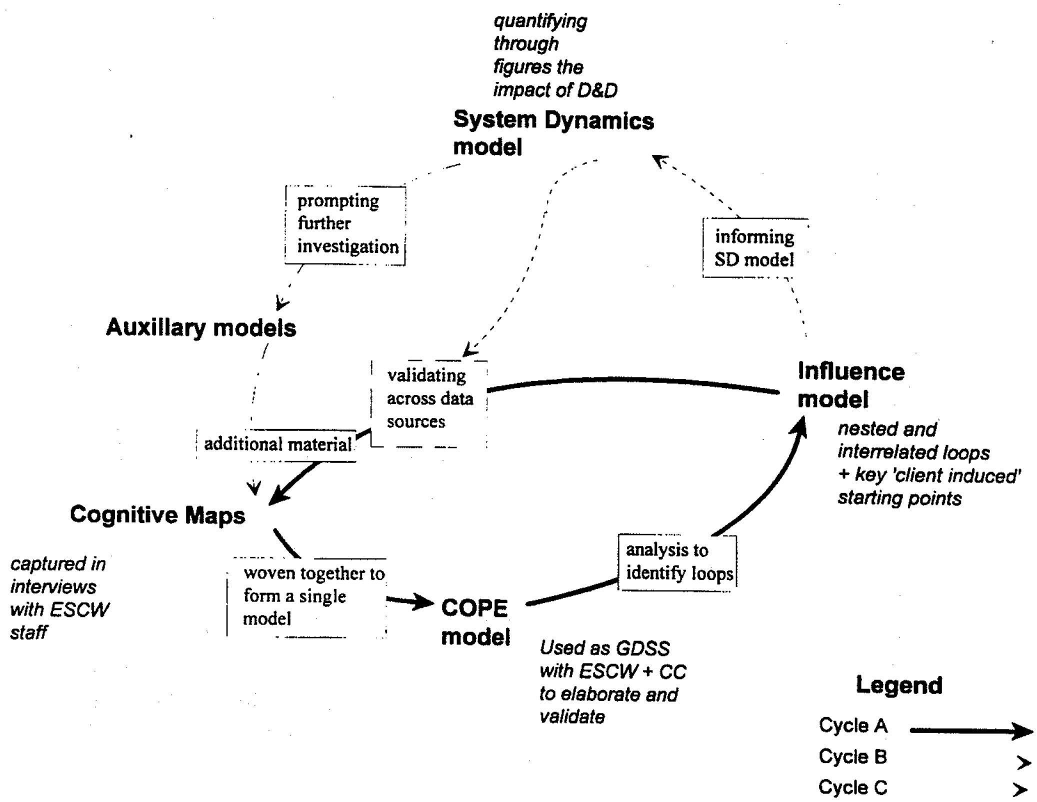
However, the role of the model constructed in this project was to recreate a historical pattern of behaviour and, after constructing a model which reflected the recorded behaviour of the actual system (for validation purposes), to use it to demonstrate the extent to which delay and distribution contributed to this behaviour. Therefore, a model which 'merely' contributed to an improved understanding of the system under study would have been unacceptable, as such a model which could not recreate the actual behaviour observed during the course of the project would be untenable in a legal context. Each individual relationship and value employed in the model had to be legally defensible. Consequently, a forensic model was absolutely necessary, and this placed the System Dynamics approach used firmly within the 'hard OR' category.

The major causes of delay and disruption were seen to be twofold. The first was argued to be that the client of the Mega project demanded **preferential engineering**, that is, additional requirements, particularly with respect to safety, which not only increased design time, but also had extensive ramifications for other parts of the system. The second was argued to be due to the large number of approval delays - caused by each design document being required to be approved by the client who frequently far exceeded the contractual time limits, or at least as seen by the client. As a result of these delays, designs had to be worked on simultaneously, leading to a disruption of the design schedule. This, in turn, resulted in numerous interfacing problems due to parts being designed in ignorance of the specifications of related parts...and *this*, in turn, lead to a further increase in design time - thus defining one of the many feedback cycles present in this project.

