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Social network analysis: using a quantitative tool within an interpretative context to explore the management of construction crises

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Abstract There is growing dissatisfaction with the static, reductionist, socially insensitive and unimaginative methods used in construction management research. The present paper challenges the emerging view that methods are strictly associated with philosophies, and in particular, that quantitative methods are at odds with interpretative aspirations. It does so by providing a practical example of social network analysis, a quantitative method which is sympathetic to these aspirations. The example is set within a crisis management context, and illustrates the dangers of using qualitative or quantitative methods in isolation. The present paper concludes by questioning the association of quantitative methods with causality and the production of universal models, and argues that both quantitative and qualitative methods have a role to play in *understanding* the complexity of people's changing social roles, positions and behaviours within construction organizations.

Keywords methodology, social networks, graphs, communication, behaviour, crisis management

INTRODUCTION

Rosenthal & Kouzmin (1993) argued that crises provide unique laboratories within which to study the sociological and behavioural complexities of management. During a crisis, the coping capabilities of an organization are tested to the limit and power configurations, differing interests and values, bargaining, and decision-making processes are highlighted by being sharply focused upon a single, well-defined issue. In essence, a crisis brings to the surface, and thereby, permits research into many social and behavioural phenomena which are of contemporary interest to construction management, and which would otherwise remain hidden and difficult to study. It follows that it also provides a valuable vehicle to discuss the methodological problems of studying such phenomena, problems which lie at the heart of the current methodological debate. This is the aim of the present paper, but more specifically, it is to use a case study as a vehicle to challenge the emerging view that quantitative methods are at odds with the social nature of construction management research and with attempts to achieve understanding rather than causal explanation (Rooke 1997).

SOCIAL NETWORK ANALYSIS (SNA): A QUANTITATIVE TOOL GROUNDED IN INTERPRETATIVE VALUES

The social network perspective is a method of conceptualizing organizations which is attracting growing interest in the social and behavioural sciences (Scott 1991; Wasserman & Faust 1994). It has its origins in sociology (Simmel 1950) and anthropology (Mitchell 1969; Boissevain 1974), and is based upon Mitchell's (1969; p. 2) widely accepted definition of a social network which is 'a specific set of linkages among a defined set of persons, with the additional property that the characteristics of these linkages as a whole may be used to interpret the social behaviour of the person's involved'. In essence, the social network perspective views an organization as a system of objects (e.g. people, groups and organizations) joined by a variety of relationships. It is particularly concerned with the structure of those relationships over time and seeks to identify both their causes and consequences (Tichy *et al.* 1979; Scott 1991). Relational structure is defined as the 'differentiated elements that can be recognised in the patterned communication flows in a system' and these can be described in numerical indices derived from mathematical algorithms (Rogers & Kincaid 1981; p. 146). In this sense, the social network perspective has much to offer the practitioner as well as the researcher since managers spend the majority of their time communicating and are likely to have an affinity with the concept of structure within information systems (Mintzberg 1973).

While the techniques of social network analysis are based in the algorithmic mathematics of graph theory, these are not concerned with causality, but with explanation and understanding. Furthermore, the principles which underpin the social network perspective are the same as those of symbolic interactionism which partially underpin the interpretative perspective which is increasingly being espoused in construction management research. These are: that people are interdependent rather than dependent; that people are embedded in complex and dynamic social networks which influence their behaviour; that relationships are as important as individuals in determining behaviour; and that change is a constant feature of social life and must accounted for in a research context (Wasserman & Faust 1994; p. 4; Strauss 1994; Stern 1994). In this sense, it would seem foolish to automatically discount quantitative techniques in the new atmosphere of social awareness which is developing in construction management research. Indeed, since the concepts of flow, dynamics, complexity and networks which are central to interpretativism are fundamentally mathematical in nature, it may be impossible to truly achieve interpretative aims without an element of quantification.

SOCIAL NETWORK ANALYSIS LANGUAGE

Social network analysis techniques are grounded in graph theory and an elementary grasp of graph theoretic language is essential to liberate the full meaning in SNA data. In the first instance, the term 'graph' is not used in its normal geometric sense in which it is a set of points in a plane whose coordinates (x and y) satisfy an equation in x and y. Rather, in graph theory, a graph is an abstract mathematical concept which is a series of 'points' (often called nodes or vertices) connected by a set of lines (often called edges, links or arcs). A pair of points is called a 'dyad' and a group of three a 'triad'. Graphs are considered as ordered arrangements of triads and dyads (Ore 1963; Wilson 1981). In sociological terms, points are used to represent people and lines, relationships. In a sociological sense, connecting lines in graphs have been used to illustrate many types of relationships such as friendship, family ties, power, information flow, resource flow, disease transfer (AIDS in particular) and drug transfer (in the detection of drug smuggling rings). In this sense, the concept of the graph is an extremely flexible one which can be adapted to a wide range of applications. Figure 1 illustrates a graph of five vertices and six edges.

