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COLLABORATIVE TRUST NETWORKS IN ENGINEERING DESIGN ADAPTATION

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ABSTRACT

Within organisations, decision makers have to rely on collaboration with other actors from different disciplines working within highly dynamic and distributed associated networks of varying size and scales. This paper develops control and influence networks within Design Structure Matrices (DSM); applying the Change Prediction Method (CPM) tool. It posits the idea of the 'Networks-in-Being' with varying individual and collective characteristics. [Social] networks are considered to facilitate information exchange between actors. At the same time, networks failing to provide trusted-information can hinder effective communication and collaboration. Different combinations of trust may therefore improve or impair the likelihood of information flow, transfer and subsequent action (cause and effect). This paper investigates how analysing different types of network-structures-in-being can support collaboration and decision-making by using the change prediction method as a way of scoping information propagation between actors within a network.

Keywords: Design, collaboration, trust, system identification, ecology, instrument, adaptation, dynamic social network, design communication.

1 INTRODUCTION

Latour [1] views humans 'collaborating amongst themselves and autonomous systems to make decisions' as central to the making of efficient and effective decisions in networked environments. This rests not only on the experience of the decision maker but also on the availability of reliable information at the point of making the decision, see Webster [2]. Such decision makers may be individuals or distributed groups. Technological advances within networked capabilities have allowed collaborators to share much greater amounts of information across interconnected personnel, platforms and sensors [3]. Being able to understand the collaborative behaviour of such networks and identify where collaboration breakdowns are likely to occur will enable more robust networks to be developed and mitigate the potential for failure. This paper outlines a method for doing this. It applies engineering change management prediction to undertake network analysis with regard to information transfer in terms of trust and control. The paper is organised as follows: Section 2 describes system identification; Section 3 introduces collaboration as a key concept and highlights its potential for breakdown and failure across complex social networks. Section 4 introduces a more dynamic means of network analysis as a way to understand and model collaboration in networks. In Section 5, change analysis is described as a way to instrument information propagation in social networks as applied within a model of a light engineering company. Section 6 concludes this paper with a discussion on future work.

2 MODELLING, METHOD AND SYSTEM IDENTIFICATION

The Design Research Methodology (DRM) proposed by Blessing et al. [4; 5] and the Spiral Model proposed by Eckert et al. [6], see Figure 1, were applied to model different organisations. This approach required questions to be identified; matrices established and models tested and verified until the characteristics and types of performance being seen matched what was being experienced. For example, scaling, clusters and coupling matched expected departmental designs including alignment, position and hierarchy. The aim of the process was to: 1) conceptualise the question; 2) develop the model; 3) agree an ethnological language; 4) develop the ecology / human terrain (where ecology refers to the web or network of relations among organisms at different scales of organisation); 4) instrument the model (by which we mean calibrate the model so that it reflects what we are seeing); 5) verify model fitness by testing against other criteria / questions and finally; 6) adapt and / or reflect.

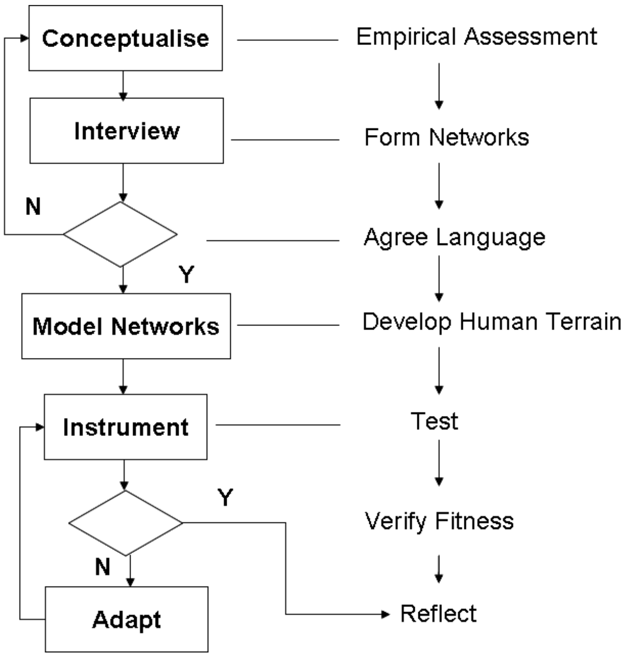

Figure 1: A methodology for dynamic network analysis adapted from Eckert et al. [6]

