The Bartlett School of Construction & Project Management

UCL

Evaluation of collaborative teams for complex infrastructure projects through Social Network Analysis

Technical Report
Knowledge Transfer Partnership

2014 – 2016

Transport for London | Technology Strategy Board Driving innovation | Knowledge Transfer Partnerships | UCL

Technical Report
Knowledge Transfer Partnership

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Executive Summary

This research project was stimulating, challenging and exciting for all involved. Like so many unique projects, some things might have been done differently with hindsight and further exploration of the data and the opportunities from the project are ongoing. However, this research study was ultimately an extremely valuable exercise for both Transport for London and University College London as well as the supply chain organisations involved.

The key findings of this research are:

1. The idea of using social network analysis to monitor, measure and eventually manage relationships in complex projects is viable and beneficial to Transport for London and its supply chain organisations, as well as for individual team members.
2. There is some benefit through the 'Hawthorn Effect' of carrying out research projects concurrently with complex engineering projects. Research carried out in this way reflects a senior manager's commitment and interest in staff, including outsourced staff.
3. We identified a method to determine the optimum efficiency of a project organisation through the attributes of an organisational network analysis. We have identified a way of ‘costing’ the efficiency of the network which offers a new method of understanding the benefits of relational approaches (i.e. collaboration) to project organisation, in addition to more formal resource cost and planning approaches.
4. We identified the issue of 'Dysfunctional Prominence' (DP). DP has the potential to drastically reduce the effectiveness of project networks through undesirable 'gatekeeping'. This results in inefficient and unnecessarily long path lengths between actors exchanging information and subsequent delays by DP actors in processing and disseminating information for other actors.
5. We identified strong evidence of 'self-organising’ project systems. Individuals are working within a project environment that is complex technically and organisationally. The pressure to perform an individual's role within this environment leads to high levels of self-organising, which effectively ignores the governance procured through contractual relationships or the functional hierarchy of their host organisation. These self-organising networks are a benefit as the systems and relationships are effectively owned by the project actors involved, but should not go unmonitored.
6. Complex project networks need enabling and facilitating, rather than managing and leading. A rethink in some of the traditionally-held views about projects and how they are managed through formal management systems might be helpful. Project management theory and practice is moving towards the management of relationships.
7. Networks are significantly more difficult to establish and evolve during the 2-10 node stage. Benefits could be achieved by providing support to this network evolutionary process through external brokerage support and/or training for project actors prior to and during these phases.
8. Relationships established at the outset of a project are commonly assumed to be constant throughout that phase of the project. This is clearly not the case with large projects as

project networks evolve and adapt continuously over time. There is a limited understanding of this evolution and its relationship with project life cycle stages. Therefore, it follows that there are currently no interventions to support this evolution.

9. Problem solving is not procured, yet is a very important function performed by the actors involved in an engineering project. Contracts could be amended to reflect this and training could be provided to facilitate problem solving in projects. It might be worth considering the creation of multi-disciplinary communities for design, dissemination and problem solving as identified through this research.

10. We identified several occasions where there was evidence of 'structural holes' in functional, contractual and communications networks. An awareness of the potential disruption caused and the best means to fix such structural holes would be beneficial to TfL. It is our belief that, going forward, organisations will increasingly take an interest in network topography and the roles that actors acquire informally. In this way, they can design network interventions that improve the speed and accuracy of information flows through project networks.

11. The use of social network analysis in project organisations stimulates discussion among project actors and creates awareness of the issue of actors' 'network roles' alongside their professional/disciplinary roles. Some training to provide more extensive awareness among project actors would be beneficial to TfL in running future projects.

Interim findings were disseminated through Infrastructure UK and the Supply Chain Management Round Table organised by RICS. TfL-sponsored MSc students on the Project and Enterprise Management programme at the UCL Bartlett School of Construction and Project Management, along with the rest of this year's cohort, benefitted from a half-day session presented by Simon Addyman and Dr Stephen Pryke. This enabled this group of students to question two members of the research team on some of the interim findings. Sessions were also held with the project teams involved who could see the networks evolving over time, draw insight and give thought to the way they understand how they exchange information with each other.

The project has been rich from an academic standpoint also. The team have used data from the project to submit a paper to the RICS annual research conference in 2015, for which 'Best Paper' was awarded. A paper was also accepted for publication by the Project Management Journal. Papers were presented at a number of international conferences, including IRNOP at UCL, COBRA in Sydney and Toronto, the International Mega-Projects Group in Rome and the International Network of Social Network Analysts conference in California.

The research was carried out concurrently with the PhD research of Simon Addyman and has enriched that research and provided academic context. The research associate for the KTP, Bala Soundararaj, benefitted from exposure to one of the world's most successful project management organisations and has received personal development training over the two-year period. He has now moved on to register for a PhD at UCL in the department of geography.

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Lead for UCL

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Knowledge Transfer Partnership

The Knowledge Transfer Partnership (KTP) initiative is one of the Europe's leading programmes organised by the UK Government's Innovate UK initiative (https://www.gov.uk/government/organisations/innovate-uk) to help businesses improve their competitiveness and productivity through the better use of knowledge, technology and skills that reside within the UK. It is set up between an industry partner (company) and a knowledge partner (university) and offers the company the chance to collaborate on a business opportunity, idea or innovation with the university directly.

This report describes the KTP established between Transport for London (TfL) and University College London (UCL) between March 2014 and March 2016, to research the application of social network analysis (SNA) in improving the performance of collaborative teams in large and complex construction project organisations.

Research need

In researching organisations that manage large complex infrastructure projects, it has been found that most of the decision making related to project uncertainties are made through non-contractual, self-organising, multi-disciplinary networks of actors who are temporarily brought together through project-related common interests, goals or tasks. This occurs despite such organisations placing significant emphasis on establishing formal organisational and contractual hierarchies between organisations and people. Within these non-contractual networks, clients/contractors tend to allocate risk in accordance with functional contract transactions to manage project uncertainty. This often results in situations where behaviours become more aligned with resolving contractual obligations than the resolution of the key project delivery issues. Traditional organisational and contractual models of infrastructure project delivery simply accept this situation, which often results in limitations in achieving radical and sustained improvements in performance. This results in a need for understanding these multi-functional, non-contractual networks in the project and how to utilise them to overcome these limitations.

Within TfL, the London Underground Bank Station Capacity Upgrade (BSCU) Project and the Surface Transport Hammersmith Flyover (HFO) Project were two case studies used to investigate these phenomena using social network analysis.

Proposal

The aim of this partnership was to understand and interpret the networks of contractual and non-contractual interfaces between the participants in the project so that effective decisions are made in the interest of successful project outcomes. This was achieved by:

- Developing a structured and tested method for identifying and evaluating networks between project participants involved in decision making in relation to project uncertainties through social network analysis.
- Developing measures and methods to interpret and draw practical conclusions from the evaluation of those networks.
- Developing a suite of network-based tools and interventions which will help project managers design their team structures to facilitate successful delivery of projects through more reliable decision making.

Objectives

The KTP project objectives are set out as follows:

- Gather information and needs from the internal TfL stakeholders and supply chain partners.
- With the help of a pilot study, understand the challenges and opportunities for the research within the project context and gather learnings and insights for more comprehensive studies.
- Carry out comprehensive studies on selected projects, record and analyse networks in these projects using SNA, draw practical conclusions from the analysis and provide recommendations for the project.
- Generate insights in improving project processes, procurement approaches and tender assessment methods which facilitate collaborative working procurement strategy, assessment criteria and input to procurement policy with business justification.
- Develop a network management toolkit - a set of management approaches and tools to resolve performance issues in projects by addressing them from a network perspective and dealing with network related issues.
- Develop user-friendly and intuitive methods for efficient capture, analysis, interpretation and presentation of data on these networks within the project in terms of software and presentation tools.
- Evaluate the outcomes of the KTP through workshops, report and recommendations.
- Embed the knowledge, understanding, processes and tools produced in the KTP within TfL more broadly, TfL's supply chain and wider industry through workshops and presentations across TfL and within Infrastructure UK (IUK).

Benefits

As a result of this KTP:

- The industry partner, TfL, will be able to develop and disseminate organisational knowledge with regards to corporate project management governance structures; local project specific governance structures; supply-chain focused procurement and contract strategies; and general systems enabling more reliable and effective decision-making in the interest of successful project outcomes. This will also result in quicker and more cost effective resolution of issues, and in the long term, the ability to reduce the amount of money which has to be set aside for managing risk and uncertainty.
- The academic partner, UCL, will be able to access case study material for the research and produce quality research outputs from the KTP which will, in turn, help in applying and enhancing the theoretical arguments in 'social network analysis' (SNA) developed by UCL. The project outcomes will also support the curriculum for networks and management in UCL.

Outputs to be achieved

The following outputs were achieved at the end of the project:

- Proven methods of measuring and evaluating optimal network configurations to understand how different project organisation structures influence collaborative relationships within and between the client and the supply chain;
- The terminology and the evidence to allow project managers to proactively develop efficient project networks, releasing investment capital for further growth and prosperity of the Capital's transport infrastructure;
- A series of tools to assist in network management including the identification of suitable software to capture network data, software to visually represent networks in an intuitively accessible and understandable way, and a tie strength tool to measure the quality of relationships;
- A series of tools and documents to interpret and understand network features and ensure that best practice is implemented into business policy and processes;
- Open opportunities for the knowledge to design and implement innovative approaches to procurement and supply chain management through the adoption of Social Network Analysis as a management tool; and
- An embedded capability in SNA and a matured understanding of its applications to continue to secure greater returns on investment beyond the pilot projects.

Scope

This report covers the work undertaken as a part of the KTP between March 2014 and February 2016. The report starts with a brief introduction to network theory and a range of network terminology, which are relevant for a project-based organisation. It discusses the way these networks can be analysed and the measurements with which the nature of the network and the actors can be interpreted.

The report then goes on to discuss the early pilot study and summarises its outputs and learnings which influenced the main studies. The next section sets out the main studies (BSCU and HFO) conducted as a part of this research project, discussing the aims, objectives, the data collection and methodology. It will then discuss each case study in turn, including the interpretation of its main findings. The report concludes by summarising the main findings, the recommendations for the practitioners and the possible next steps for the research.