Freeman (1979; p. 218) gives a concise explanation of the basic graph theoretic concepts which is as follows:

'When two points are directly connected by an edge they are *adjacent*. The number of other points to which a given point is adjacent is called the *degree* of that point. Given an un-ordered pair of points (p_i, p_j), each is *reachable* from the other if and only if there exists a *path* – a sequence of one or more edges (p_i, p_a), (p_a, p_b), (p_b, p_c) . . . (p_z, p_j), beginning at P_i, perhaps passing through intermediate points p_a, p_b, p_c, . . . p_z, and ending up at p_j. A path that begins and ends at the same point is called a *cycle*. When every point is reachable from any other point the graph is called *connected*. Associated with each path is a *distance* equal to the number of edges in that path. The shortest paths linking a given pair of points are called *geodesics*. Points falling on the only geodesic or on all geodesics linking a given pair of points are said to stand *between* the end points.'

The edges connecting two points can be given directionality by the use of an arrow which illustrates the *direction* of the relationship or flow between those points. Graphs with directed edges are called *digraphs*. The edges connecting points can also be given values which reflect the *intensity* or *strength* of that relationship. Such graphs are referred to as *valued graphs* or *networks*.

NUMERICAL REPRESENTATIONS OF GRAPHS

The interrelationships in a graph can be represented in matrix format and structurally analysed using graph theory. The matrix corresponding to a graph is known as its *adjacency matrix* and the adjacency matrix corresponding to the graph illustrated in Fig. 1 is illustrated in Fig. 2.

An adjacency matrix is a numerical representation of the relational data contained within a network, digraph or graph. Graphs result in symmetrical matrices since all relationships are assumed to be reciprocated, and either

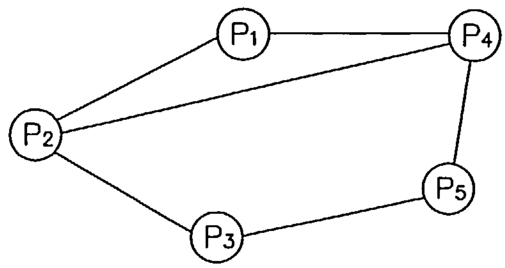

Figure 1 A simple graph.

	P1r	P2r	P3r	P4r	P5r
P1s	0	1	0	1	0
P2s	1	0	1	1	0
P3s	0	1	0	0	1
P4s	1	1	0	0	1
P5s	0	0	1	1	0

Figure 2 Adjacency matrix corresponding to the graph illustrated in Figure 1: (P*n*s) person *n* sending; and (P*n*r) person *n* receiving.

existing or not, digraphs result in non-symmetrical matrices and networks result in non-symmetrical, valued matrices.

SOCIAL NETWORK ANALYSIS SOFTWARE

The use of SNA requires the assistance of a computer and the most widely used programs commercially available are SOCK (Alba & Guttman 1972), NEGOPY (Richards 1976), STRUCTURE (Burt 1982), GRADAP (Stockman 1983) and UCINET (Borgatti *et al.* 1992). The incompatibility in programs in terms of their assumptions means that it is most sensible to use only one package, and this choice should be based upon the range of measures and assumptions which are most appropriate to the problem being investigated.

THE VALUE OF SOCIAL NETWORK ANALYSIS IN INVESTIGATING CONSTRUCTION CRISIS MANAGEMENT

Social network analysis was used as a tool to investigate the patterns of communication and behaviour which emerge within a traditionally procured project organization in response to a construction crisis. Leavitt (1951), Shaw (1954), McGregor (1960) and Mintzberg (1976) suggested that such patterns may influence the efficiency of response. A detailed account of the data collection strategy is provided in Loosemore (1996) and what is provided in the present paper is how the communication data were analysed using SNA.

The product of the data collection process and the basis for SNA was a communication network, as illustrated in Fig. 3. On the network, horizontal lines represent people involved in the crisis and vertical lines represent interactions between them. Different mediums are indicated by the nature of the line and a key is provided at the top of each network. Alphabetically ordered blocks run along the base of the network which, on average, contain three days of interactions. This was done to condense the data into manageable chunks, and thereby, aid analysis and the presentation of results. Data were collected in relation to the basic content of each communication shown on a network, and this was supplemented by data collected from retrospective semi-structured interviews with each network participant and non-participant observation of meetings during a crisis.

Before SNA, a communication network was converted to matrix format, during which letters and faxes were treated as a one-way flow of information, and telephone conversations and meetings as a two-way flow of information. However, conversion to matrix format was only carried out after different phases of efficiency within the crisis management process were identified by a content analysis of the network interactions. See Loosemore (1996) for a detailed account of this process. The whole network was then split along these lines and a distinct adjacency matrix produced for each phase. This was done because one of the objectives of the research was to draw associations between communication structure and efficiency. In analysing the adjacency matrices associated with each crisis, a programme known as UCINET Version 1.00 (Borgatti *et al.* 1992) was used. It was chosen in preference to other programs because it is designed for relatively small networks and the range of structural indexes produced were the most meaningful to the present research. The rationale underlying the choice of structural indexes is presented below.

RATIONALE UNDERLYING THE CHOICE OF STRUCTURAL DIMENSIONS INVESTIGATED

With such a wide range of structural indexes available in the SNA literature and from UCINET, those most relevant to this research had to be isolated. In the present research, a particular index was used only if there was evidence that it could be given a meaningful and useful interpretation in the context of the crisis management process. Two levels of communication structure were of interest, the first being the 'socio-centric' structure of a network as a whole and the second being the 'ego-centric' structures of the communication networks associated with each individual member.