2.1 System Identification and Modelling Implications

Building on work by Ljung [7], Ma suggests that: 'System Identification covers a very wide range of techniques for obtaining a system model from its input-output data [8]'. Applying System Identification and building on work by Emery [9], Ropohl [10] considered that one of the major 'organisational relationships' and hence ecology to be understood was between the social and the technical, where '**Socio-Technical systems**…stress the reciprocal interrelationship between humans and machines and to foster the programme[1] of shaping both the technical and the social conditions of work, in such a way that efficiency and humanity would not contradict each other any longer'.

Ropohl [10], Mumford [11], Zairi [12] and Dorfman [13], recognised the reciprocal ecology existing between the technological and the social as emphasised by 'the enormous transformation process from the industrial era to the information era due to the vast development in technologies [14]', from which we posit that **Techno-Socio systems** seek to regulate the relationship between technical "processes" and humans by "optimising performance" and applying protocols for repeatable "failsafe" procedures in governed-control-spaces so that "method" and "risk" do not [legally] contradict each other.

More recently, Harmaakorpi [3] noted a 'shift from the industrial era to the information era [based on an] emerging techno-socio-economic paradigm ', from which a third ecology may be suggested **Info-Techno-Socio** systems seek to program[2] the relationship between technical "processes" and humans by "digitising performance" and coding for repeatable "risk free" procedures in computer-control-[cyber]-spaces so that "data" and "communication" do not [temporally] contradict each other.

Each of these system ecologies interact with each other individually and collectively and each has a different signature that may be considered to consist of connected and co-dependent variables:

1. A **Socio-Techno Influence System**, in which the 'ability to comprehend, explain and understand by logic[3]' and so 'Influence' (through shared awareness [15]) the conditions of work are the key variables, after [16],[17] and [18];
2. A **Techno-Socio Control System** in which 'System Likelihood[4]'and 'Control' are the key variables, after [13] and [14].
3. A **Info-Techno-Socio Computer System** in which 'System Information[5]'and 'Communication' are the key variables, after [3], [14] [19] and [20].

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[1] As opposed to program. This is an essential distinction in meaning and between UK and US English.
[2] As opposed to programme.
[3] Sometimes described as Intelligibility, taken to be a function of comprehension, 'explainable and understandable by logic'.
[4] As a means of valuing the combination of possibility and probability – taken to be a function of speculation, estimation and fuzzy logic within the parameters of statistical inference.
[5] As a means of probabilistically valuing system flows of data and information.

Design within any organisation cannot be considered in isolation to the other concurrent and parallel activities going on simultaneously. For example, those involved running the accounts may be applying a Info-Techno-Socio system; whereas those involved in production are more likely to be applying a Techno-Socio system and those doing design, research and sales a Socio-Techno system. Each system connects and interacts to influence the decisions as to what can or cannot be adapted, designed, built or sold. Failure of any one part will impact on the whole – for example product design and development costs that are insufficiently funded.

3 THE IMPACT OF NETWORKS ON COLLABORATION

As networks have increased in size and complication, so too did the potential for unforeseen emergent properties of the network to impact negatively on collaborative effectiveness; leading to collaboration breakdowns and sub-optimal decision-making [21]. This leads to a need to understand the "ecology" of the network. Understanding the ecology should enable more robust networks to be developed and mitigate the potential for failure. Actor-networks considered by Latour are not new, (for example [22]) but the early work has developed rapidly in recent years to deal with much more complex networks in the modern age [23]. Keller et al [25] took forward the concept of networks to consider them as 'being' in the sense of Badiou: 'What happens in art, in science, in true (rare) politics, and in love (if it exists), is the coming to light of an indiscernible of the times, which, as such, is neither a known or recognized multiple, nor an ineffable singularity, but that which detains in its multiple-being all the common traits of the collective in question: in this sense, it is the truth of the collective's being [24].' From Badiou and Admiral Lord Torrington's (1690) concept for a *Fleet in Being*, the concept for Networks-in-Being (NiB) was developed: 'NiBs are largely implicit – existing tangibly in the shape or form described by an organisation's physical limits that [reflect] their overt capabilities rather than their 'implicit network capacities', upon which their actual effectiveness rests [25]'.