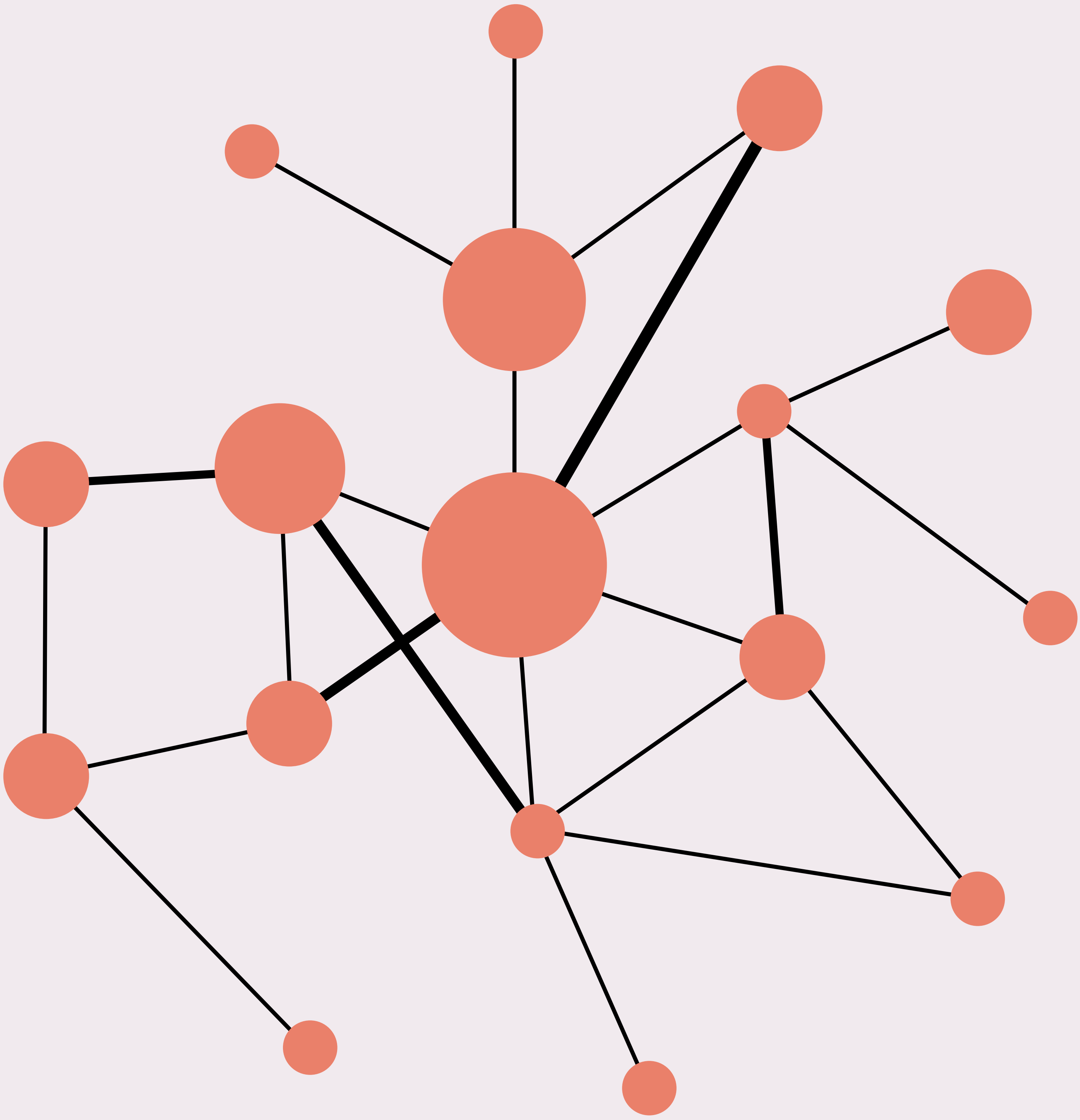


Figure 1.1 Sample network diagram

Introduction to Networks

A network is defined as a set of nodes connected through a set of clearly specified relationships, which constitute the linkages between the nodes. These nodes can be various types of entities such as people, organisations and IT hardware. The links or relationships can be social or contractual and can be 'directed' flowing from one node to the other, such as information, trust or finance; or 'undirected', such as discussion or membership of a group. Network analysis attempts to understand the different structural properties of the network and explain the effects these have on the individual actors and the performance of the network as a whole.

Network diagram

A network diagram is the graphical representation of a network. An example of a social network diagram is shown in figure 1.1. The circles in the network show the nodes (the entities) and the lines between the circles denote the relationship (the links) between them. The width of the line shows the strength of the relationship and the colour and size of the circle denotes the type and prominence of the entity. The prominence of the entity is measured in various ways as detailed in the following sections.

The layout of a network diagram is the way the nodes are placed in the network relative to each other. There are various layout algorithms which have various advantages. For example, circular layout is the simplest and focuses on the destiny of the diagram, Frutcherman Reingold's algorithm tends to put the highest connected nodes in the centre and draws less connected nodes around them based on tie strength.

The layout used for this research is ForceAtlas2, a force-directed layout algorithm which treats all nodes as objects with mass and links as springs with strengths (link weights) suspended in space and uses a gravitational model to calculate their relative positions. This gives us a network diagram where nodes are placed relative from each other depending on the existence and strength of the links between them. This is beneficial as the resulting network diagram is legible with less overlap of nodes and links and the resulting graph shows structure (clustering based on the links between them). An example of various layouts discussed when applied to same sample network is shown in figure 1.2.

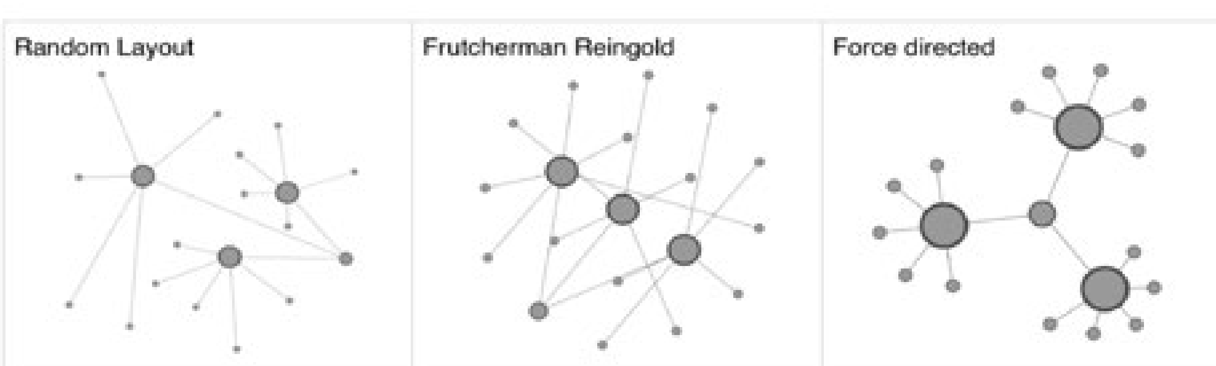


Figure 1.2 Types of Layout Methods

Types of networks in a project

<u>Organisational Network</u>

The organisational network in a project is a network where the nodes are organisations involved in the project and the links are the contracts between them.

<u>Functional Network</u>

The functional network in a project with a matrix organisational structure, is a network where the nodes are the personnel working on the project and the links are the functional reporting relationship between them. Functional reporting can be defined as the person whom the respondent 'functionally' reports to within their professional discipline within the organisation which employs him/her. i.e. an Engineering Manager may report to the Head of Engineering in the same organisation.

<u>Contractual Network</u>

The contractual reporting network in a project is a network where the nodes are the personnel working on the project and the links are the contractual reporting relationship between them. Contractual reporting can be defined as the person whom the respondent is contractually obliged to report to with respect to the project management governance structure of the project. The person who is reported to may be from a different organisation to the one in which they are employed, or a different function than that from within the functional network. i.e. the engineering manager may contractually report to the project manager with respect to the day to day management of the project.

<u>Communication Network</u>

The communication network in a project is a network where the nodes are the people working on the project and the links are the interpersonal communication between them. The strength of the communication can be defined with various parameters such as frequency of the communication and perceived quality of the communication. Quality can be further defined in detail with various parameters such as importance, accuracy, trust, timeliness and clarity.

Network Properties

The networks can be measured using three major parameters which describe the structure and properties of the networks as detailed below.

<u>Network Size</u>

The size of the network is defined by the total number of actors in the network. Though the size of the network has no direct relationship with the performance or efficiency of the network, it affects the complexity and cost of the network (discussed in detail in the next section). Generally, when everything else remains the same, a bigger network would be more complex and costlier in terms of both building it and operating it. In addition to this, the changes in the size of the network may indicate change in the scope of the network, such as a change in organisation, new department opening etc. and can give us clues in understanding any sudden changes in the project context.

Figure 1.3a shows the building cost and operational cost of a theoretically constructed network model (Albert-Barabasi model for social networks) at various sizes from 1 - 100. We can see the building cost of such a network increases linearly with size while the operational cost increases exponentially. Bigger networks, even though may have a large scale and scope, might not be efficient in terms of their operations.

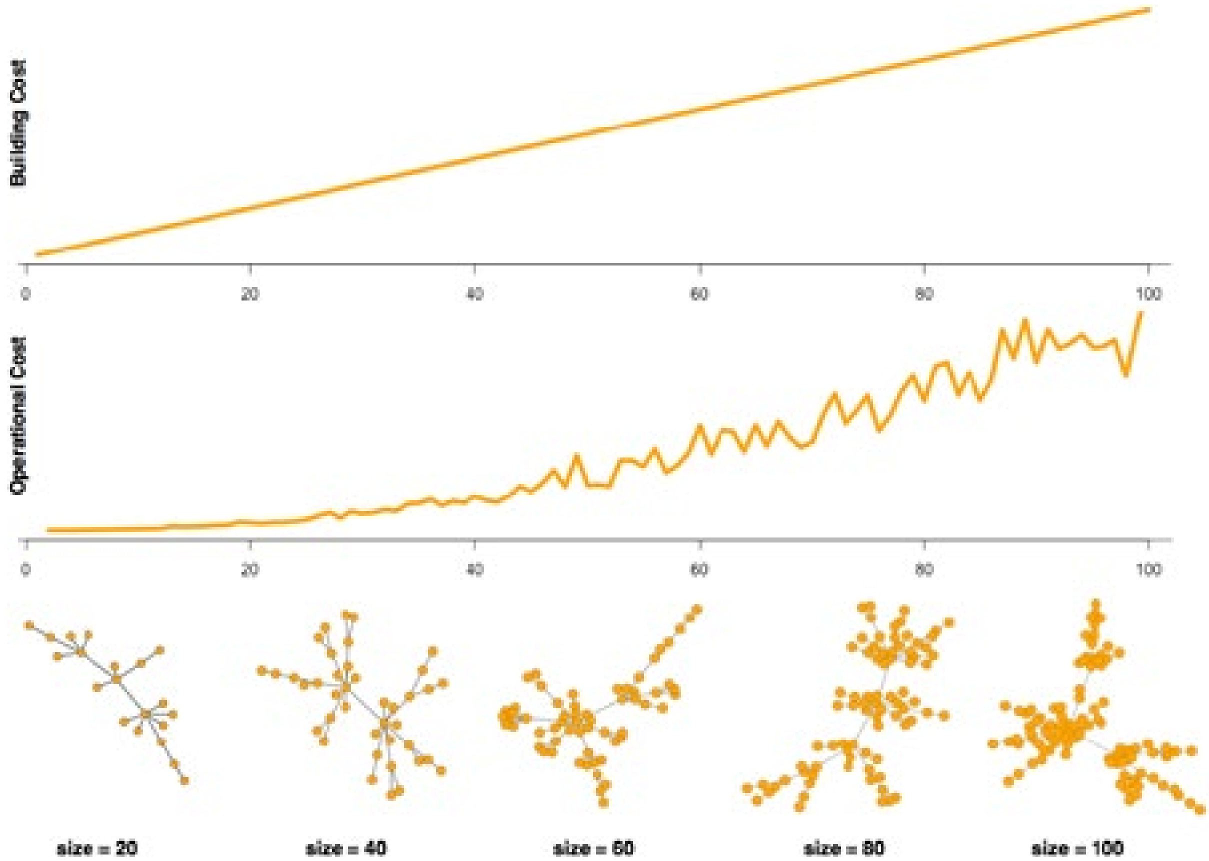


Figure 1.3a
Costs of networks of various sizes

Network Cost

The cost of a network can be defined as the amount of effort required to build the network (building cost) and transmit information through it for a set period (operational cost).

The *building cost* is measured by the number of links in the network. Assuming all the links take the same amount of effort to build. It is defined as bc = e x l, where bc is the building cost of the network, e is the number of links in the network and l is the average cost of every link. The *operational* cost is measured by the total number of steps which need to be taken through the links to transmit information from every actor in the network to others. It is defined as, oc = [vn] x m, where v is the set of all the shortest distances from every actor in the network to every other actor and m is the average cost of a communication between two actors. Finally, the total cost of the network is defined as tc = bc + (t x oc) where t is the period for which the cost is measured.