Factions

A faction is a collection of people who communicate more frequently with each other than they do with others (Glover 1989). These cohesive subgroups are based

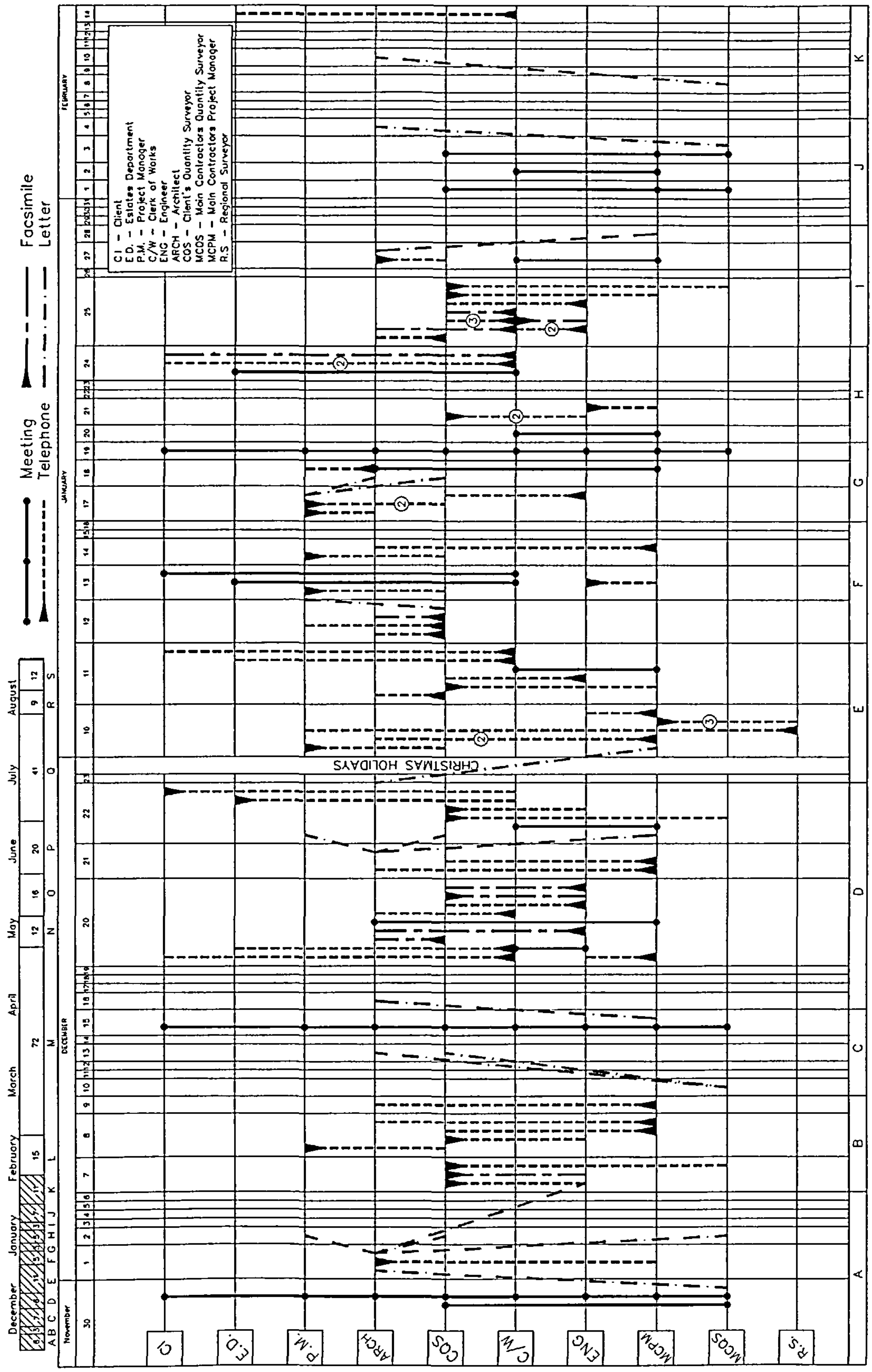

Figure 3 A typical communication network.

around people's informal social relations and have their own norms, values, orientations and subcultures (Weis & Jacobson 1955, Van de Ven & Ferry 1980). Many studies have seen the concept of the faction as central to explanations of social structure arguing that they perform important social functions by providing a source of identity and sense of belonging (Scott 1991). UCINET's output is presented in a grouped adjacency matrix where the number of factions (n) is set by the researcher. The value of this flexibility is that by setting increasing values of n, a hierarchy of factions can be identified. An example of a grouped adjacency matrix, where $n = 4$, is illustrated in Table 1.

Each individual in a reaction network is given an identification number, as specified in the key in Table 1. These identification numbers are listed outside the matrix along its x- and y-axes. Faction membership is indicated by the groups of numbers listed along these axes. For example, there are three factions in Table 1: (3, 4, 5), (6, 10, 9) and (2, 7, 1). Person (8) is not a member of any faction, and thus, is classed as an isolate. The numbers within the matrix's diagonal cells indicate the strength of ties within factions, and thus, the relative cohesion. For example, in Table 1, the strongest faction is (3, 4, 5), the second strongest is (2, 7, 1) and the weakest is (6, 10, 9). The numbers in other cells indicate the strength of ties between factions. For example, in Table 1, group (3, 4, 5) has only one weak tie with faction (2, 7, 1), but numerous and stronger ties with faction (6, 10, 9). UCINET also produces a sociocentric 'fit' index which ranges between one and zero and indicates the degree of factionalism in the whole network, a higher fit indicating lower factionalism.