3.1 Network Collaboration

A characteristic of networks is people increasingly working and collaborating in large-scale, dynamically reconfigurable networks across a range of organizations (commercial, civil and non-governmental). In such situations, teams will potentially consist of a large number of members communicating and sharing information with each other across organisational, linguistic and national boundaries. Monitoring and participating in numerous ongoing communications, in addition to performing individual tasks can be organisationally and individually overwhelming. Technology has the potential to further increase the volume of information available to individuals concerning the activities and availability of their remote collaborators, to the extent that the sheer volume of this information becomes too much for them to reflect on and deal with efficiently. For example, Dabbish and Kraut [26] showed that when participants were given a full view of a remote team-mate's activities, they found the task of having to extract from that information whether their team-mate was available or not, distracted from their own work. This problem is likely to be compounded through the increase in the number of team members to be *monitored / controlled* in large-scale networks. Different forms of networks might lend themselves to the more effective formation of teams more so than others. What helps people climb the ladder in vertical hierarchies might be the very thing that impedes horizontal collaboration. This suggests that the "right" dynamic network structure needs to be investigated. Essentially, by taking forward Networks-in-Being from a technological position, one is also identifying the need for a 'philosophy of being' with which to better describe and so articulate network phenomena. It is this idea of the 'multiple-being' that holds within it the 'traits' of the collective in question – the 'true' sense of the collective's being – that we identify within networks. It is their 'truth' – or in this regard, their trusts – that '[contain] the common traits of the collective in question'. When these 'trusts' dissipate or are allowed to wither the organisation may remain as a physical entity (when a building becomes derelict) but its essence and being – its 'ineffable singularity' – is no longer. For example, 'Deming [27] wanted work to be exciting, challenging and enjoyable with management offering both "trust" and job security [11]'.

3.2 Trusts

Frankenberger and Badke-Schaub [28] studied the information-seeking behaviour of designers with respect to the design situations they were in and distinguishing between routine work and critical situations. They reported that designers contact their colleagues for information and knowledge in nearly 90% of the critical situations. They argued that the information needs of design engineers can be adequately supported by software tools only during routine work, but that during critical situations, social interaction cannot and should not be substituted for. This understanding would complement the Bunge and Szilard maxim that 'Knowledge is social and like information is costly to acquire and use'. The knowledge of an organisation is within its social-networks; not its computers or communication systems, no matter how sophisticated or large their bandwidth. It is relatively simple to examine the formal communications-signal network. It is far harder to examine the social-networks that underlie and inform the formal. This raised the question as to 'why engineers often turn to their colleagues for information? [28]' It might be convenience, or (limited) shared awareness (knowledge) and, or, trust in the quality and truthfulness of sought after information, or, a combination of a number of factors. From a sender's point of view, incentives to give truthful information and advice can be in the interest of maintaining a trusted reputation and, or, as a stake in the receiver's actions: trust in sociology is a relationship between people. It involves the suspension of disbelief that one person will have towards another person / idea and especially having one person thinking an 'other' person / idea to *be* benevolent, competent / good, or honest / true, after Misztal [29].