Figure 1.3b shows the *building*, operational and total cost for random networks (Erdos-Renyi model for random networks) of the same size and number of links varying from 0 - 100% possible links (density). We can see that the building cost increases linearly with the number of links while the operational cost follows a completely different

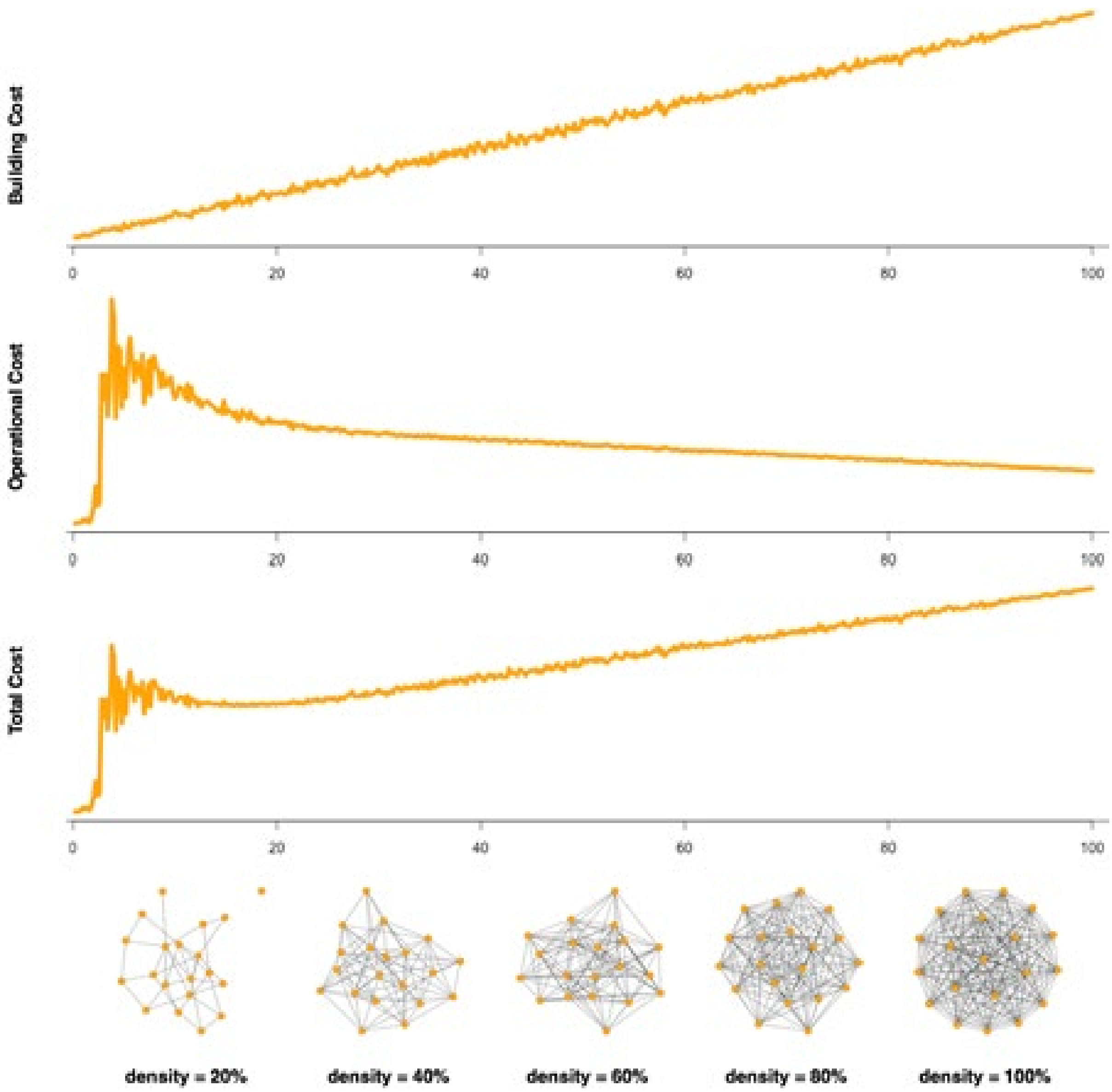


Figure 1.3b
Costs of networks of same size (20) and various densities.

pattern. It shows 5 different zones, 0-2.5% where there is only small increase in the cost with increasing links, 2.5 -3.75% where there is rapid increase, 3.5-7.5% where the cost remains stable before decreasing slowly from 7.5-20% and, finally, showing a very slow decrease after 20%.

The total cost being the combination of both building cost and operational cost and assuming a unit period and building cost of a link higher than operational cost, the total cost shows similar but a slightly different pattern with respect to the number of links in a random graph. The cost of the network gives us an idea about the structure of the networks and combined with size of the network this gives us a measurable framework for evaluating the networks objectively. The regions and the observations are shown in table 1.3b.

Density Range	Comment
0.00 % - 2.50 %	Slow increase
2.50 % - 3.75 %	Sharp increase
3.50 % - 7.50 %	Relatively Stable
7.50 % - 15.0 %	Slow decrease
> 15%	Very slow increase

Table 1.3b
Stages of cost of a network with varying number of links

Network Efficiency

The efficiency of the network is defined as the per unit cost of the network in relation to the performance of the network. This is defined as $E = p / tc$ where p is the performance of the network and tc is total cost of the network. Since we are looking to find effect of density on efficiency, in this case we define performance as the connectedness of the network, which is the size of the largest connected component.

Efficiency is the key global property of the network since it gives us insights into how the network is performing with respect to the cost of building and maintaining it. This in turn provides an indication of the direction in which we would desire the network to change to. The efficiency of the network also allows us to benchmark existing networks to the theoretical network models and offers the opportunity to find the optimum value for the money which is being invested in the communication network.

For example, figure 1.3c shows the total cost, connectedness and efficiency for a series of random networks (Erdos-Renyi model for random networks) of the same size, showing varying densities (possible links) from 0 - 100%. We can see that the connectedness (middle graph) grows rapidly and reaches its maximum by the time the network reaches a density of 15%.

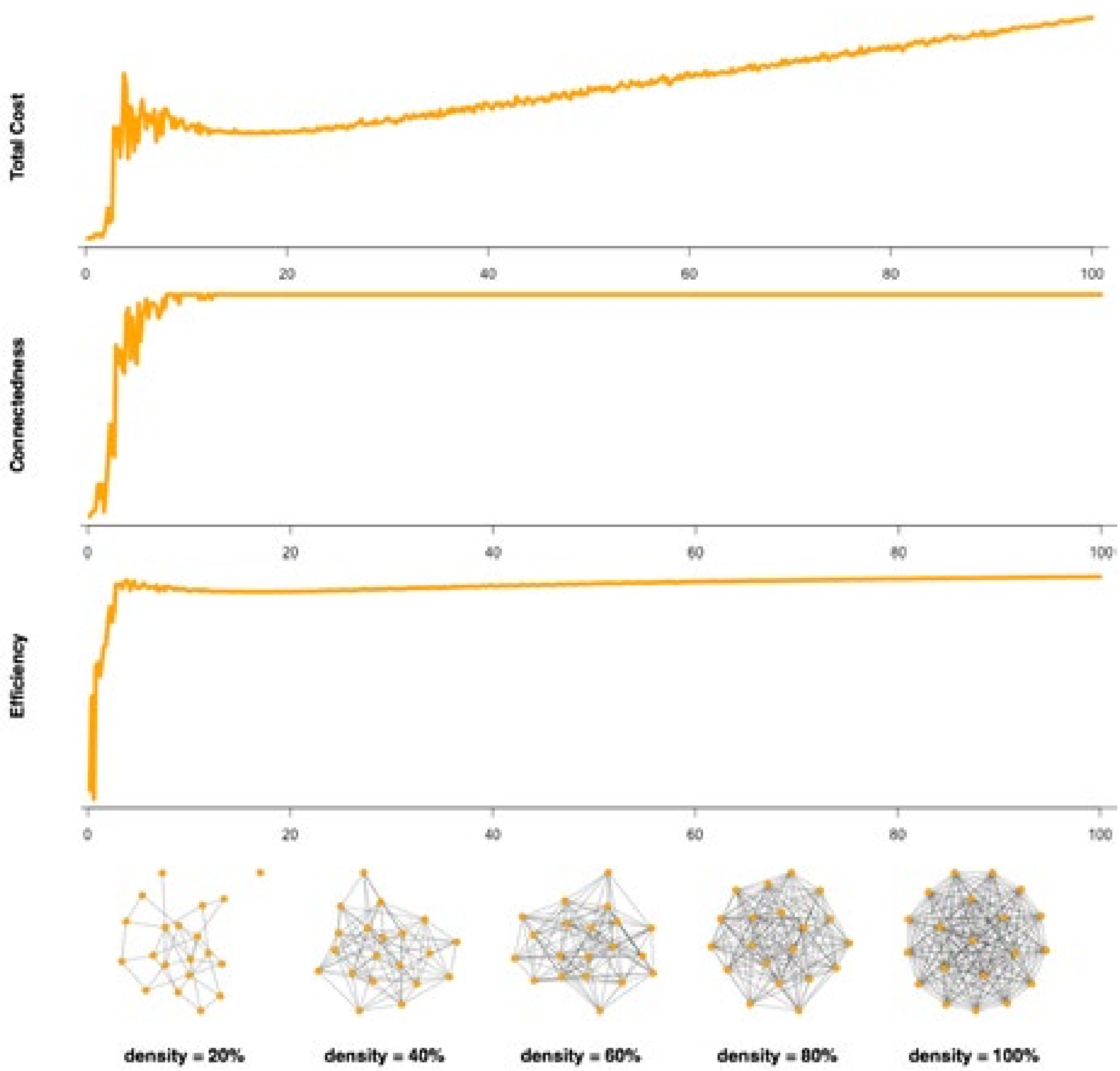


Figure 1.3c
Efficiency of networks of same size (20) and various densities.

Combining the connectedness with the total cost gives us 4 distinct regions of efficiency in the density scale as shown in Table 1.3c.

Density Range	Effect on Efficiency
0.00 % - 2.50 %	Sharp increase
2.50 % - 7.50 %	Stable
7.50 % - 15.0 %	Slow decrease
> 15%	Very slow increase

Table 1.3c
Stages of efficiency of a network with varying number of links

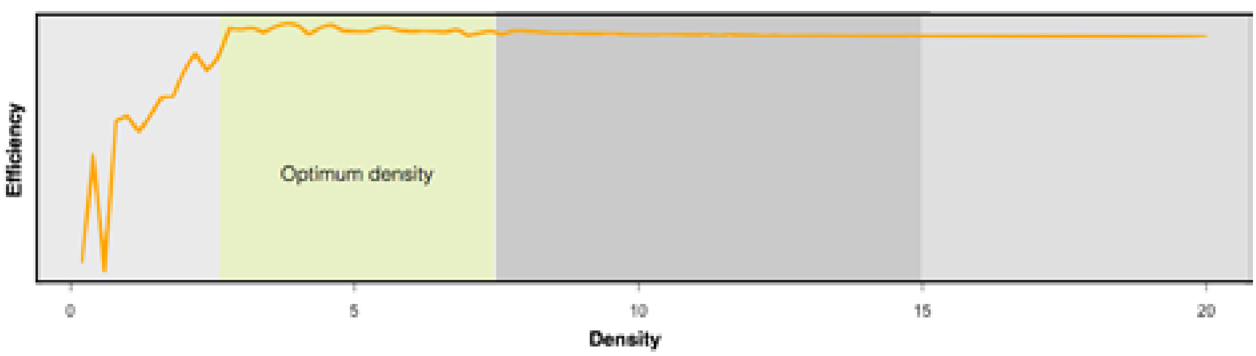


Figure 1.3d
Optimum density range of a network for maximum efficiency.

This enables us to propose that the optimum range for the density of a network is between 2.5% to 7.5%, where the efficiency can be kept relatively stable without increasing the costs. Any densities moving from 0% - 2.5% show a sharp increase in efficiency, while a decrease in density from 2.5% - 0% is undesirable due to a sharp decrease in efficiency. Any increase in the density from 7.5% to 15% has a negligible decrease in efficiency, with a density above 15% offering only a marginal increase in efficiency but a large increase in costs. Figure 1.3d illustrates this optimum range of density for a network.

Prominence of the Actors

The major characteristic of an actor in a network which can be found from network analysis is his/her prominence derived by measuring how central the actor is with respect to the whole network. There are various methods through which this can be analysed and each parameter can explain specific characteristics (network role) of the actor in the project. The various measures are explained below.

<u>Connectivity</u>

The connectivity of a person is the number of people with whom he/she communicates and the number of people who communicate with him/her on any one issue. For example, the connectivity of A in the Figure 1.4a is 4 compared to connectivity of B which is 1.