Structural and regular equivalence

A pair of people in a network are structurally equivalent if they have exactly the same pattern of contacts. It has been argued that such people play the same role in a network and are interchangeable (Lorrain & White 1971; Burt 1976). However, the concept of structural equivalence merely considers similarities between people's patterns of interaction. It ignores the nature of people within those patterns which means that people can be highly structurally equivalent by having the same patterns of connections with different people. Both Borgatti & Everett (1989) and Scott (1991) argued that this does not mean that they are playing the same social role and advocate the concept of 'regular equivalence' which takes account of both the pattern and the nature of people within that pattern. Two people are regularly equivalent only if they are connected to the same people in the same way. In presenting regular equivalence data, UCINET uses a hierarchical clustering matrix, an example of which is shown in Table 2.

Each individual in a reaction network is given an identification number, as indicated by the key in Table 2, and these are listed in bold along the top of the hierarchical clustering matrix. The hierarchical clustering matrix groups people on the basis of their regular equivalence where an index of 100 indicates strict regular equivalence between two people and an index of zero denotes no regular equivalence. For example, in Table 2, the engineer (6) and the clerk of works (7) have identical personal communication networks, suggesting that they play the same role in the reaction process. The client's quantity surveyor (5) and the contractor's quantity surveyor (8) also have a very high regular equivalence of 96.935. In contrast, the client (1) and the contractor's project manager (9) only have an equivalence of 88.407. The client's (1) equivalence with the architect (4) is 42.168. A socio-centric measure of regular equivalence is produced by averaging the equivalences of all pairs of people in a network.

Table 1 A typical grouped adjacency matrix when $n = 4$; FIT = 0.782 (source: UCINET)*

	Receiving unit									
Sending unit	3	4	5	8	6	10	9	2	7	1
3	5	5	5			1				
4	4	5	4			2	3			
5	5	5	5	3	5		4		2	
8			3	5			2			
6			5		5		3			
10	1	2				5	3			
9		2	4	2	3	3	5		5	
2								5	3	
7		1	3		3		5	3	5	5
1							1		4	5

* Key: (1) client, (2) estates department; (3) project manager; (4) architect; (5) client's quantity surveyor; (6) engineer; (7) clerk of works; (8) contractor's quantity surveyor; (9) contractor's project manager, and (10) contractor's regional quantity surveyor.

Level	2	3	4	5	8	6	7	1	9	10
100.000						XX	XX			
96.936				XX	XX	XX	XX			
93.770	XX	XX	XX	XX	XX	XX	XX			
88.632	XX	XX	XX	XX	XX	XX	XX			
88.407	XX	XX	XX	XX	XX	XX	XX	XX	XX	
56.346	XX	XX	XX	XX	XX	XX	XX	XX	XX	
42.168	XX	XX	XX	XX	XX	XX	XX	XX	XX	
28.498	XX	XX	XX	XX	XX	XX	XX	XX	XX	
0.000	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX

* For key, see Table 1.

Table 2 Hierarchical clustering matrix (source: UCINET)*

UCINET produces a matrix showing these figures and an example is provided in Table 3.

Since the matrix is symmetrical about the diagonal, only half of it is needed to compute a socio-centric equivalence index. The socio-centric index is computed by averaging all individual indexes below the diagonal. This results in an index which can range between 0 and 100, and reflects the level of regular equivalence in the whole reaction network from which the data came. In the case of Table 3, the socio-centric index is 37.96.

Centrality

Mackenzie (1966; p. 17) defined socio-centric centrality as 'the degree to which information flows are centred on one or a few organizational units'. The location of these central points can be established by computing ego-centric indexes for each person in a network. Ego-centric centrality is defined by Mackenzie (1966; p. 17) as 'the degree to which information flows focus upon a target individual'.

There has been a proliferation of research which has confused the literature relating to centrality and Freeman (1979) is credited with clarifying it. He differentiated between *degree centrality, closeness centrality* and *betweenness centrality*.

Degree centrality

The simplest measure of ego-centric centrality is the 'degree' of a point, i.e. the extent to which a person is connected to its immediate environment or neighbours. However, it is important to distinguish between a person's 'in' and 'out' degree centrality. A person's in-degree and out-degree centralities represent the degree to which s/he is a receiver or sender of information from or to her/his neighbours, respectively. A person's in-degree is a good indication of her/his popularity in a network and its accessibility to information. A person's out-degree is an indication of her/his control over a network and of the dependence of the network upon it. A person with a high in-degree can be classified as a sink and one with a high out-degree, a source.

It is also possible to discuss degree centrality at a socio-centric level. The socio-centric in-degree index reflects the extent to which one or a few people are the focus of information supply in the network, and the out-degree index shows the extent to which information supply is controlled by one or a few people.