What follows is that, not surprisingly, knowing how people connect makes collaboration work better, e.g. Mintzberg et al [30]. They suggest that collaboration may ultimately depend on trust. Collaboration for new product development depends on the engineer's ability to trust each other, and to appreciate one another's expertise. Perhaps, surprisingly, they argue, the best collaboration may be the least realised as collaborative, giving the example of interdepartmental collaboration for new product development. In the best of such collaborations of reflective joint learning whilst designing, people focus intently on shaping the new product but may not even realise they are collaborating, so that shifting their focus to formal techniques of collaboration may, in fact, reduce their capacity and propensity to collaborate. This confirmed the importance and necessity of maintaining the proximity of trusted and knowledgeable people in a network. Thus, the information seeking behaviour is linked to the set-up of the network and to the nature of how people collaborate within those networks – in other words, positions, ranks, trusts and hierarchies. Network structure, collaboration, reflection and information seeking behaviour are probably mutually dependant. Knowing that design engineers turn to their colleagues, it is important to structure the networks with the 'right' people and to find the 'right' ways of coupling different networks so that the most important information will / can be captured and knowledge exchanged.

3.3 Risk and Trust – different sides of the same coin?

In 1989 the UK Ministry of Defence (MOD) Chief Scientific Adviser considered 'risk to be a function of both the probability of an adverse event occurring and its impact'. Building on this interpretation of risk, it is possible to suggest that **Risk** may be a function of both the 'Likelihood' of an adverse event occurring and a system or person's ability to comprehend, explain and understand by logic.

Risk, as identified is about 'knowing' and 'not knowing'; 'comprehending' and 'not comprehending'. Applying the above understanding of risk, if an organisation cannot 'estimate' the 'likelihood[6]' of an adverse 'event' occurring – then that, in itself, is a 'risk'. This suggests that existing risk models may be inadequate. Equally, if an 'adverse event' occurs but is 'unnoticed' because the models cannot 'comprehend' what has actually taken place, then that is also a risk. Chernobyl might be indicative: 'The scale of the Chernobyl accident was therefore not determined by personnel actions, but by a lack of understanding. This led to an <u>incorrect analysis of operational safety</u>; to a <u>disregard of repeated manifestations</u>; to a <u>false confidence</u>; and, naturally, to the formulation of <u>incorrect operating procedures</u> IAEA [31]' (underlining our emphasis).

Mintzberg [30] 'suggest collaboration, may ultimately depend on trust'. Mumford [11] considers an important risk factor to be that of 'trust': 'because innovation is frequently a journey into the unknown, trust is a major factor in its successful assimilation'. Giddens [32] defines Trust as 'confidence in the reliability of a person, or system, regarding a set of outcomes or events'. 'Risk and trust are inextricably intertwined. Trust can minimise danger. It is necessary when others are involved in a new activity and using skills which a manager does not. Confidence is part of trust, although blind faith should not be. Trust involves knowledge, integrity, capability and unflappability. All necessary

[6] As per 'System Likelihood', see Footnote 4.

components of successful innovation. It is the responsibility of the manager and the expert to ensure that knowledge that reduces risk is passed on [11]'.

Taking forward Mumford, Giddens and Mintzberg's understanding of Trust, it is suggested that **Trust** may be a function of the 'Likelihood' of a person or system being 'able to comprehend, explain, understand by logic' and deal with a set of outcomes or events.

4 MOVING TO DYNAMIC SOCIAL NETWORK ANALYSIS

Although there are a multitude of definitions, broadly speaking a social network consists of individual entities (or actors) and the relationships these actors have to other actors in the social system. The "social" in social network analysis (SNA) refers to the interaction between people that distinguishes it from other sorts of interaction between technical networks.

Social network analysis can be used to describe the relationships between a range of actors be they at the organizational, group or individual level. Where traditional social science has focussed on the attributes of the individuals engaged in collaborative activity, SNA focuses on the relationship between pairs of actors in the network. The relationship an actor has to others in the network presents opportunities to access information not previously held by the actor. Hence, the structure of the network as well as the type of link between actors affects the quantity and quality of information available across the network. The most common form of relationship between actors in the network is the communication of information, with the most common measures of the strength of this relationship being its duration and frequency. Typically the output of SNA is a graphical representation and mathematical analysis of the relationships exhibited within the network under analysis. For example in Figure 2 the nodes in the network diagram represent individual actors while the thickness of the lines represent the frequency of communications between the nodes.