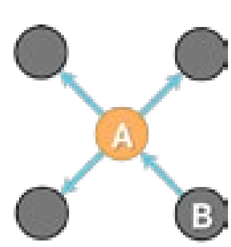


Figure 1.4a
Connectivity

More formally, degree centrality is an indicator of the ‘connectivity’ of an actor, based on measuring an actor’s direct connections. It is categorised into ‘in-degree’/incoming and ‘out-degree’/outgoing centrality, depending on the tie’s direction. In-degree measures ‘receptivity’, while out-degree is a measure of ‘expansiveness’. Degree centrality indicates prominence within one’s own group, but not necessarily beyond that.

Influence

Influence is the measure of the number of people a person is connected to weighted by the relative importance of those connections. For example, despite having the same connectivity, the influence of 4 in the figure 1.4b is greater than that of 1 since it connects to 5 and 6 which have more connectivity than 2 and 3.

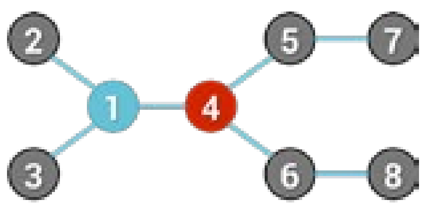


Figure 1.4b
Influence

More formally, eigenvector centrality is an indicator of ‘influence’ which identifies actors who are well connected to other well-connected actors. Actors with high eigenvector centrality have the power to connect to other influential individuals and have the power to build norms and expectations that others in their group will relate to.

Brokerage

A person is a broker to the extent that the communication is likely to flow through him/her. For example, in figure 1.4c, node 1 has the most brokerage potential as it sits between most of the paths between members in the network. Actors with high brokerage have the best opportunity to filter or change information flowing to others in the network, thus information could potentially be delayed, changed or stopped at these points in the network, with either positive or negative consequences.

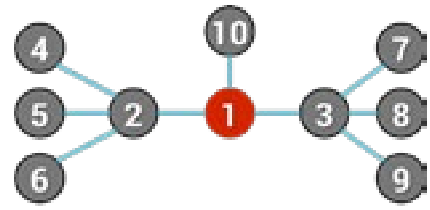


Figure 1.4c
Brokerage

More formally, betweenness centrality is an indicator of prominence and in particular the ‘control potential’, ‘brokerage’ and the ‘coordination activity’ based on identifying actors on the path between most of the other nodes in the network.

They could act as funnels through which most communication travels across the network, or as ‘choke’ points filtering or passing a view of the information, or even misinformation. Some nodes may exhibit high betweenness but lower degree centrality, and often termed ‘boundary spanners’, they are key individuals who connect otherwise disconnected groups and their removal may fragment the network and cease the flow of information.

Communities

Communities in a network are defined as collections of relatively densely connected people compared to the entire network. For example, figure 1.4d shows possible communities in a network. Communities are a set of network actors that are joined together in densely connected groups with looser connections to other parts of the network. Communities may form based on common interest, occupation or co-location. Identifying these sub-structures can offer insight into how networks function and typology may affect each other.

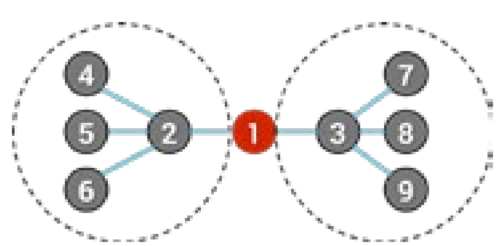


Figure 1.4d
Communities in a network

Pilot Study

As a part of the KTP, a pilot study was conducted between 9th January 2014 and 30 April 2014 for the Bank Station Capacity Upgrade (BSCU) project which captured and analysed the contractual relationships between organisations and communications between the people involved in designing the Central Line escalators. The specific issue being investigated was how its design impacted on the settlements, switchgear and maintenance space proofing requirements.

Objectives

- To apply and test the currently available tools in the collection, analysis and visualisation of the networks.
- To quantify and understand the size, scale and complexity of the contractual and non-contractual networks in a typical large infrastructure project.
- To disseminate the initial research to the team and obtain feedback on how the research can be applied to support future network-based interventions.

Methodology

The pilot study followed the methodology set out in figure 2.1.

Data Collection

The team was issued with a simple online questionnaire capturing the data shown in table 2.1.

What are the details of the respondent?	Name, Organisation, Role, Time spent in project [%]
Was he/she involved in resolving the issue?	[yes/no]
Who he/she communicated with in resolving the issue?	Selected from an expandable list of people [yes/no]
What was the quality of communication for each one?	Frequency [nominal], Importance, Clarity, Accuracy, Timeliness, Reliability, Understanding, [Ordinal -2:2]

Table 2.1
Information gathered in the survey

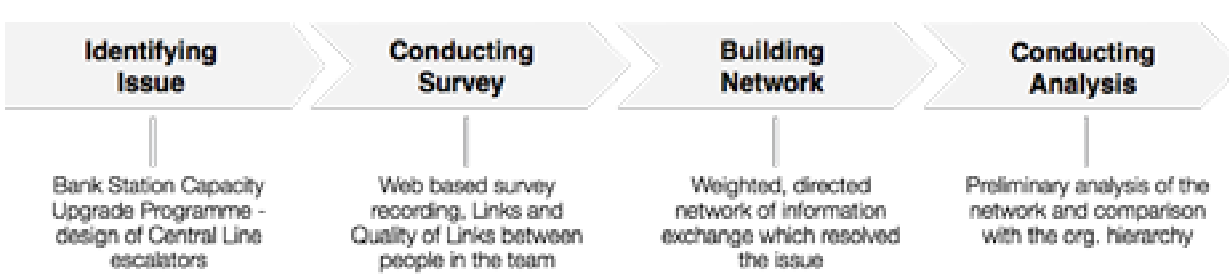


Figure 2.1
Methodology followed in the pilot study

Outputs

The primary outputs of the pilot study were:

- Organisational networks showing the formal contractual links between organisations and people in the Bank SCU project; and
- Communication networks showing the communication links between people involved in resolving the Central Line escalator issue.

A quantitative analysis was conducted to consider the structure of these communication networks, the prominent people in the network and the contrast with the formal organisational and contractual structure. Finally, qualitative feedback was sought from the team on evaluating the networks and deriving inferences from them.

Organisational Network

The Bank SCU project at the design and approvals stage involved contributions from 6 organisations and more than 250 personnel across various teams and roles. The contractual structure consisted of the client (TfL) and three tiers of contractors as shown in Figure 2.2a.

Contractual Reporting Network

The formal organisational structure for the project is linear and hierarchical with a limited degree of mixed teams and responsibilities as shown in Figure 2.2b.

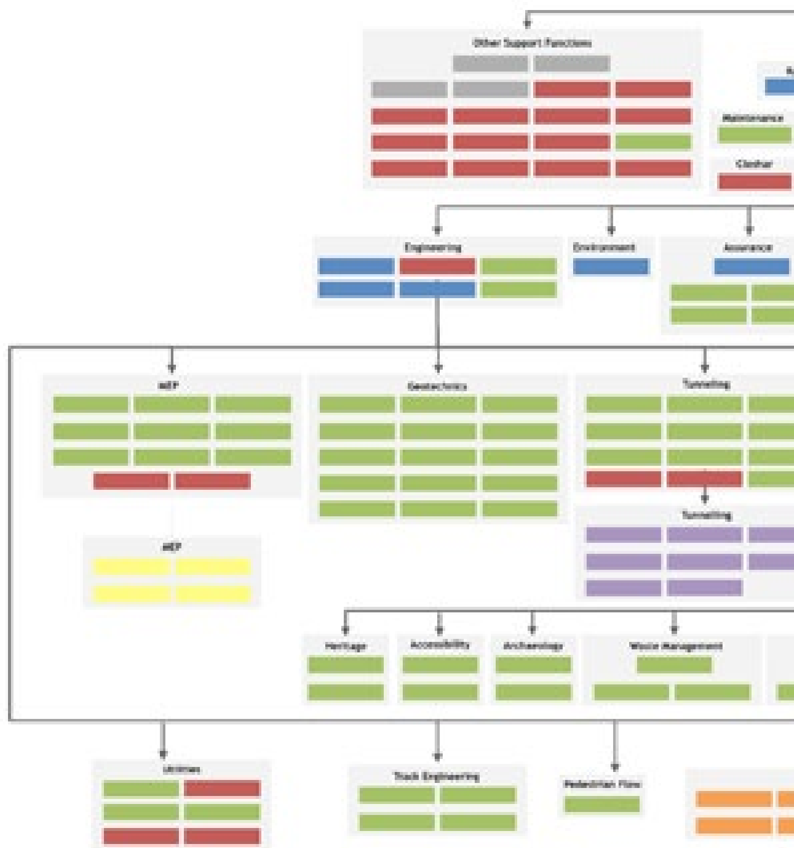


Figure 2.2b
Formal Organisational Structure of BSCU Project (March 2014)

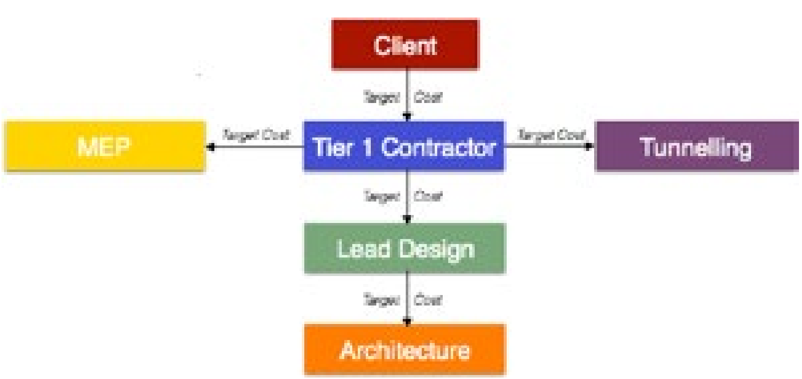
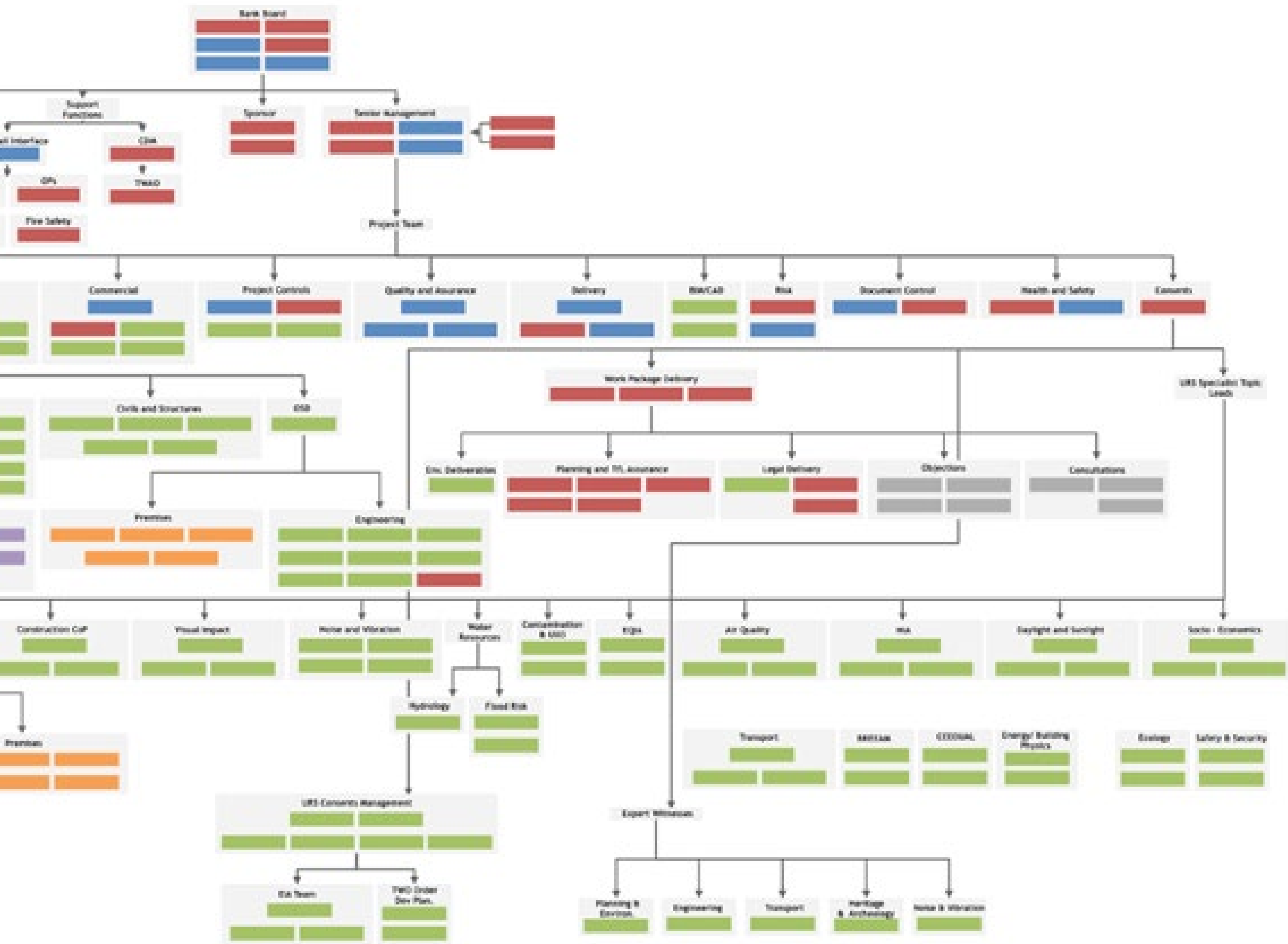