To provide the basis for the construction of the System Dynamics (SD) model, the team needed to understand how the different parts of the project impacted upon one another, what the implication was for these impacts, and whether sustainable data existed which would enable the model to be quantified. The method used took the form described in Figure 1 - that is, to use soft methods such as cognitive mapping (Eden 1988) to capture the individual perceptions and begin to weave them into a single model, a format often adopted when using the SODA methodology. A SODA workshop was then instigated to validate the model and, from this revised model, the research team extracted the feedback loops and variables (separated into exogenous and endogenous) to construct an intermediate model - an influence diagram. It was *this* model which

[1]focusing on identifying the costs of specific events

was then used as a blueprint for the SD model. In turn, the results generated by the SD model were compared with the numerical data available, and where inconsistencies occurred, further investigation was initiated, thus leading to a review and updating of the original SODA model. This formed a cyclical process which was to last throughout the project.



The following section describes the process more fully and provides some explanation.

What happened

Towards a problem definition

In order to begin to gain an understanding of the nature of the Mega project and its attendant delay and disruption (with the intention of building a model representing the different perspectives of the client team), a round of interviews with key members of the client team was conducted. From these interviews, a model was created which was then examined by the client team members to ensure it was both sound and complete. This method of data generation and structuring followed the Strategic Options Development and Analysis (SODA) methodology - a soft OR method. SODA is based around Kelly's Theory of Personal Constructs (1955) along with organisational and behavioural theory. Personal Construct theory asserts that 'man as a scientist makes sense of his world though compare and contrast and through this detects patterns and themes which enable him to manage future events'. It would be these themes that the research team aimed to extract. The cognitive mapping technique has been developed to capture the discussion and enables maps or networks to be constructed reflecting the individual perception of the issue or problem being discussed. The cognitive maps may then be used as means of managing the problem through analysis and reflection on an individual basis (Eden, 1991) or weaving a number of these maps together to form a group model (Cropper et al 1992). The building of a group model is facilitated through the use of a software tool, Graphics COPE[2], which mirrors the cognitive mapping technique. This group model can be explored, amended and used as a negotiative device to help groups develop a way forward, and later, as a decision support system to monitor progress and reflect on the rationale for decisions (Ackermann et al 1992)

Cognitive mapping was used because it enabled the team to capture the different perceptions of the delay and disruption claim as networks of ideas which could then be woven together to form a single model. Due to the project focusing on a highly technical area, and the increased importance of getting the data right from the start as it would form the nucleus of the SD model, each interview involved two members of the team - one member directing the interview and focusing on covering as much of the subject area as possible, while the other took more extensive notes in the form of cognitive maps and only asked questions of a clarifying nature. This method increased the likelihood of collecting all of the information presented and highlighting any ambiguities. Each map was then entered into the COPE group model which was analysed for emergent issues and reoccurring themes (Eden et al 1992). In accordance with the cognitive mapping technique, and further aided by the analysis within the software, the hierarchy of the model was refined so that the key issues could be clearly identified. These key issues would play an important part in the construction of the SD model.

Validating the model with the client group

Up until this particular point in the project, the research team had followed a standard SODA format - that of eliciting individual representations, weaving them together into a single composite model and then presenting the model back to the group for review and further work. However, it was at this point that the process deviated from the standard use of SODA. Normally, a SODA workshop begins with an exploration of the data, followed by a period of working on the issues through adding material and refining existing ideas as the group members negotiate a plan of action, and finally the workshop concludes with a period of agreeing on the next steps, with the person responsible for the action and the dates for completion often being decided. The workshops are a forum for agreeing a way forward.

This was not the situation for this project. Usually, a group begins exploring the problem in a workshop, moving on to work towards a new understanding and finally arriving at conclusions that may not have occurred to them without the decision support intervention. The client team in this project had well defined ideas about the major aspects of the problem and were more interested in filling in any missing detail and checking the structure of the model. There was less expectation that they would derive a radically new perspective on their situation than is usually the case however some learning and increased understanding was arrived at. This reduction was in contradiction to the growing trend in contemporary decision support research which attempts to educate the clients via the modelling process (Wolstenholme 1993), but in some cases (such as here) is an unrealistic, and indeed, inappropriate goal. The research project reported here used the decision support approach (i.e. SODA) to facilitate a knowledge acquisition process.

In practical terms, this difference meant that the group spent a great deal of time debating the *structure* of the model as they were already convinced of its content. This is important with respect to the task of constructing a System Dynamics model. In conventional SODA models, the linkages between concepts deliberately tend to have a vague definition in order to facilitate negotiation. However, the linkages between variables in a forensic System Dynamics model have to be exact. The extended discussion over the nature of the linkages helped to provide the extra information required - clarifying with more precision than is normally the case.