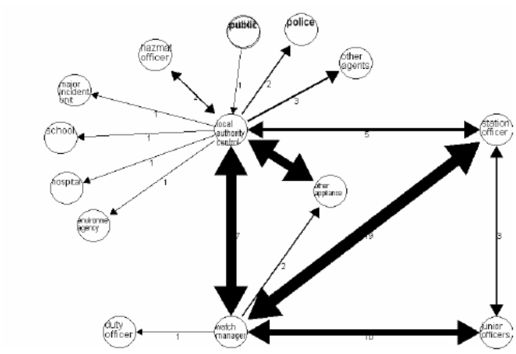

Figure 2: Example of SNA diagram [33]

4.1 Centrality, Density and Closeness

In most organisations determining what may be 'company interest' is extremely problematic and may vary depending on an individual, departmental, collective and organisational level and less politically charged terms often need to be found to dynamically resolve both global and local differences. It is through such resolution that 'organisational reality is constituted…and through which each [network-in-being] coheres as a distinct cultural entity [34]'. The language of networks, therefore, becomes important in developing *trusted* narratives and resolving 'non-technical challenges that might arise from these scenarios [35]'. One can consider, for example:

- 'Centrality' (who is at the centre; how connected and why);
- 'Closeness' (the degree a node is associated with / near other nodes);
- 'Clustering' (degree of connection / association with specific nodes);
- 'Cohesion' (the degree by which other actors are connected);
- 'Coupling' (as a measure of functional dependency on a specific node);
- 'Reach' (the degree a node can reach other nodes in the network) and;
- 'Edge' or 'bridge' (the extent to which a node lies between other network nodes).

Expressing interest in network relationship terms enables the researcher to build up a more complex understanding of where individuals / nodes within a network may position themselves and / or others. Networks are dynamic and complex; not certain or linear. Conceptualising *interest* as a *network of networks*, enables political differences to be ethnographically resolved within a multi-dimensional dynamic language; allowing, for example, friends to be both 'close and on edge' in a way that can be questioned objectively and assessed more subjectively. To undertake an initial network assessment, a Likert-type scale [36] was derived in which the *question* was one of placing the respondent within the network and positioning the relative performance of the organisation / other individuals on a scale from 1 to 10, where deliberately no middle assessment - 5 - could be made.

4.2 CPM Modelling

Maier et al [37] consider that a 'network of individual factors [including] roles and responsibilities, relating to organisational structure [can influence] design communication' Generally speaking, most organisations have available hierarchical organograms which show position in terms of rank. At a first stage in the process hierarchical organograms were developed and agreed. These models were then used to assist in a) capturing hierarchical information and b) developing the network models for c) application to a theoretical UK based light engineering company, see Section 5.

The next step was to take this information and to model it in terms of CPM [38]. CPM was selected primarily because of the way it handled information and enabled a dynamic interpretation based upon the way a node was seen and saw the 'other'. Two primary values were identified to do with likelihood and impact, where likelihood was the probability of information being received by a node – or received from – and impact was an indication of the response of the information on an individual. In this respect, likelihood and impact could be judged in terms both of rank and position within a department, up and down, and qualified as such. A Likert-type scale was used to judge network positioning and relationships. Atkinson [39] observes that 'control is a function of rules, time, and bandwidth, whereas command is a function of trusts, fidelity, and agility'. The relationship between 'control and time' was seen to be particularly relevant to techno-socio designs such as a production plant where information likelihood and impact might be high. This was considered to be a control-type environment where repeatability was the major driver. On the other hand, where an individual can be trusted – and they no longer need to be controlled – then the likelihood of information being transferred to control a 'function' may be low, even though their impact may be high.

Links for each individual node were identified in terms of their formal / hierarchical / vertical scaled relationships, top-down or bottom-up (signal) and their informal / semi-scaled / horizontal (point-to-point) relationships, in-out and out-in, see Keller et al [25]. This recognised that an effective organisational *ecology* is likely to reflect its *web or network of relations* and to adapt its decision-making processes dynamically in order to resolve competing influences / demands (controls) acting upon it. It also recognised that when one cannot influence one may need to control and vice versa. In other words, without *trust* one may have no option but to control.