Figure 2.2a
The contractual network between organisations BSCU project (March 2014)



Communication Network

The data collected from the survey was collated to build a network of communications between the people involved in the resolution of the Central Line escalator issue. This was chosen as an example of the project team engaging with a specific task. The network shows who communicated with whom and the strength of their communication links (a collective measure of both frequency and quality). The process of building the communication network is outlined in figure 2.3. The communication network has a size of 60 people and 265 links. The structure of the network is such that any two people in the network are connected within a maximum of 5 steps (or links) and an average of 2.23 steps. The overall structure of the network is shown in figure 2.3.

Figure 2.3
The communication network between people in BSCU project (Jan - April 2014). Please refer to figure 2.2a for a key. The grey dots denote external parties. The three dots in the top right corner each denote an isolated party not connected to others.

Analysis

The communication network was analysed to find the importance of people in the network in terms of connectivity, influence and brokerage. The network was also analysed to bring out the communities of closely connected actors. The network was drawn with a force-directed layout to show the overall structure of the relationship between the actors. These network diagrams were analysed qualitatively and quantitatively along with the senior management team to derive observations and interpretations.

<u>Connectivity</u>

We would normally expect the communication between the Delivery Manager and Engineering Manager to be stronger. There is a possible need for future intervention. We would expect the Lead Engineer for Lifts and Escalators to have a more central role resolving this issue. The Asset Discipline Engineers for Premises and Systems seem to have a relatively central role which is unexpected.

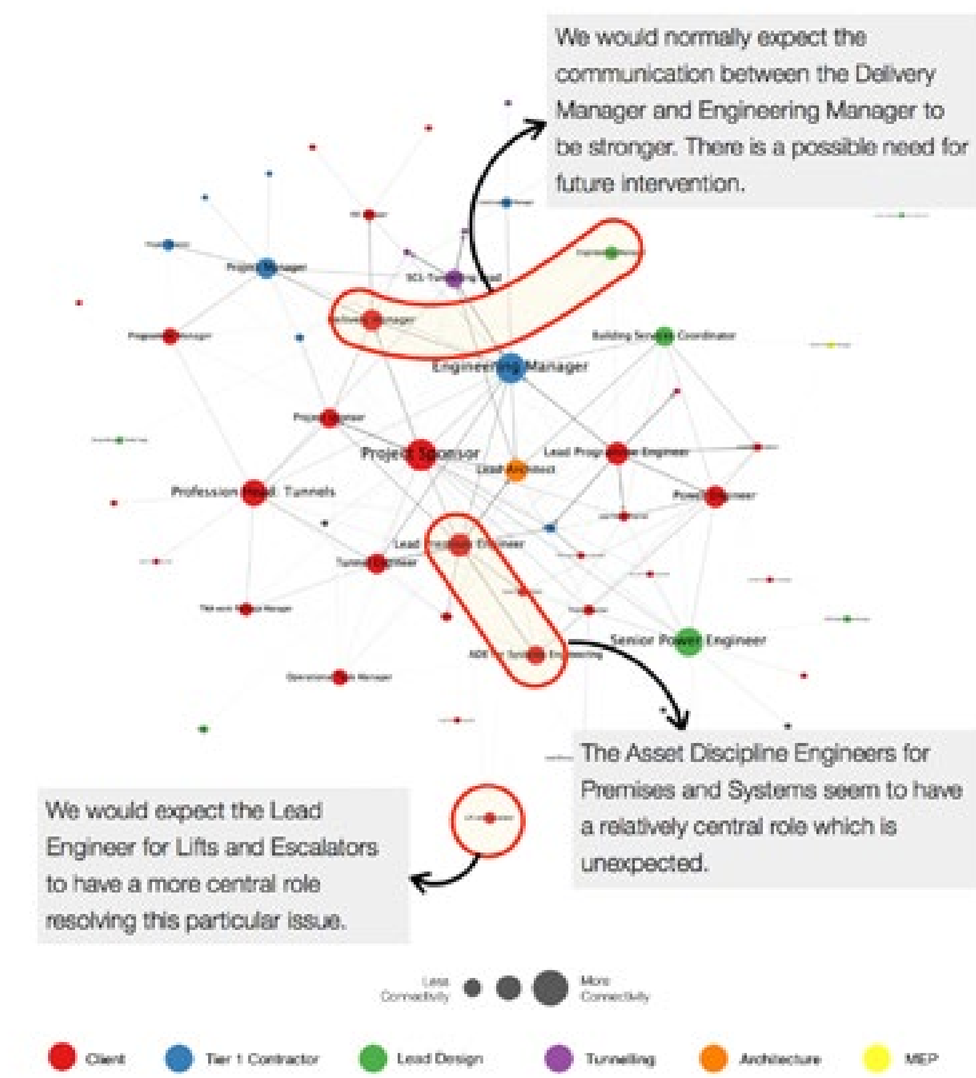


Figure 2.4a
The connectivity of actors within the communication network (March 2014)

Influence

The Senior Management Team is on the periphery while the Project Sponsors are in a more influential position in the network. Understanding why this is the case should be explored further. We would expect the Asset Protection and Discipline Engineer (Maintenance) to have more influence in the network for this issue. The Tier 2 leads have much more influence in the communication network than the formal organisational hierarchy would suggest.

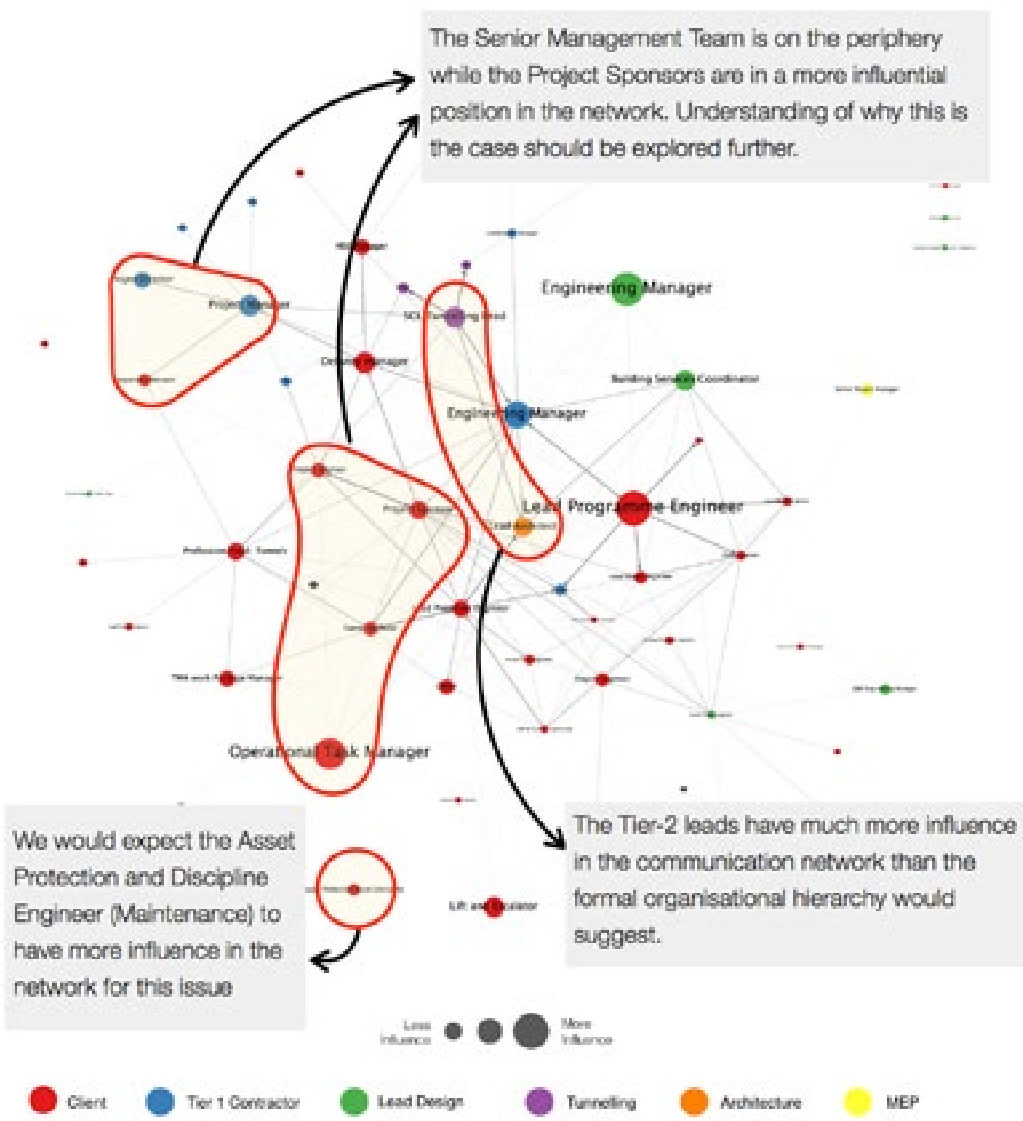


Figure 2.4b
The influence of actors within the communication network (March 2014)

Brokers

Despite having significant influence in the network, the Tier 2 leads on premises and tunnelling have low broker roles in the network. Significantly influential people in the network also have low broker role. This shows that the structure of the network makes these people by-passable in terms of communication flow. This can have both positive and negative implications which need to be explored further.