Along with this difference, the workshop involved not only those members of the client team but also lawyers working on the direct claim. The lawyers were included for two reasons - the first

[2]Graphics COPE is developed and supplied by the Department of Management Science at the University of Strathclyde, and runs in the Windows environment on a PC.

was to help them understand more about the project, the second, and possibly a more important reason, was to ensure that the direct claim and the indirect or delay and disruption claim were compatible and did not contradict one another. In addition, the lawyers provided advice as to the legal validity of some of the modelling procedures used by the research team. This inclusion of people who were not in the group interviewed could well have caused problems as those outside of the group interviewed had less ownership of the data and may well have been critical to the point of damaging the group dynamics. In fact, this was not the case and both the client team and the lawyers worked hard towards agreeing a model which reflected the state of affairs. This was perhaps due to the relationship between the client group and the 'outsiders' - the lawyers were employed by the client group. An independent group may have been more critical. Indeed the extensive arguement clusters in the model became, in effect, the first draft of the overall claim and had the claim finished up in court then it was the intention to use the COPE model to support the lawyers directly.

Creating the Influence Model

Following the validation of the SODA model in the series of workshops, it was agreed that further work would be carried out in order to begin to understand the dynamics of delay and disruption which would make up the claim. These dynamics were to be displayed in the form of feedback loops reflecting an escalating effect on the project which mirrored that which had actually occurred in the Mega Project (Williams et al 1994). Through this identification of the dynamics it was anticipated that the key elements could be extracted and used to form the Influence Diagram wich would direct the construction of the System Dynamics model. Through building a separate model containing only the feedback loop items and the initial triggers, the original SODA model could be kept intact, acting as a continually changing record which reflected all of the richness generated through the interviews and subsequent refining. This would not only provide a data source when disagreement or confusion occurred over the feedback loops, but also demonstrate, in a natural and transparent manner, the explanatory material which supported the feedback loops elements - this was taken to be important when presenting the final SD model to the judge. The SODA model would act as a DSS to the research team as well as to the client team.

The analysis undertaken was one which examined the model to determine the feedback loops and, on discovery of them, would place each feedback loop's components into a labelled sub-set for further exploration. The analysis detected over 98 feedback loops. The contents of all of these loops along with the key initial triggers, which had been highlighted and elaborated by the client team members, were then routinely copied and extracted from the main Graphics COPE model and placed into an influence model, again using the Graphics COPE package. From further exploration of the loops it was possible to begin to construct clusters of loops which reflected different areas of the Mega Project. This clustering was possible as many of the loops overlapped one another. By sharing a large percentage of components, but illustrating a new dimension of the feedback loops, each of these variations impacted upon another, further exacerbating the effect. Where there were questions about the loops, and how the components related to one another, reference could be made to the Graphics COPE model, or failing that, shown to the client members for further clarification. The clarification could then be added to the cognitive maps thus recording the author and then entered into the Graphics COPE model thus completing a cycle for the research model - (see cycle A, Figure 1).

From the clustering of the loops it emerged that the largest amount of feedback loops occurred in the design phase of the Mega Project, whilst others occurred in the "methods engineering"[3] and manufacturing stages. The dominance of feedback loops in the design phase, the first experience when working on any project, had an immediate effect on the rest of the project, with those

[3]The methods stage refers to the process often termed process or production engineering in the United Kingdom. The methods agents (or process engineers) determine the process via which the design will be realized in the manufacturing stage by defining the organization of the plant and the assembly sequences.

occurring in the methods and manufacturing phases accelerating the process. This analysis was to provide the rationale for starting the building of the SD model with the design phase.

System Dynamics Modelling

System Dynamics is based around the work of Jay Forrester at MIT in the 1960's (originally known as Industrial Dynamics). The technique was created to allow problem solvers to explore the dynamic systemic effects of the situation under investigation. People have a tendency to reason in a linear fashion i.e. that events are connected by one-way cause and effect relationships - they fail to appreciate the holistic structure of the system. Parameters in a situation are usually both cause and effect - categorizing them as either one or the other limits the power of the decision maker to
influence the system. Addressing a single factor in isolation of the rest of the system can often make a bad problem worse. It is pointless to treat a single symptom - the whole organism must be cured.