Closeness centrality

A person has a high closeness centrality if s/he lies at short 'distances' from every other point in a network. At

	1	2	3	4	5	6	7	8	9	10
1	100	0	44	37	35	74	74	46	88	50
2	0	100	0	0	0	0	0	0	0	0
3	44	0	100	94	90	22	22	90	62	21
4	37	0	94	100	89	16	16	88	55	20
5	35	0	90	89	100	16	16	97	54	17
6	74	0	22	16	16	100	100	22	48	0
7	74	0	22	16	16	100	100	22	48	0
8	46	0	90	88	97	22	22	100	64	23
9	88	0	62	55	54	48	48	64	100	48
10	50	0	21	20	17	0	0	23	48	100

* For key, see Table 1.

Table 3 Matrix showing regular equivalences between all pairs of people in a network (source: UCINET)* a socio-centric level, closeness centrality reflects the extent to which the whole network is close to one or a few people, i.e. tightly knit around one or a few points. Distance is defined as the number of intermediaries which two people have to go through to communicate. Freeman (1979) argued that the closeness of a point to all others is a reflection of its independence. A person who is close to many others finds it difficult to act independently without others knowing. However, conversely, they have the capacity to directly monitor and control more people, and to quickly disseminate decisions and ideas to a wider range of people.

Betweenness centrality

At an ego-centric level, the concept of 'betweenness' measures the extent to which a particular point lies between other points in a network, i.e. it reflects the extent to which a point plays the part of a gatekeeper between or coordinator of different groups. Freeman (1979) argued that people with high betweenness have the potential to control others by controlling and filtering the information flowing between them. They are powerful people, acting as the valves within a network, and occupy a critical position in maintaining free and open information flow. Cohn & Marriott (1958) pointed out that these people act as the glue that hold the parts of a system together and weaknesses at these critical points can lead to disintegration.

At a socio-centric level, betweenness centrality is a good indication of a network's vulnerability. This is because it measures the extent to which information flow within the network is channelled through a few people of high betweenness. The network is vulnerable because these people can manipulate information flow to serve their own interests.

A CASE STUDY TO ILLUSTRATE THE VALUE OF SOCIAL NETWORK ANALYSIS

This project was a leisure centre with a construction programme of 16 months and a project value of approximately £1.7 million. A crisis arose out of a complex series of events which were linked to building activities on an adjacent site. This was located in an elevated position behind a high retaining wall which formed a boundary between the two sites. This wall was at the top of a steep bank which was to be cut away to provide a level area for the new leisure centre. This involved excavating close to the base of the existing retaining wall and to support it, a new retaining wall had to be constructed below it. Construction had started on site and the designs for the new retaining wall had been fully completed well in advance. They were based upon the loadings of a factory which originally occupied the adjacent site. However, soon after the retaining wall designs had been completed, the factory burnt down. A new factory had been rapidly redesigned and was under construction. The crisis started when it was discovered that the design of the new retaining wall had not been changed to allow for the loadings of the new factory. This necessitated a complete redesign of the new retaining wall under extreme time pressure because the contractor had started on site and there was little flexibility in their programme. A communication network of the crisis management process was plotted (partially illustrated in Fig. 3) and a content analysis of the network interactions revealed three phases of efficiency during the crisis. A scaled illustration of these phases is illustrated in Fig. 4. In Fig. 4, the letters correspond to the blocks running along the base of the network and the figures represent the number of days in each block.

For analytical purposes, the communication network illustrated in Fig. 3 was split along these lines. This process resulted in separate communication networks which could be converted to matrix format for SNA purposes. The adjacency matrix and SNA data for each phase of crisis management efficiency are presented in Table 4 and form the basis of the following account.

Phase 1

From the content analysis, phase 1 was attributed an efficiency index of 48.4%, the maximum being 100% and the minimum being –100%. The Tabu factional data show a phase of relatively high fit (0.89). This is

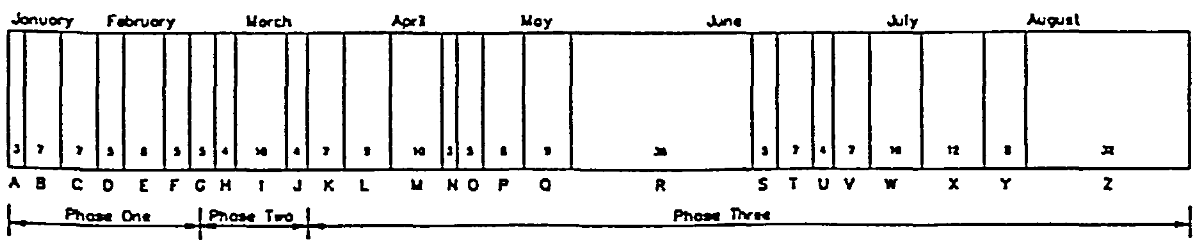

Figure 4 Phases of efficiency during the crisis management process.