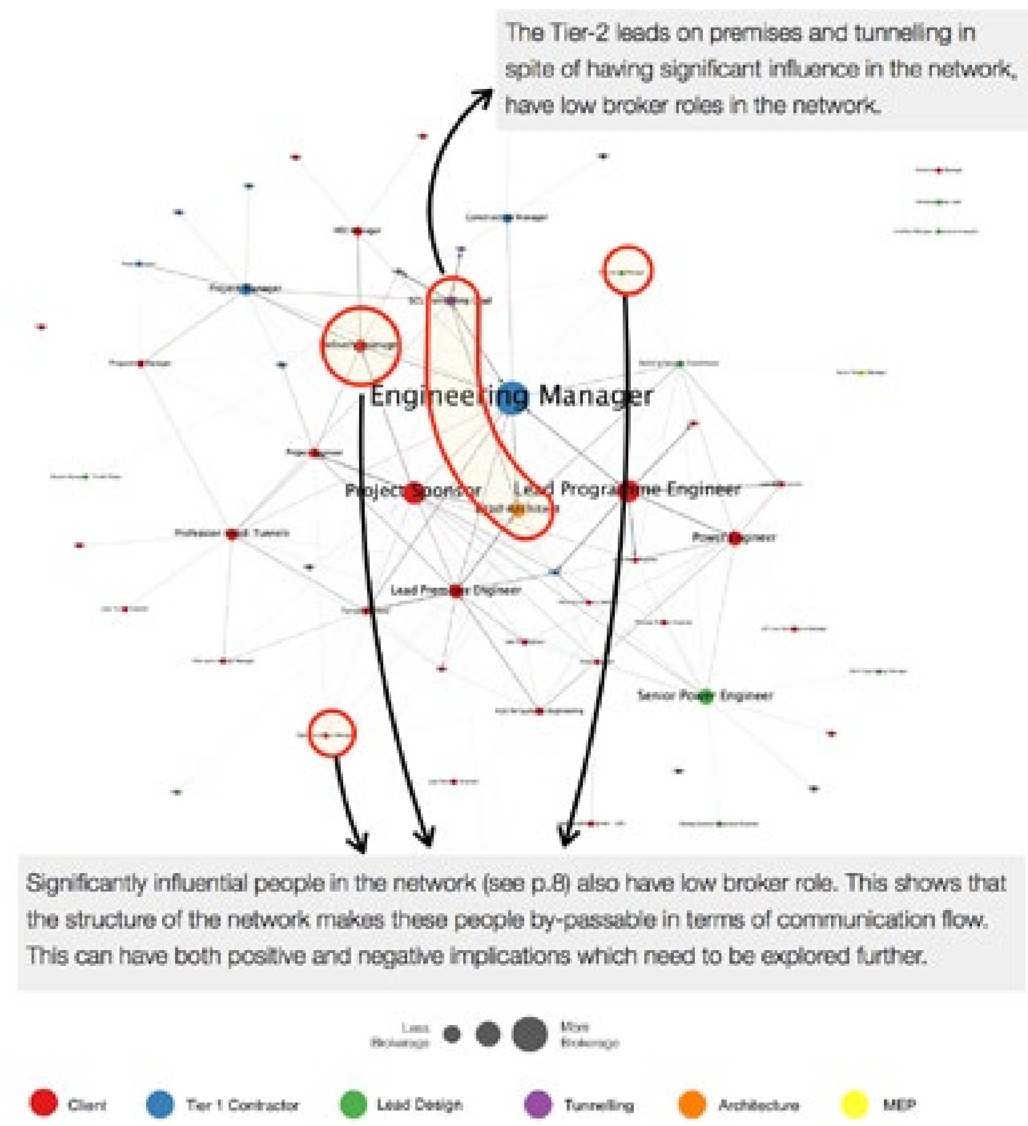


Figure 2.4c
The brokerage of actors within
the communication network (March 2014)

Communities

There are three distinct self-organised communities within the network which are not designed by the management team. These communities are formed around highly influential people within the network and have the themes of “Doing”, “Designing” and “Decision Making”. The ‘Doing’ group consists mainly of people from the Engineering team formed around the Engineering manager. The ‘Designing’ group is formed around Tier 2 designers who, in turn, are around the Tier 2 Lead for tunnelling. The ‘Decision’ making group consists of senior management and sponsors and is formed around the operations task manager.

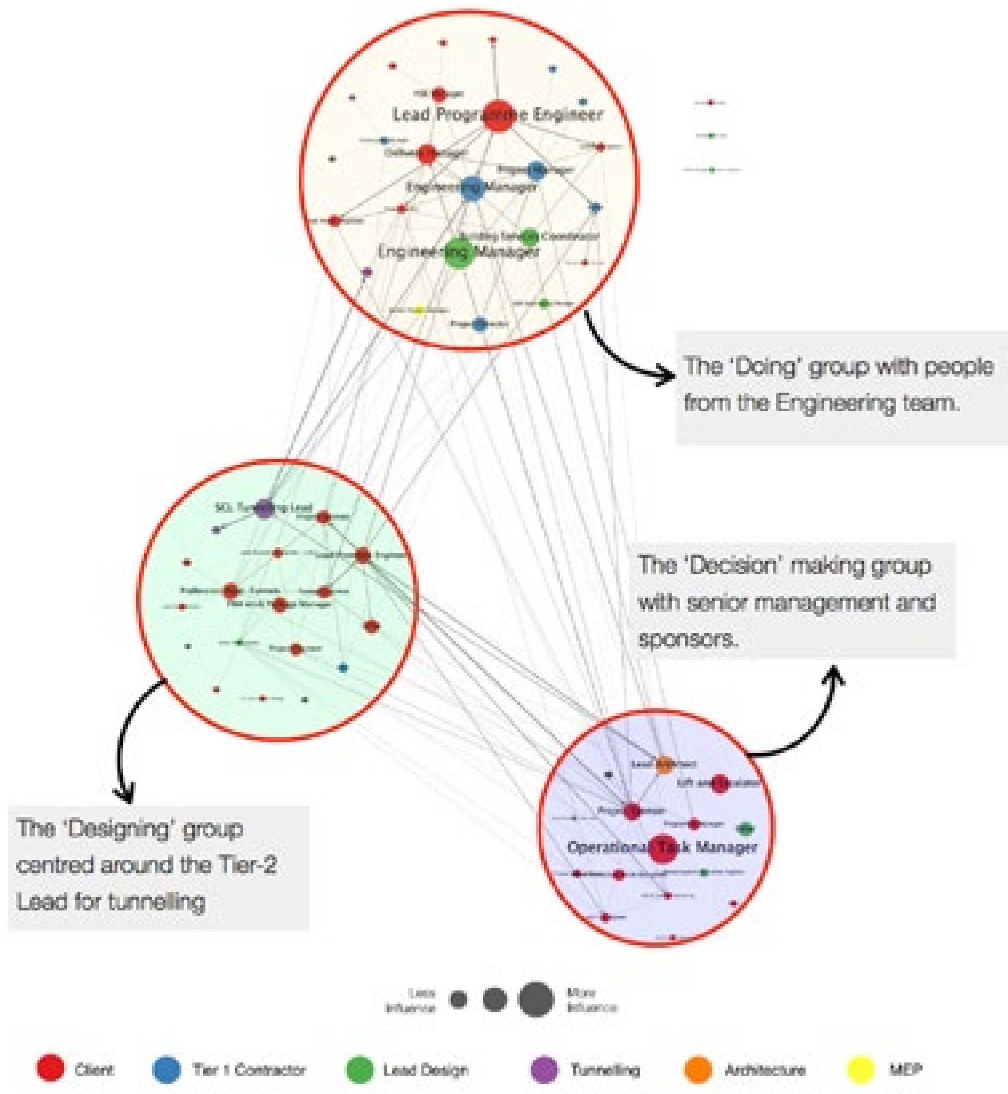


Figure 2.4d
The communities within the communication network (March 2014)

Discussion

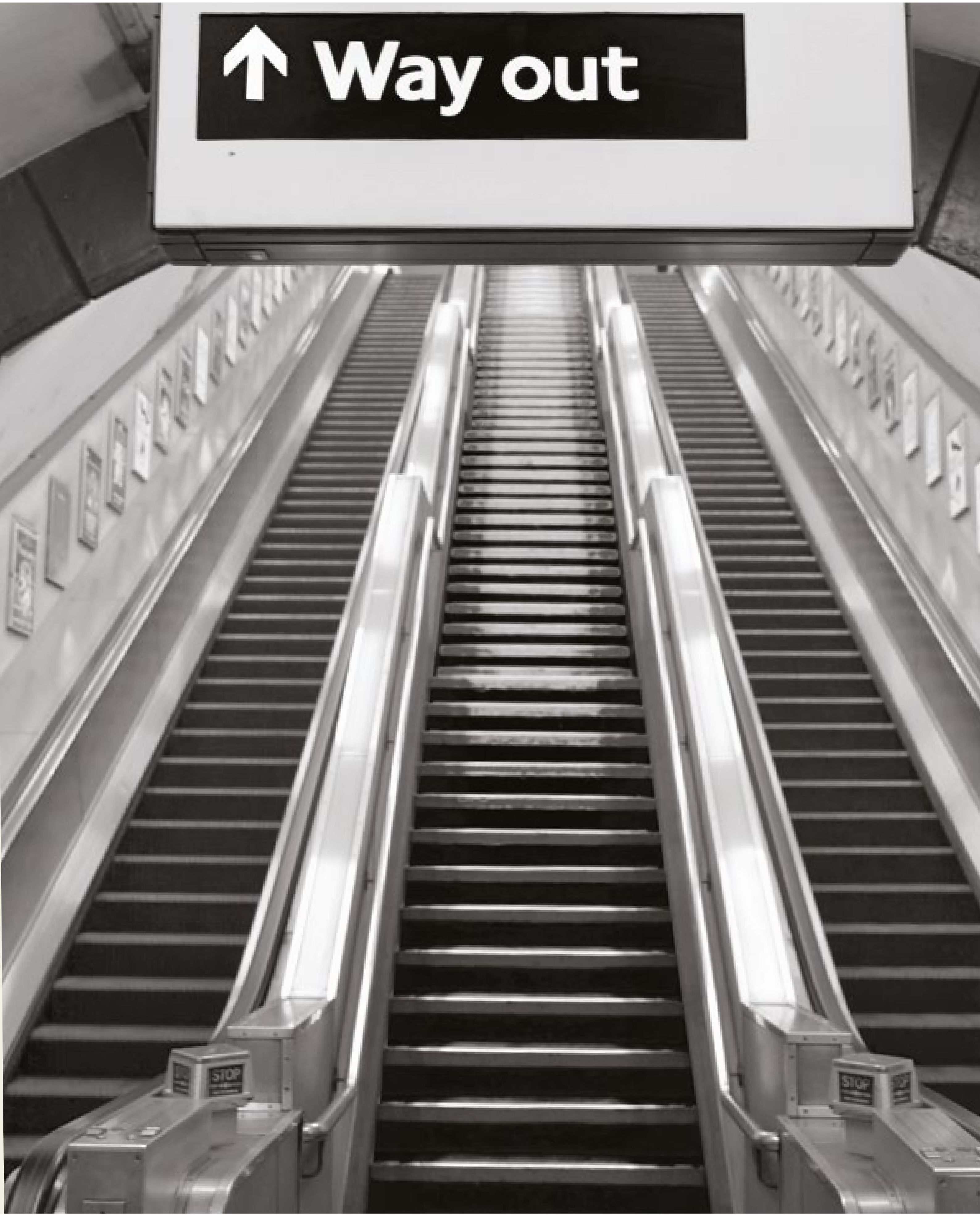
- All the communication networks and the quantitative aspects of them (connectivity, influence, broker roles and communities) broadly matched the intuition of the team about how the team worked together.
- The quantitative network measures also signified the strength and character of the individuals who were represented in the networks.
- Considering that the Central Line escalator design was resolved successfully, these networks are evidence of how the alliance protocol (Bank Board, G5 and the ADT) operated to achieve effective decision making.
- The Central Line escalator issue was an engineering dominated issue which did not require a significant amount of input from other disciplines. This is reflected in the distinct community structure in the team.
- The analysis also helped in identifying and exploring the issues/gaps with respect to network roles within the team.

Learnings and next steps

The pilot study demonstrated the potential for social network analysis to be used by teams and their managers for doing both predictive and reflective analysis of team structures. We have also demonstrated that SNA can be used to understand these communications and relationships and improve their effectiveness, in contrast to a more hierarchical and contractual decision-making process.

We have also established that social network analysis could also be used to demonstrate the effectiveness and success of management measures (e.g. alliance protocol, incentivisation mechanisms) implemented in the project. It might also be used to develop tools to influence and manage communities within the team.

However, to achieve this, further studies should be completed that have a more comprehensive view of the relationships between actors (contractual, hierarchy etc.) and be undertaken over a period (longitudinally) to see how different actors move in and out of the network as the project evolves.


Way out
STOP
STOP

Main Studies

Continuing from the pilot study, comprehensive studies were conducted between November 2014 and May 2015 for the Bank Station Capacity Upgrade (BSCU) project and between March 2015 and May 2015 for the Hammersmith Flyover Strengthening Project. These captured and analysed the contractual relationships between organisations and functional reporting, contractual reporting and communications between the people involved in specific issues identified within the corresponding projects. The objectives, data collection strategy and the methodology for the studies are detailed below.