Another limitation of human reasoning processes is that people tend to focus on events rather than *patterns* of behaviour developing over time.. This is desirable from a historical perspective as a creature (say prehistoric man) that is not responsive to certain events, such as the sudden appearance of a tiger, may well suffer as a result (end up as the tiger's next meal). However, this evolutionary artefact makes it difficult for decision makers to grasp the long-term patterns of change that tend to prove fatal for organizations. System Dynamics modelling helps to elucidate these long-range behaviours and provides suggestions as to how they may be modified.

Advances in computer technology have revolutionized the use of quantitative System Dynamics modelling. It is now possible to construct, test and refine complex models rapidly using a number of simulation tools. The Stella[4] package used in this project (similar to I-think and PowerSim) was particularly attractive as it is highly visual which made it accessible to the client group, the lawyers and, if necessary, to the judge.

For these reasons, amongst others, System Dynamics modelling provides a suitable framework for investigating the rather nebulous, and highly emergent, effects of delay and disruption. In addition, System Dynamics modelling has it roots in the analysis of industrial systems, so, although it has been successfully applied in a number of diverse areas since Forrester's initial work, this system represents a classic example of the type of problem System Dynamics was conceived to address.

Constructing the System Dynamics Model

As described earlier, analysis of the COPE-based influence diagram suggested that a System Dynamics representation of the design sub-system should be constructed as a first stage. Further analysis of this influence diagram demonstrated that the design system could be further decomposed into two main areas - design process and acquisition of design resources. Therefore, the construction of the System Dynamics model proceeded with the development of the design process section.

A 'main chain' of operations that a design must go through before it is approved was constructed and the feedback relationships relating directly to this change were added. After this initial SD model structure was completed, steps were taken to quantify the relationships contained within it in order to determine how successfully the sub-system had been modelled.

From the description given above, it is clear that the System Dynamics modelling process contains qualitative and quantitative stages. A system structure is constructed which documents

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[4] Stella is a registered trademark of High Performance Systems Inc. Hanover, NH. USA. The package runs on Macintosh computers

the elements and relationships present in the system (the qualitative stage) with the nature of the relationship then being specified algebraically (the quantitative stage). Whilst this is a technique using both qualitative and quantitative data, the aim of this paper is to discuss the combination of soft and hard techniques in a much wider context: - a cognitive mapping stage supporting the construction of influence and system diagrams, and analytical techniques supporting the quantification of variables and thus informing the cognitive maps.

As the construction of the system diagram proceeded, constant reference was made to the SODA model in order to clarify the precise meaning of elements in the model. Occasionally, the process of constructing the system diagram would illuminate deficiencies in the scope of the SODA model. For example, when attempting to model the ramifications a design modification has for related designs, it became apparent that information gathered and recorded in the map was insufficient. This prompted the team to use the rich Graphics COPE model to explore further the issues and identify the key elements not yet fully understand in relation to the SD model. The process gave a clear direction for returning to the client group for more information. The existing SODA map was used to remind the client group of their current views on this issue and the further debate was incorporated into the model during the course of the workshop. In this way, the SODA model and the System Dynamics model enriched one another [see cycle B, Figure 1].

Throughout the course of the work, the SODA map was used as a knowledge repository for the project. Communication between the analysts and the clients was usually mediated via the model. Problems encountered by the team, and possible theories relating to these problems, would often be encoded in map form to enable them to be presented and discussed in a consistent manner.

Quantification of the System Dynamics Model

A number of difficulties arose when an attempt was made to quantify the model. Most of the available data was event-based in nature, for example, the time taken to approve each individual design was available in the form of a database, but as the number of designs ran into thousands, it was infeasible to add each delay as a separate event in the System Dynamics model, indeed this would defeat the philosophy of the team's SD method of simulation. As a result, an average delay had to be computed and disaggregation of some of the model considered, but this was problematic as long delays on key drawings had a disproportionately negative effect on the efficiency of the design process. A statistical analysis was conducted on the distribution of approval times, taking into account the 'centrality' of certain designs. Again, the process of analysing this data, demonstrated flaws in the logic proposed by the client team and recorded in the SODA model and it was updated to reflect a deeper understanding of the issues involved.