5 APPLICATION TO A LARGER SCALE MODEL

A model was constructed from the first author's experience working with medium sized, UK based light engineering companies. The model envisaged a company of 175 employees; comprising five departments across six or seven management levels (after Likert [40] and Purser [41]), i.e. Production; Research & Development; Sales and Finance; Human Resources and Clerical (including Health and Safety and Training) and Operations and Logistics.

5.1 Scenario Development

For the purposes of this study it was assumed that the CEO and Managing Director (MD) came from a sales, accounting, or operations and logistics background and therefore had closer affinity with – and thereby trust in – these departments than potentially the Production and R&D Departments (Figure 3).

The Company was established in the 1950s and the timeframe in question is the late 1990s. The Company has a turnover in the region of £20M but its profit margins are falling as competition sets in from India and China. At present, 40% of the budget is allocated to production; 30% on Operations and Logistics and 10% each on R&D, Sales and Finance and HR and Clerical. A management consultancy company, brought in by the bank, is advocating an entirely new business model that will contract out operations and logistics and displace production to China. The proposal is to reduce the numbers of personnel involved in production by 60% and to contract out entirely operations and logistics in order to boost expenditure on R&D and to maintain a *be-spoke* manufacturing capability. This is being resisted by the unions and senior management who have a traditional view as to how the company should be run. The CEO and MD want to press ahead with changes but see only minimal need to invest in training and development and R&D in order to stay on the cutting edge. Announcements have yet to be made and employees are concerned about the future. In terms of Systems Identification, the Production department is considered to be a Techno-Socio system, where Likelihood is the key variable and which is optimised exclusively on delivering timely repeatable outputs. The Logistics and Operations department combines both Techno-Socio (Operations) and Info-Techno-Socio (Logistics) characteristics in which Information and Communications are the key variables. The HR & Clerical and Research & Development Departments are considered Socio-Techno systems in which shared awareness, taken to be indicative of the degree of collaboration and thereby trust, is the key variable. The Sales & Finance Department combines both Socio-Techno characteristics (sales) and Info-Techno-Socio (finance and accounting). Based upon the scenario a network involving over forty entities was developed in CPM, see Figure 4.