Objectives

Having defined the aims of the main study and its scope, eight key objectives were identified as follows:

1. To identify and map all the actors who constituted the project, including people and organisations.
2. To understand the organisation of the project in terms of contractual obligations between the actors identified.
3. To understand the organisation of the project in terms of functional links and hierarchies defined for the project between the actors.
4. To map the information exchange network between actors, over time, during the detailed design phase of the project.
5. To attach quantitative values in terms of time(a), money(b) and risk(c) to the contractual, functional and information exchange networks identified in the organisation.
6. To analyse the identified networks using SNA techniques to find patterns and roles emerging from the organisation overall and individual actors.
7. To qualitatively assess the emerging networks alongside the quantitative data (Objective No. 5) to find out those areas of the organisation which are working well or which need improvement and identify possible improvement measures.
8. To design and implement the improvement measures identified and track the impact the measures have in the networks and the overall project.

Scope

Since the entire projects of detailed design for BSCU and HFO were large and complex enough to generate complete information exchange networks it was a challenge to identify the cause and effect of these networks' measures. Because of this, it was essential that the scope of the research was narrowed to either a work package, a complex multidisciplinary problem or specific risk items identified in the project which could be clearly delineated with a determinable boundary.

Keeping in mind the above criteria, the detailed design of the station box and new ticket hall was selected in BSCU and the finalisation of the detailed design (expansion joints, permanent monitoring, bearing pit covers and pavement reinstatement) in HFO were selected as the aspects to be studied. This study's scope was limited to the issues mentioned above which fall within the timescales of the KTP project. The data was captured at certain intervention points as detailed in the data collection strategy.

Data Collection

Keeping in mind the objectives, all the data required and their corresponding sources are identified and listed out in table 3.1.

Objective	Required Data	Sources
1	People directory	Administration team
2	Contracts	Commercial team
3	Organisational Hierarchy	Project Controls team & team Leads
4	Questionnaires	Primary Survey
5a	Cost Codes and related data	Commercial team
5b	Activity Codes and related data	Project Controls team
5c	Risk Codes and related data	Risk Management team

Table 3.1
List of data to be collected and respective sources

The collection of the above data, excluding item 4, were commenced early and completed before the commencement of the primary survey. This data was updated regularly along with the primary survey collection as outlined below.

Primary survey

The primary survey was designed to capture both the communication links between people involved in the specific issue identified within the project and the quality of those communications. It aims to verify and validate certain information acquired through the secondary data collection. The primary survey was carried out using the network study toolkit (detailed in appendix 2).

Timescales

The primary surveys were conducted according to the schedule in table 3.2 a and b. Following each survey, an analysis of the issues and the schedule of activities for the work package was carried out to ascertain if there were more appropriate and subjective intervention points, rather than a fixed timescale approach.

Stage	Duration
1	Nov 2014 - Jan 2015
2	Mar 2015 - May 2015

Table 3.2a
Survey times for BSCU project

Stage	Duration
1	Feb 2014 - April 2015

Table 3.2a
Survey times for BSCU project


UNDERGROUND
BANK STATION
Exit 5
St Paul's Cathedral
Magistrates' Court

Bank Station Upgrade Project

The Bank Station Capacity Upgrade is a project within London Underground Limited which was selected as the case study for the KTP. This project is unique in that it is part of several pilot projects that aimed to promote collaborative working arrangements to drive down the cost of risks associated with successful project delivery.

With an estimated cost of £563m, the project was initially launched in 2003. It went through the development of several options before arriving at a base case in 2011. In 2012, it entered an innovative and novel tender process entitled Innovative Contractor Engagement (ICE), which saw the Tier 1 contractor and their supply chain involved in the creation of a revised design that enhanced the project's business case. The conceptual design was completed in May 2014 and application for permission under Transport and Works Act Order was submitted in September 2014. The detailed design process started by August 2014, while the construction started in Spring 2016. The project at the conceptual design stage involved contributions from more than 20 organisations and more than 250 personnel across various teams and roles.

Scope and Research Question

The scope of this study is the detailed design of the station box/whole block site (WBS) and new ticket hall within the detailed design stage of the BSCU project. The specific research question asked to the participants was as follows:

"With respect to the ongoing development of all aspects (design, commercial, planning, reporting, operation, maintenance, construction, etc.) of the detailed design of the station box and ticket hall, as defined by the boundaries in the 3D CAD model, the cost account codes, activity codes and risk codes [provided to the study participants], please identify those people with whom you have exchanged information with (either to or from) within the last four weeks.

Once identified, please describe the predominant nature of the information exchange within the last four weeks. Please then go on to describe the quality of information that you 'receive' from that person."

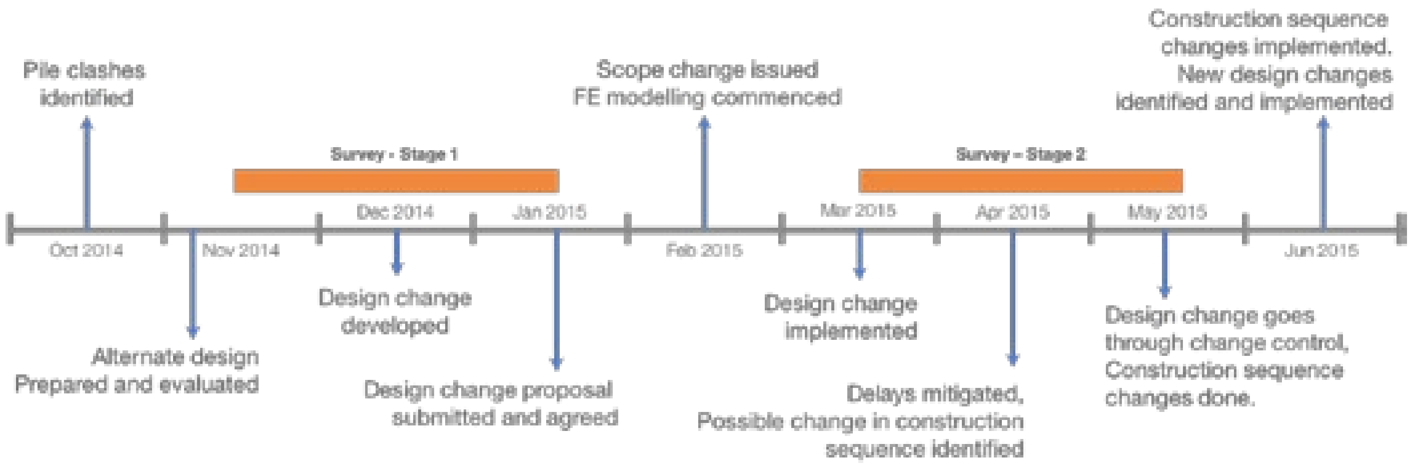


Figure 3.0
Context for the main study surveys on BSCU project

Context

During the study, from October 2014 to June 2015, the detailed design of the station box underwent major changes. To summarise, around October 2014 while conducting the detailed design of the WBS, pile clashes were identified which required the development of alternate designs and construction sequences for the whole block site. This was carried out through the rest of the year resulting in some delays to design activity but which was ultimately mitigated. By January 2015 the final decision on design change was made and was sent through change control by May 2015. Around April 2015, new information was received from London Underground which, along with the design change, resulted in changes in the construction sequence to get some time savings. These changes were carried out in May 2015 and were implemented by June 2015. The events are shown in figure 3.0 below. They are not described in detail in this report but are used as a contextual understanding for the networks and derived from project reports and discussions with the project team.

Networks

The data collected was collated and combined to produce four different types of networks for the BSCU project. The communication network was created for both stages of the survey and was compared.

<u>Organisational Network</u>

The BSCU project involved around 18 organisations contractually connected to each other. The structure is hierarchical with Transport for London at the top as the client and three tiers of contractors who are connected with the tier immediately before or after them. With this network, we can see that Dragados has the most connectivity and 'brokerage' but Robert Bird Group had the most influence.

<u>Functional Reporting Network</u>

The functional reporting network between people is shown in figure 3.2. In this network, we can see a lot of disconnected hierarchies, which are homogenous in terms of the membership organisations. This is unsurprising, recognising that ‘functional’ leads often reside in the individual’s host organisation. The connectivity analysis of this network shows that the functional leads and functional heads of these organisations have the most connectivity with a relatively large number of people reporting to them. Again, this is unsurprising in a functionally-structured organisation. The distribution of connectivity

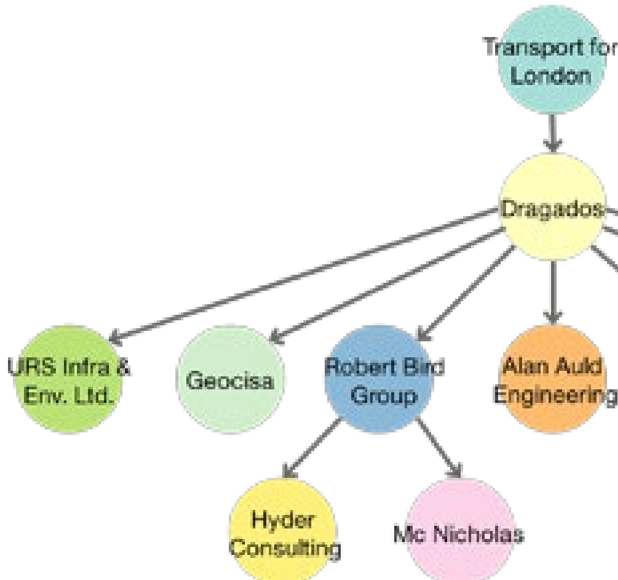


Figure 3.1a
The contractual network between organisations for Bank SCU project (2015)

within the functional reporting network therefore results in a few heavily connected nodes (hubs) and many low connectivity nodes.

What is most notable in the functional reporting network diagram is the large number of actor dyads in the centre. These are people who report to their corresponding managers in the home organization but who are not necessarily directly involved in the project. There is a noticeable difference here between the client organisation and the contractor organisation. Within the contractor organisation, the project manager is seen as the functional lead, whereas the client organisation is dominated by the actor dyads in the centre of the network, suggesting a much more 'functionally' structured organisation.

Much can be inferred from this network diagram that was not specifically looked at within the timescales of this study. However, questions for further research could include: Is such a functional reporting network common among temporary inter-organisational structures in the construction industry? Does this difference in functional reporting structures affect the ability of the member organisations to the temporary organisation to become more integrated?

Contractual Reporting Network

The contractual reporting network between people is shown in Figure 3.1a. In this network, compared to the functional reporting network, there is a single large connected component and lesser disconnected components. The single large component is formed by the reporting structure between the leads in these clusters who were not connected in terms of functional reporting. We could infer that the contractual/line reporting within the project is much more cohesive and collaborative and such inference was intuitive to the senior management's vision and expectation for the project.

However, there are significant disconnected components within the client organisation, particularly engineering and commercial management. This raises questions as to why they see themselves reporting both functionally and contractually (as defined within this study) outside of the project. Within traditional matrix structures where clients establish temporary organisational project structures, it would be expected that these would be split between the project manager of the project (contractual) and the functional manager of the host organisation (functional).

Much can be inferred from this network diagram that was not specifically looked at within the timescales of this study. However, questions for further research could include: Does the client organisation experience a more fragmented decision making process? How is authority distributed, used and indeed perceived in such functional organisations and what impact does that have with integration of supply chain organisations?

Interpersonal Communication Networks

The communication networks between people in stages 1 and 2 are shown in Figure 3.4a and 3.4b. Their key global parameters are given in Table 3.3 along with a comparison to the global parameters of the communication network in the Hammersmith Flyover strengthening project which will be discussed in detail in the following chapters.

Size

The network starts with 162 actors in stage 1 and grows around 21% to a size of 197 in stage 2. This might be due to the appointment of the Robert Bird Group for the design process, the completion of this and the introduction of the planning team into the specific issue. The issue under consideration also changed from being a specific engineering issue to a design change proposal which needed to be included in the broader design and planning of the project. This brought more actors into the network.