Phase		Key	Degree Centrality Out (%)	Degree Centrality In (%)	Flow Betweenness Centrality (%)	Closeness Centrality (%)	Tabu Factional Data	Regular Equivalence Data
Phase One	1	Client	2.36	2.82	0.50	60.00		
	2	Architect	27.23	17.37	38.18	100.00		
	3	Client's Q.S.	7.04	8.45	8.41	85.71		
	4	Engineer	18.30	19.72	23.16	85.71		
	5	Clerk of Works	9.86	15.02	10.71	85.71		
	6	Contractor's Q.S.	15.02	16.43	17.67	85.71		
	7	Site Manager	20.19	20.19	28.04	100.00		
		Socio-Centric	15.11	6.89	23.43	35.62	Fit = 0.89	75.19
Phase Two	1	Client	2.56	2.56	0.00	37.50		
	2	Architect	7.68	12.82	3.33	42.86		
	3	Client's Q.S.	7.68	5.12	10.26	42.86		
	4	Engineer	28.23	28.23	16.00	46.15		
	5	Clerk of Works	12.82	10.24	18.75	46.15		
	6	Contractor's Q.S.	0.00	0.00	0.00	14.29		
	7	Site Manager	41.03	41.03	88.46	50.00		
		Socio-Centric	31.20	31.20	80.41	25.74	Fit = 0.73	39.76
Phase Three	1	Client	0.50	0.50	0.27	60.00		
	2	Architect	17.44	16.67	21.47	100.00		
	3	Client's Q.S.	13.08	13.85	18.98	85.71		
	4	Engineer	21.79	21.54	17.99	85.71		
	5	Clerk of Works	9.25	9.50	11.73	85.71		
	6	Contractor's Q.S.	12.05	12.05	14.96	85.71		
	7	Site Manager	25.89	25.89	29.18	100.00		
		Socio-Centric	13.54	13.54	14.95	35.62	Fit = 0.76	58.14

Phase One – Adjacency Matrix (Sending unit × Receiving unit)

Sending unit	1	2	3	4	5	6	7
1		4					1
2	5		7	15	11	13	7
3		4		3	3	2	3
4		12	3		6	5	13
5			3	6		4	8
6		10	2	5	4		11
7	1	7	3	13	8	11	

Phase One – Tabu Factional Data (Sending unit × Receiving unit)

Sending unit	4	2	6	7	3	1	5
4	15	12	5	13	3		6
2	15	15	13	7	7	5	11
6	5	10	15	11	2		4
7	13	7	11	15	3	1	8
3	3	4	2	3	15		3
1		4		1		15	
5	6		4	8	3		15

Phase One – Regular Equivalence Data

level	1	3	5	2	6	4	7
94.338	.	.	.	.	.	xx	xx
92.209	.	.	.	.	xx	xx	xx
89.803	.	.	.	xx	xx	xx	xx
89.668	xx	xx	.	xx	xx	xx	xx
82.806	xx	xx	xx	xx	xx	xx	xx
63.318	xx	xx	xx	xx	xx	xx	xx

Phase Two – Adjacency Matrix (Sending unit × Receiving unit)

Sending unit	1	2	3	4	5	6	7
1							1
2							3
3			1	1	1		1
4		1			1		9
5		1	1	1			2
6							
7	1	3	1	9	2		

Phase Two – Tabu Factional Data (Sending unit × Receiving unit)

Sending unit	2	6	5	3	4	7	1
2	9					3	
6		9					
5	1		9	1	1	2	
3			1	9	1	1	
4	1		1		9	9	
7	3		2	1	9	9	1
1						1	9

Phase Two – Regular Equivalence Data

level	6	1	3	2	5	4	7
85.865	.	xx	xx	.	.	.	.
84.861	.	xx	xx	.	.	xx	xx
76.619	.	xx	xx	xx	xx	xx	xx
68.647	.	xx	xx	xx	xx	xx	xx
44.739	.	xx	xx	xx	xx	xx	xx
0	xx	xx	xx	xx	xx	xx	xx

Phase Three – Adjacency Matrix (Sending unit × Receiving unit)

Sending unit	1	2	3	4	5	6	7
1		1					1
2	1		16	16	7	8	20
3		13		9	8	10	11
4		16	9		7	8	45
5		6	8	7		6	9
6		9	10	7	6		15
7	1	20	11	45	9	15	

Phase Three – Tabu Factional Data (Sending unit × Receiving unit)

Sending unit	5	6	4	7	1	2	3
5	45	6	7	9		6	8
6	6	45	7	15		9	10
4	7	8	45	45		16	9
7	9	15	45	45	1	20	11
1				1	45	1	
2	7	8	16	20	1	45	16
3	8	10	9	11		13	45

Phase Three – Regular Equivalence Data

level	1	2	5	3	6	4	7
93.544	.	.	.	.	.	xx	xx
90.583	.	.	.	xx	xx	xx	xx
86.187	.	.	xx	xx	xx	xx	xx
82.521	.	xx	xx	xx	xx	xx	xx
69.339	.	xx	xx	xx	xx	xx	xx
9.284	xx	xx	xx	xx	xx	xx	xx

Table 4 Adjacency matrices and SNA data relating to Fig. 3

reflected in the grouped adjacency matrix by the relative absence of empty cells which indicates widespread communication. It supports the positive image of this phase which emerged from the content analysis. There is one faction which dominates the reaction process which consists of the architect, engineer, contractor's quantity surveyor and site manager (4, 2, 6, 7). However, when the value of n is increased to 5, this faction splits into two further factions (4, 2) and (6, 7), which highlights that, while there was good communication across the consultant/contractor divide, a divide was certainly present. When the value of n increases to 6, the faction (6, 7) between the contractor's quantity surveyor and site manager splits, leaving (4, 2) as the only remaining faction. This indicates that the architect and engineer (4, 2) had the strongest ties during this phase of the reaction process, and that the problem was primarily one of design. It also indicates that they recognized their interdependency and took collective responsibility for the problem's resolution. However, the strong connections between their faction and other project members indicates that they did not isolate themselves and recognized their responsibility to others. This was particularly so in relation to the contractor. However, the limitation of SNA is that it cannot show that this information was largely superficial and was not sufficient to satisfy the contractor's needs. The qualitative analysis indicated that it was this inability to satisfy the contractor's information needs which resulted in a decision to temporarily stop the site.