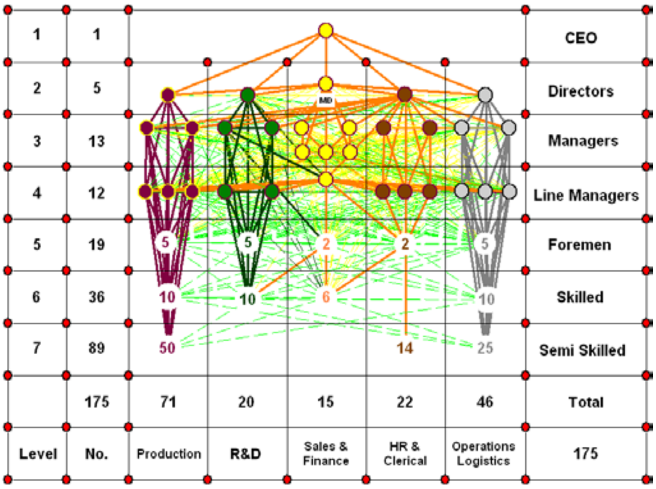

Figure 3: Simplified Model of a Light Engineering Company

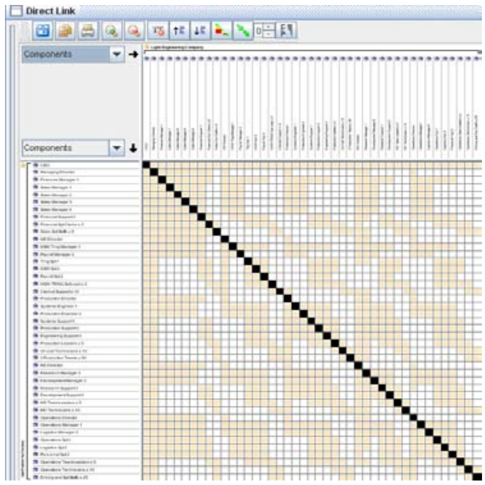

Figure 4: Company DSM

5.2 Implications for Research and Practice

Two models of the company were constructed, one in which the organisation reflected a high degree of trust in / between departments; the other in which control had become dominant, see Figure 5. The differences between the two organisations are noticeable. On the one hand, in the trusted organisation, the CEO is more central and the organisation is 'inclusive' showing significant closeness (density) and coupling. If one enters the trusted organisation from any point on its circumference, the organisation is similarly replicated – the same 'story' would be shared. If one enters the control organisation, a different class is likely to be encountered, for example, workers rather than managers. It is 'exclusively' scaled and a different story is likely to be told. The control organisation demarcates along rank rather than positional lines (workers versus managers), in which the CEO is less central and coupling is by hierarchy. This is borne out by CPM cluster analysis.

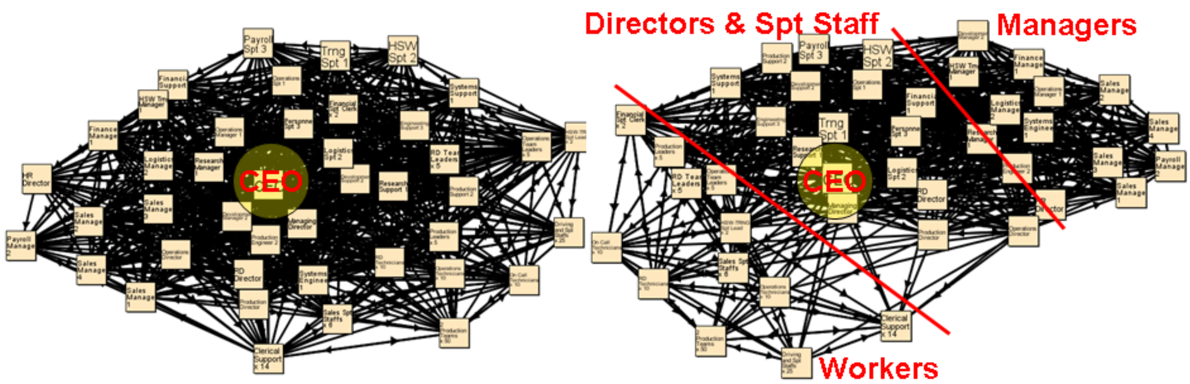

Figure 5: Light Engineering Company, Trusted Organisation (LHS) v Control Organisation (RHS)

In the trusted organisation, the likelihood-impact clusters form more along departmental lines whereas in the control organisation they form along closed hierarchical lines – managers, staff, technicians and directors – see Figure 6. In the trusted organisation, R&D and Production are strongly coupled and the most 'influential' departments. The socio-techno/techno-socio positioning of these innovation, design, research, development and production/engineering departments would be expected: both essentially learning and adapting to/from each other. In the trusted organisation, the other departments and management act in support of R&D and Production. These Departments and directors tend to 'control more and influence less' and occupy more techno-socio (for example Operations and Health & Safety) and info-techno-socio (for example logistics, accounting and pay) positions. Significantly, the departments occupy unique 'edge' positions and so are not in either personal or collective competition with each other for the same resources of time and space. In other words, there is a degree of healthy 'performance variety'. The R&D Director is essentially placed 'on edge' in a trusted position where he may be most likely to sense and influence change. Broadly speaking, the trusted organisation could be said to be 'under control' and 'in command' – there is both leadership (the CEO and Directors are 'in charge') and followership.