Extensive use was also made of spreadsheet modelling. Organizational and personal learning were central features of the manufacturing section of the System Dynamics model (Eden et al 1994) and great effort was spent in understanding the nature of the "learning curve" (Wright 1936) in the organization. An 'Excel' model of the manufacturing rates was constructed to explore the learning issues. This model was highly visual and flexible, and, as a result, could be used directly with members of the client organization. By reflecting the ramifications of a set of assumptions back to the client in real time, rapid progress could be made. The clients quickly came to grips with paradoxes in their beliefs and were able to resolve these paradoxes with the help of the analyst and the spreadsheet model. Again, the SODA model was used to capture the details of this enhanced understanding [see cycle C, figure 1].

A recurrent theme throughout the entire modelling process was the fact that the team were faced with apparently inconsistent data. The views of corporate managers often differed from plant managers and verbal reports seemed to contradict much of the hard data available. The SODA methodology was invaluable in this case as it allowed the aggregation and management of a number of conflicting viewpoints. On receiving new information, it was possible to incorporate it in the SODA model and re-evaluate the validity of the viewpoints that had been transferred into the model. This facility was especially important as the System Dynamics model was only capable of supporting one opinion at a time - sections of the model would occasionally undergo a paradigm shift in the light of new evidence.

After the design process stage of the System Dynamics model had been completed, the model was extended to include recruitment, "methods" work and manufacturing. On experimenting with the model, a number of *categories* of problems were identified -

- The model did not show the required level of detail although it was already large by most standards
- Parts of the model did not perform as the real-life system had performed.
- Some of the understandings of the clients were shown to be illogical

The first point occurred as new theories arose as to the causes of delay and disruption. When experiencing difficulties in matching the existing knowledge to the quantitative data acquired, discussion with various members of the client organization often yielded new information relevant to the claim. The model then would be updated with this finer detail so that its effect could be gauged. For example, when struggling to understand the implications of the cross impact matrix (showing the interfaces between one system and another) upon the feedback loops, additional detail was required in order to understand how a change made to one system impacted upon various other related systems and what the resultant ramifications were. This additional detail was then used to extend the Graphics COPE model as well as refine the SD model.

As stated previously, the goal of the project was to build a forensic model and, as a result, the output of the model was compared against the parameters of the actual project. This test was to show that the basic model was valid - a pre-requisite to anyone having confidence in the results when the model was altered to demonstrate the behaviour of the system under alternative, *hypothetical* conditions. However, it is unreasonable to expect that a simulation model will ever match reality exactly - if it did, it would be as complex as the reality it was modelling! This gave rise to the second category mentioned. Nevertheless, this model had to be built in such a way that it could respond to a large number of possible scenarios for agreed liability in court - for example, only some of the "preferential engineering" might be accepted by the Court. This requirement puts an enormous strain on the degree of detail to be included in the final SD model.

In essence, the goal of building a forensic model was the goal of building a requisite model (Phillips 1984). The System Dynamics model was expected to *demonstrate the same general patterns of behaviour* as the real system, and the model had only to be complex enough to meet this objective. For example, one of the reference patterns available was the recruitment level of freelance designers during the course of the project. It was felt that the output of the model (for this variable) should match the real data in the following aspects -

- The total freelance designers employed over the course of the project should be similar.
- The maximum, and minimum, number of freelance designers contracted during the project should be similar.
- The contracted freelance designers should begin to increase, and tail-off, at roughly similar dates.

The validity of the 'real-life' data used to evaluate the model was often called into question. This data merely reflects one person's interpretation of reality for a particular variable. For example, in attempting to determine the number of hours spent manufacturing the product, apparently conflicting sets of data were presented to the team, and, for each set of data presented, numerous interpretations were offered by members of the client organization! - multiple perspectives on so called objective data is always important for good O.R. Fortunately, this issue of alternative interpretations could be managed through examining them for emergent characteristics (those that re-occurred) and also taking into account the ability in legal cases to exploit a concept termed 'best evidence'. In layman's terms, this means that the plaintiff need only convince the judge that the data given is superior (or at least equal) in quality to any other data which could be provided. Therefore, the members of the team might leave the lawyers to establish a 'working reality'.

Before the initial model had been constructed, the team had certain expectations about the causes of the delay and disruption (gleaned from the clients). When the model was explored, it contradicted some of the detail supporting these beliefs. This would immediately prompt suspicion in the structure of the model (which was often well founded!), but occasionally, deeper investigation of the System Dynamics model would reveal errors in the client's logic. The insights gained in these cases were so compelling that they represented times that client's altered their view of the problem. As an example, the client group had originally thought that the delays in the approval of designs would make a good basis for a case, but the model demonstrated that approval delays, considered in isolation, made a relatively weak case - only when they were examined in combination with other elements (such as increased preferential engineering) did they have a significant effect.