The degree centrality data indicate a relatively equal distribution of in-degree and out-degree centralities, which accounts for the low socio-centric centrality index. The architect and site manager had the highest out-degree centrality, indicating the leading role which they played in driving this phase forward. However, the content analysis indicated that they played quite different roles. It indicated that the architect's centrality was motivated by a desire to coordinate a response. In contrast, the motive behind the site manager's communications was to attract attention to his own dilemma on site at a time when the consultants could have become inwardly orientated and focused upon their own problems. In this sense, his outward orientation was an attempt to place himself in a central position and his high in-degree centrality reflects his success in this regard. The engineer also had a relatively high in-degree centrality, which shows that he was seen by others as important to the reaction process. Indeed, his similar out-degree centrality indicates that he was able to respond to people's requests for information in a positive manner. The low in-degree centrality of the client's quantity surveyor reflects the low priority accorded to financial issues by others in light of the immediate need to keep the project progressing.

The closeness centrality data show a relatively high level of ego-centric closeness, a positive sign indicating that those drawn into the reaction process were tightly knit in their widespread and direct contacts. It is the widespread nature of this closeness which accounts for the low socio-centric index. Within this structure, it is probable that communication would have been effective with minimal distortion and that there would have been a widespread mutual understanding of the problem. The architect and site manager have the highest level of closeness, indicating that they were the first point of contact for most people. Clearly, they were central to this phase of the reaction process.

The betweenness data show the architect, engineer and site manager having the greatest control over information flow, although the low socio-centric index indicates that their level of control was limited. This is a positive sign since the network was clearly not vulnerable to the attitudes and perceptions of a few people, a potential problem in the early phases of a crisis when people are likely to be at their most defensive.

Finally, the regular equivalence data show a relatively high level of socio-centric equivalence. This indicates that there would have been a good common understanding of the problem between all involved because of their access to similar information. The data indicate that the engineer (4) and the site manager (7) were the most structurally equivalent. The reason is evident from the Tabu factional data, which illustrate that their contacts were primarily with each other and also with the architect who appeared to act as their main point of contact with the rest of the project team. The architect (2) had a lower level of equivalence, although to place this in context, it is still a relatively high index at 89.803. This indicates that he played a slightly different role to the engineer, one which the Tabu factional data suggest had less of an orientation towards the contractor, but a greater one towards the client, his fellow consultants and those outside the immediate project boundary, i.e. the architect appeared to insulate the engineer from external political concerns enabling him to progress unhindered with redesign.

Phase 2

Phase 2 had an efficiency index of 0%, a reduction in efficiency compared to phase 1. The Tabu factional data show a lower level of fit than in phase one (0.73), and while the factional patterns are similar, there is a far lower level of widespread communication. There were three factions (2, 6), (5, 3) and (4, 7), but at successive values of n, they all disintegrated except for (4, 7). This indicates that the site manager and engineer formed a strong faction, and dominated this phase of the reaction process compared to the engineer and architect in phase 1. The most dramatic change is the peripherality of the architect and the contractor's quantity surveyor, who played important leading roles in phase 1. In contrast to phase 1, the engineer became the main supplier of information to the contractor. However, the content analysis indicated that this was a responsibility which the engineer found difficult to cope with. As a result, he increasingly fell into a reactive mode of management as information demand ran ahead of its supply.

The degree and closeness centrality data show the reaction process becoming increasingly driven by the site manager. This is a pattern which reinforces the emerging picture from the content analysis of a site manager who increasingly takes a proactive stance in generating his own information supply. It also reinforces the engineer's increasing reliance on the site manager's abilities to detect problems in the information supplied. In complete contrast, the client's quantity surveyor becomes increasingly isolated as a target for communication. The content analysis indicated that this may have been a deliberate exclusion by the architect and engineer because, in trying to meet the contractor's information needs, they became increasingly complacent in issuing verbal instructions on site. This is something which the client's quantity surveyor would have curtailed in order to maintain cost control.

The betweenness data show the site manager as a highly important channel for information flow, something which made the whole reaction process vulnerable to his vested interests and personal abilities. However, the site manager was extremely capable and experienced, and had interests which were coincident with the engineer's concerns, i.e. to minimize delays. In this respect, his high betweenness had a positive influence upon the reaction process. One aspect of betweenness that emerged within the content analysis, but not in this SNA, was the tactic of the engineer and architect in placing themselves *between* the contractor and the client's quantity surveyor. As discussed above, the content analysis suggested that this might have been a deliberate strategy to hide the problem, and thereby, maintain their flexibility in the face of an increasingly out of control situation on site. The reason for its non-emergence in the SNA is that they were so effective in this tactic that they virtually prevented any information flow to the client's quantity surveyor. In this sense, the engineer and architect do not appear *between* anyone in the data, although the reaction process was highly vulnerable to their interests. This demonstrates the limitations of SNA and the need to use it in combination with complementary qualitative methods.