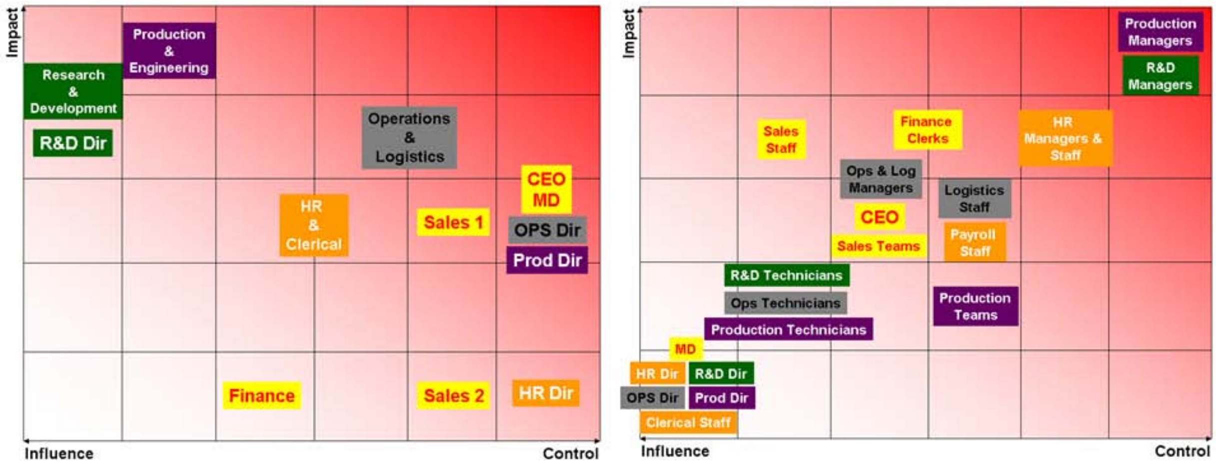

Figure 6: Company Cluster Analysis: Trusted Organisation (LHS) v Control Organisation (RHS)

By contrast, the control organisation appears to be neither under control; nor command. It is being controlled by its R&D, HR and Production Managers; arguably the means have become the ends. The departments in the control organisation have fractured into their component elements (hence the greater number of entities visible that were previously departmentally grouped). Moreover, departments and individuals are competing for the same resources and against each other (them and us), for example the relatively ineffectual cluster of Directors at bottom left. This is an unhealthy place to be, where lack of variety and limited resources may have created grounds for incoherency, elitism and Hyper-Competition. This may also include suborning from the top (headhunting) or bottom (industrial action). From an organisational perspective, the control organisation appears to be fracturing and is unlikely to be able to support the type of change envisaged and retain a coherent R&D Department. By the same token, the challenge facing the trusted organisation would be to maintain collaboration between the newly forming production, operations and logistics departments now based overseas whilst sustaining morale within the R&D and be-spoke production departments and staffs remaining. This would be a real test of leadership.

6 CONCLUDING REMARKS

This paper has introduced concepts for networks-in-being and trusts as a means for understanding the way in which organisations may aggregate and behave. Information seeking and Collaboration were introduced as key factors *influencing* shared awareness and effective decision-making in a networked environment. We introduced a classification of existing social networks in terms of connectedness and formality. A scenario was developed and the CPM programme run to determine repeatability around a number of possible results. This modelling appeared to 'identify' expected types of system performances and signatures, namely Socio-Techno; Techno-Socio and Info-Techno-Socio. This suggests that it may be possible to non-obtrusively and dynamically 'instrument' the performance of organisations by subjectively modelling and objectively validating by falsification, after Popper [42], rather than objective verification through evidence and measurement alone, after Wittgenstein [43], (for example Performance Management). It also indicates a linkage between the degree of control, likelihood, shared awareness, influence, collaboration and trust which will be the basis of future work. For example, in some situations, one may influence and control but not control and influence / be shared aware. From the worked example, it is possible to state that the organisation may be prepared to continue as primarily a production and sales company but is much less prepared to either manage the changes envisaged or develop a new model based around R&D, consultancy and be-spoke production. The next stage will be to instrument CPM to examine what combinations and changes to existing and observed networks might be possible to improve an organisation's ability to dynamically learn and to adapt to changing environments.

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