Triangulating the Alternative Models

After demonstrating the validity of the "base" model (i.e. the model simulating events as they actually happened), the model was run with the exogenous parameters set to emulate other *possible* scenarios - e.g. what would have happened had there not been any preferential engineering. As there was obviously no data available to check the validity of *these* explorations, alternative modelling techniques were exploited in an attempt to triangulate the results (Eden and Huxham 1993).

Insights gained from this project

Using Soft and Hard techniques

The team realised early on in a project of this nature that there was a likelihood that the client's views might be in conflict with one another. Through developing a sustainable and representative SD model which would provide the basis for a delay and disruption claim, the model itself would be relatively opaque. This is as a result of two characteristics of the model. The first was the size of the SD model. Due to the complexity of the Mega Project, incorporating an extensive number of variables was necessary placing the resultant model in the region of 300 variables. Navigating through this model was to prove very difficult especially to those not familiar with the project - in this case a judge not familiar in any way with computer simulation modelling. The second characteristic was one determined by the software package used to build the System Dynamics model. "Stella" models begin to look extremely untidy unless the labels attached to the elements of the model are kept short. This brevity resulted in some obscure naming conventions which occasionally confused even the members of the team. Using the Graphics COPE model it was possible to illustrate the meaning and context of any of the variables if required.

Furthermore, as the Mega Project involved State of the Art technology and was itself complex, understanding the different aspects, and dynamics, to an extent at which they could be modelled, had taken the research team a considerable amount of time - would a judge with no experience in System Dynamics modelling be able to comprehend and feel confident in the model? One of the difficulties in building SD models is that they, as with all forms of simulation, are simplifications of reality - a representation of the problem - and as such, would the judge be able to relate the SD model to the Mega Project?. Through using a combination of both System Dynamics and the COPE model, it was possible to provide a transparent medium, the COPE model, which directly mapped onto the System Dynamics model, which in turn provided the quantified claim.

This transparency also proved valuable not only when considering the impact of a judicial system on the claim but also during the research project itself - the act of building the SD model. Through being able to relate the SD model to the influence model and COPE model, it ensured that the team were able to work together with an increased likelihood that they shared a common understanding. This was achieved through consulting the COPE model whenever a question about the structure emerged (how did one variable relate to another?) or when the data provided for the System Dynamics model highlighted an apparent inconsistency in the current information. As such, the COPE model could be returned to and frequently acted as a starting point from which further discussion, if necessary, could take place.

As discussed in previous sections, the System Dynamics model was supported by a number of auxiliary models, even more opaque than the System Dynamics model itself! These models were also documented by the COPE map, and this proved to be an invaluable explanatory aid - for both the clients and the team.

This was also the case for the client team, who were constantly involved during the research project. Their involvement was important in order to continue to validate the changing COPE model and associated SD model, but also in providing help in resolving any contradictions or questions that had emerged. The COPE model not only provided them with an instant picture of the existing knowledge, which speeded up the process of discussion, but also acted as a continual guide to the SD model and its components.

Keeping a record

The continual updating of the COPE model also provided a sense of history. This was important as a rich, well documented source of the project's progress could prove invaluable when defending the method used. Therefore, the model acted as a decision support system, in a manner not dissimilar to a standard use of the model after the SODA methodology had been carried out (Ackermann et al 1992). This use of a DSS not only related to the progress and decision making of the project, but also to navigation of the SD model itself. As mentioned earlier, the System Dynamics model was one of the biggest built and this, therefore, led to difficulties in understanding how particular variables linked together.

Another aspect of the project which made the COPE model invaluable was the aforementioned amount of inconsistent information encountered in the investigation. Old theories were constantly being over-turned by new evaluations of the data and further interviews with managers and, as a result, work had to be back-tracked to incorporate new assumptions. If it had not been for the richness of the data contained in the SODA model, whole sections of work would have had to be discarded and redone. However, the SODA model enabled the research team to determine the ramifications of the new data fairly precisely and, therefore, utilize the parts of a previous analysis that were not altered by the new information.

Finally, the resultant model provided the client with a rich picture of the project, which could be a powerful tool when considering other complex or 'State of the Art' projects. Through reflecting on the detail, obstacles and dangers could be identified and planned for in any subsequent tenders for contract. Many of the areas covered by the delay and disruption claim has challenged the thinking of the client group and the model acts as a useful reminder. Thus while organisational learning was not an objective of the project, it did occur as an important secondary outcome.