The regular equivalence data show the client (1) and client's quantity surveyor (3) as structurally equivalent, an indication of the inappropriate exclusion of the client's quantity surveyor from the reaction process. In light of this crisis' significant impact upon costs, it is reasonable to have expected a far greater level of involvement from the client's quantity surveyor than from the client. The site manager (7) and engineer (4) are still highly equivalent, but not as much as in phase 1. The content analysis indicated that this reduction in equivalence was pre-empted by the site manager, who, faced with an increasingly unreliable engineer, started to look beyond him for information. Indeed, the Tabu factional data show that the architect and the clerk of works were the main sources of relief. Furthermore, the Tabu data also show that the engineer was being bypassed in the opposite direction by the client and client's quantity surveyor in their attempt to discover what had been happening on site.

Phase 3

Phase 3 had an efficiency index of –7.42%, a further fall in efficiency compared to phases 1 and 2. The Tabu factional data indicate that the overall level of fit marginally increases from phase 2 (0.76). This positive sign seems to contradict the content analysis which pointed to a deterioration in relations and reduction in efficiency compared to phase 2. The explanation is that, although frequent, the communications were not positive. Once again, this vividly highlights the limitation of SNA if used in isolation from complementary qualitative methods. However, the detailed data in the grouped adjacency matrix do give some indication of the negativity underlying this phase. For example, despite the wide connectedness, the site manager and engineer still remain the strongest subgroup (4, 7). This reflects the continuing problems on site, but more importantly, a lack of focus amongst other project participants. However, what is most discouraging is the separation of the two quantity surveyor's (6 and 3) because the serious financial problems which characterized this phase (as indicated by the content analysis) should have drawn the quantity surveyors closer together. Their relative distance reflects the reluctance of the client's quantity surveyor to discuss the problem in depth. This was because of his exclusion during phases 1 and 2 by his fellow consultants (engineer and architect), which left him with a lack of information and in a disadvantaged negotiating position. Indeed, the divide between the contractor and the consultants seemed particularly strong because the architect and client's quantity surveyor formed a very strong faction (2, 3), something which would have reinforced the exclusion of the contractor's quantity surveyor. The content analysis indicated that this faction emerged because of the client's quantity surveyor's attempts to clarify what instructions had been issued on site so that he could reduce his disadvantaged negotiating position with the contractor.

In the degree centrality data, the site manager and engineer continue to dominate communications in terms of sending and receiving. This reflects the continuation of their close working relationship, a relationship which the content analysis indicated was plagued by communication problems. In contrast to phase 2, the architect and the client's quantity surveyor are far more involved, the Tabu factional data showing them communication mostly with each other.

The closeness data are identical to the first phase indicating the re-emergence of the architect's and site manager's importance as the main leading forces during this phase. On first inspection, the high closeness is a positive sign because it reflects a more integrated communication structure. However, the content analysis suggested that this was an increasingly negative phase, characterized by acrimonious interactions and negative momentum.

The flow betweenness data show a dramatic fall in the site manager's betweenness, but the maintenance of his position as the person with the greatest control over information flow. The socio-centric index is at it lowest for the three phases, which indicates that the reaction process was at its least vulnerable to the attitudes and relationships of a few people. The content analysis suggested that this fall in vulnerability was brought about by the contractor bypassing the previously impermeable boundary of the architect and engineer by making direct contact with the client's quantity surveyor to resolve their claim. However, once again, the data are deceiving, since these do not highlight the betweenness of the client's quantity surveyor, a betweenness which the content analysis indicated damaged the reaction process. The content analysis indicated that the client's quantity surveyor utilized his position between the client and contractor to his advantage by blocking communication of the problem to the client. In this sense, the concept of betweenness is of limited use in detecting vulnerability since the most effective exploitation of a high betweenness position means that little information will get through and that, in this sense, the person will not appear to be between anyone. Again, this highlights the importance of using qualitative data to complement SNA.

The regular equivalence data show the site manager (7) and the engineer (4) increasing their structural equivalence, and indicate that they would have had a common understanding of the problems on site. The client's quantity surveyor (3) and the contractor's quantity surveyor (6) also emerge as structurally equivalent. While they may have had access to the same information, the content analysis indicated that the communication between them was of poor quality. This was because of the negotiating position of the client's quantity surveyor, which had been compromised by his earlier lack of structural equivalence. This made him highly defensive towards the contractor.

CONCLUSION

The aim of the present paper was to illustrate the methodological value of quantitative methods within an interpretative context, and thereby, to challenge the potentially dangerous association of methods with philosophies. A case study of a construction crisis, which used the quantitative method of SNA in its investigations, illustrated that the association of quantitative methods with causality and the production of universal models is simplistic. It is clear that quantitative methods can be used to complement qualitative methods in enhancing understanding and providing explanations of peoples changing social roles, positions and behaviours during a construction project. The case study also showed the dangers of using quantitative or qualitative methods in isolation, and that diversity in methods is essential in producing reliable accounts of social reality.

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