Mixing methods means richer data

By using a 'mixed methods' approach in a decision making process, different techniques can be applied at the points where they are most appropriate. The results produced by the different methods can inform and enrich one another, providing better models than the individual techniques could elicit on their own. Models generated in this way are also subjected to a greater degree of validation - each model provides a check on the others.

One of the advantages quoted for the cognitive mapping approach is that it does not restrict decision makers to operating within a certain rigid framework, but rather allows decision makers to explore the problem in a flexible and transparent manner. This is contrary to more formal modelling schemes which tend to push the decision group in pre-defined, possibly unhelpful, directions. However, there is a real danger that the more flexible approaches enable difficult and complex issues to be stated in a vague, ill-defined manner which effectively hides the problems that the process is attempting to uncover. This danger may be overcome when working with a group which challenges some of the assertions posed and examines the linkages in detail - as was the case with the project.

Formal modelling schemes may impose a structure on the user's thinking, forcing them to address issues that would not normally have occurred to them. As such they may help them to increase their creativity, within given constraints. However, this increase in creativity is limited and the reasoning processes used to arrive at the new insights is lost. Using both formal modelling schemes and those more open, a greater degree of flexibility, transparency and creativity of thinking may be encountered. In addition to this, the use of both qualitative and quantitative data may also result not only in new insights into the problem area and therefore more creativity but also add to the degree of validation gained through the triangulating the results of different forms of data.

When the team began to build the System Dynamics model, the fairly rigorous specification required by the methodology uncovered gaps in the SODA model which had to be rectified. By the time the System Dynamics model was complete, the dialectic produced between the two models throughout the development period meant that the team members and client group had greater confidence in both of the models. Therefore, the rigorous nature of many modelling schemes, often cited as a disadvantage of these approaches, is extremely beneficial - provided the weaknesses and strengths of these schemes are fully appreciated.

Conclusions

As a result of cycling between the different representations benefits can be gained that cannot be attained by either approval on its own or by the representation being developed without continous interaction. This process ensures that data is continually scrutinised, structures examined from a number of perspectives and insights gained from those familiar with the 'other' method of working asking apparently "stupid" BUT revealing questions thus challenging existing practices and assumptions. For example, a member of the research team who was not familiar with the quantitative modelling techniques being used to model 'learning', was as a result of this apparent ignorance able to ask a question which changed the assumptions currently held and managed to break what was appearing to be a deadlock.

This paper is primarily concerned with discussing the issues involved in linking SODA with System Dynamics. However, this is only one example of how soft and hard methods can be used to complement one another.

One particular research direction of this nature uses the SODA methodology to develop and elaborate a framework for MCDA. Each individual member of the client group then supplies criteria weights and scores (electronically), and the differences of opinion present within the group are collected, summarized and reflected back to the group. This creates a dialectic which prompts discussion around the area under analysis. The comments generated during this discussion are captured using the SODA model - the clients extending their previous model and understanding. Usually, this leads to re-submission of new weights and scores (with increased agreement within the members of the group) or, possibly, a re-definition of the MCA structure.

It seems highly likely that many other soft OR methodologies could benefit from the synergy created by a 'mixed methods' approach. For example, some initial ground work has been performed in attempting to join Metagame analysis with MCA techniques

Finally, it is believed that through working and developing new methodologies weaving together Soft and Hard techniques both researchers and decision makers stand to gain. For the researcher this comes from learning new techniques rather than working solely on either hard or soft OR areas, from enhancing the use of OR to meet the needs of mixed methods and finally gaining further robustness for the model's outputs through the additional ability to triangulate data. The client also benefits, not only from methods/techniques being developed to help support his decision making in these areas but also from the increased creativity gained through mixing methods, the enhanced understanding of processes and a facility to provide not only transparent and understandable outcomes but also quantifiable outputs which relate to them.

Postscript: This paper reports on a project directed by Colin Eden and involving all of the authors in all aspects of the project. The project took place over 15 months and was aimed at supporting litigation in relation to "disruption and delay (D&D)". The claim was ultimately settled 'out of court' and the clients were very clear that the overall "management science" modelling approach to calculating alternative scenarios for the costs of the D&D played a significant and persuasive role in negotiating what they regarded as a satisfactory settlement.

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