	BSCU Stage1	BSCU Stage2	HFO
Size (Actors/Links)	162 & 1440	197 & 2207	57
Building Cost	£ 0.72 m	£ 1.10 m	£ 0.12 m
Operating Cost	£ 0.78 m	£ 1.16 m	£ 0.10 m
Total Cost	£ 1.50 m	£ 2.26 m	£ 0.22 m
Per unit link Cost	£1,043	£1,025	£902

Table 3.3
The global parameters of the Interpersonal communication networks

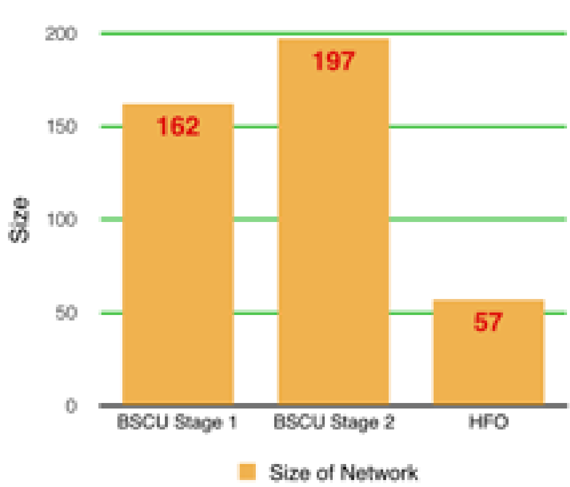


Figure 3.1b
The size of the communication networks.

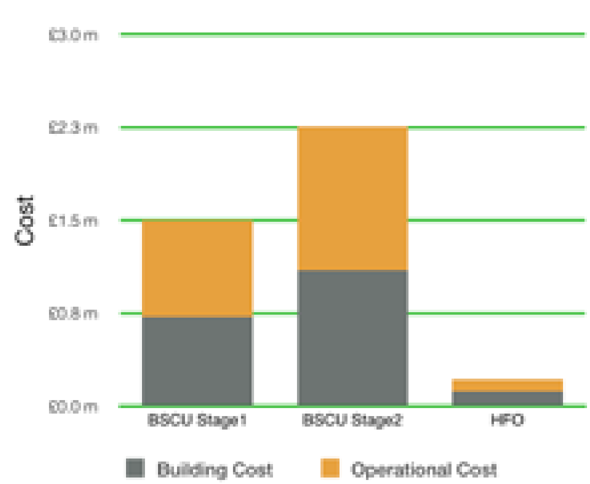


Figure 3.1c
The size of the communication networks.

Cost

With a 21% increase in the size of the network, there was an exponential increase in the building cost of the communication from stage 1 to stage 2. Assuming an average of one working day needed to build a link in the network at the assumed average rate of £500 /day, the size of the network cost around £0.72m and £1.10m to build respectively showing a 38% rise. Assuming an average of three communications between any two connected actors in a month at a rate of £10 (10 mins) the operational cost of this network for a month was approximately £0.78m and £1.16m in stages 1 and 2 showing a significant 48% increase between the stages. This shows that the network went through a more intense process of densification in addition to growth during this period.

This compared to the random graph scale for density (figure 3.1d) shows that the increase in the cost with respect to the density of the network would be volatile and might not increase significantly until 7.5% density.

Efficiency

IIn the context of the increase in the size and density of the network, we see that the efficiency of the network has improved over time from stage 1 to 2. This is shown by the per unit link cost of the network which improved by 2% from £1043 to £1025 which, with the size of the BSCU project, translated into a total saving of £0.5m per year for resolving this specific issue. The increase in efficiency also showed that the project had matured from stage 1 to 2 and was organising itself more efficiently as the actors reinforced and strengthened the links between them over time. The comparison of the current project stages with the density scale of random graph is show in figure 3.1f.

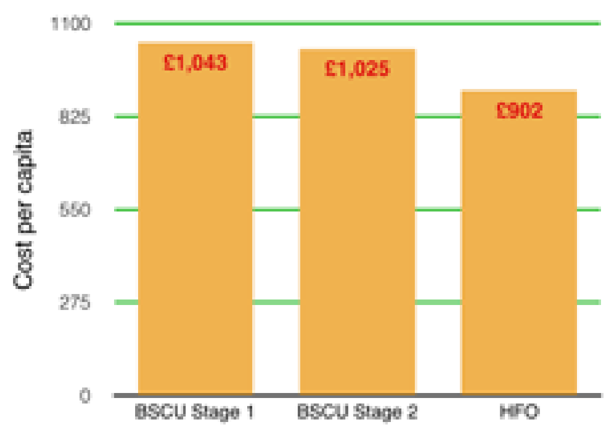


Figure 3.1e
The efficiency of the communication networks (Stage 1 and 2)

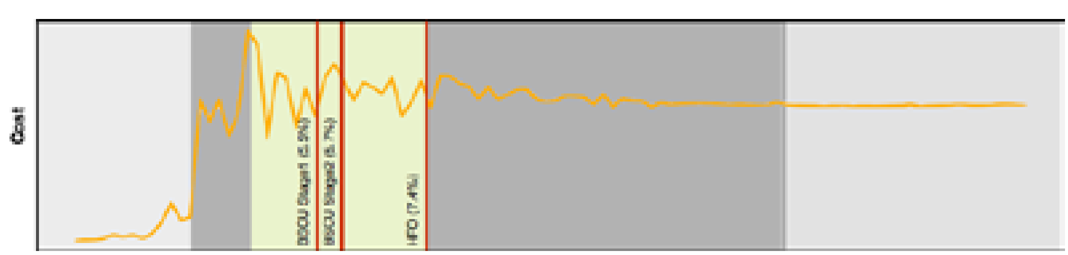


Figure 3.1d
The cost of the communication networks with respect to random network (Stage 1 and 2)

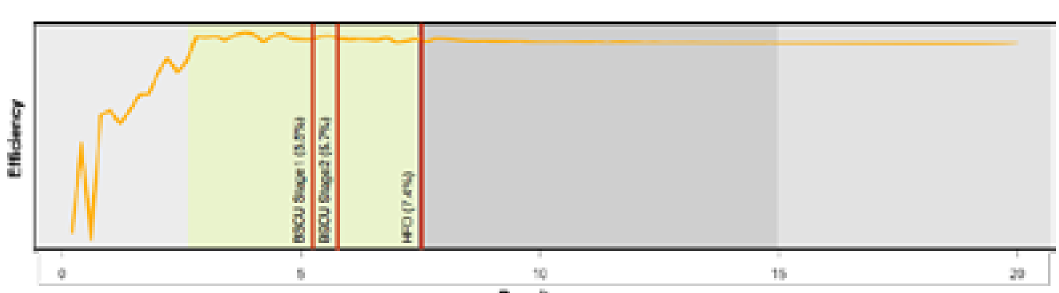


Figure 3.1f
The efficiency of the communication networks with respect to the random networks (Stage 1 and 2)

Analysis of interpersonal communication network

Connectivity

The diagram showing the connectivity of people in the network is presented in figure 3.5a and 3.5b. In stage 1 (figure 3.5a), we can observe that the network is more evenly distributed in terms of clusters of people from same organisation, where all organisations involved in the project are equally represented. We also observe the presence of a cluster of many high connectivity nodes who are connected with each other with strong links. There is some indication of clustering according to organisation (homophily).

Dragados, the Tier 1 contractor had the most reach in the network with most connectivity on average. The distribution of connectivity was even within Dragados and exponential in T-Clarke, Robert Bird Group and Transport for London as the client. This shows the presence of strong hubs in the Tier 1 contractor who connect the rest of the organisational teams for collaboration.

The strongest links within the network are equally distributed within organisations and between organisations. This shows that there are high connectivity nodes who connect everybody within the organisations and, in turn, they connect with themselves and the Tier 1 contractor to form the broader network. An example can be seen in Mechanical Design Engineer in T-Clarke, Lead Premises Engineer in Transport for London and Senior Technical Engineer from Wilkinson Eyre. There were instances of personnel being embedded within different organisations in the communication networks. This can be seen in the Technical Director, in Geotechnics who was deeply embedded within the Dr Sauer & Partners cluster and the Project Manager from the TfL client within the Tier 1 contractors.

We can also observe that there was a significant design management cluster in the middle of the network which formed around the Project Engineer, Dragados. Apart from this, we can also observe two areas around this design management axis, where the prominence of actors was distributed differently. The area which carried out the design function showed a more exponential distribution of prominence, relatively few major hubs and more low prominence nodes. The area which carried out the regular project management function showed a more even distribution of prominence. This local variation in the distribution of prominence could be an indicator for the activity within the network and could also be used to infer any problems in the network.

We also found two major exclusive clusters where many nodes are connected to a single prominent actor. This can be seen around Mechanical Design Engineer in T-Clarke and Engineering Manager from Transport for London. This might be due to the key actor being a gatekeeper or the team being relatively new to the project.

As we move towards to stage 2 the network changes in two ways:

1. The prominence of actors in terms of connectivity become much more exponential, emphasising the presence of major hubs.
2. The network becomes more inter-organisational, though clusters of same organisations still exist. The actors are distributed and embedded in the network more evenly.

This shows the network maturing as the project moves forward in the project cycle and the actors in the network realign themselves to be more connected.

We also observe that the prominence remaining within Tier 2 has shifted significantly to the planner. He/she commands a closed cluster of low connectivity actors from various organisations communicating with him/her. As we saw in the stage 1, this might be the indication of strong activity within this aspect of the design/planning within the project.

We also notice the isolated groups around the Senior Engineer for Robert Bird Group and the Project Manager, Tunnelling for Dr Sauer and Partners, which is like the patterns seen in stage 1.

Influence

The influence of people in the network is shown in figure 3.6. Influence is not distributed in the same way as connectivity. In stage 1 it is more evenly distributed and in stage 2 it is exponentially distributed. Overall, influence is more exponentially distributed than connectivity. This suggests that many people are active in the network and that there were few key people in the network who influenced most decision-making.

In stage 1, the prominent actors were from M&E, structures and premises and this moved towards Project Controls in stage 2, suggesting that the presence of influential actors is reflected in the activity within that local group in the network. This is an indication of whether the right people are involved in the appropriate issues and to see where the problem areas were in a broader communication network. In this case, stage 1 shows a much more collaborative network where many influential actors are working together, while stage 2 showed project controls taking over the issue.

We also observed a hierarchy in the distribution of influence where there were people of high influence within every discipline and organisation and there were influential people within this group of people with high influence.

Brokerage

The brokerage of actors in the network is shown in figure 3.7b. We can observe that in contrast to connectivity and influence, brokerage is exponentially distributed. This suggests that, in terms of brokerage, there were key gatekeepers in the network who had influence over most of the communications in the network.

We observe that, in stage 1, the key gatekeeper in the network was the Project Engineer with Civil and Structures who was the work package manager for solving the specific issue. This is intuitive and would be expected from this network. This changes drastically in stage 2 where there were brokers in every discipline. This showed that, although the network became more centralised in terms of connectivity and influence around the Project Planner, it became more distributed in terms of brokerage moving from stage 1 to 2.

Communities

The communities in the network are shown in figures 3.8a and 3.8b. In stage 1, there were seven inter-organisational, inter-disciplinary communities organised around the major themes of design, management and special functions. A simplified depiction of the communities and the themes they belong to is shown in figure 3.8c. The major community is project management and design management since the design change was identified during this time and the alternatives were being finalised. The communities are strongly connected within themselves and strongly connected within the themes. We observe that the communities formed around a small number of relatively prominent actors and these influential actors were strongly connected within those communities. This shows that the communities were emerging from personal work based ego networks of influential actors within the network. We also note that Community 7 was homogeneous in terms of both organisation and discipline. This may be due to fact that the team was included recently to the project and still in the process of integrating into the project.

As we move from stage 1 to 2, the communities merge and we see a community structure as shown in stage 2 in figure 3.8c. From the context, we see that functions move from design to project control and this may be due to the completion of the design changes and implementation of the construction sequence change into the program. The M&E community is more or less homogeneous and more connected as the project matured.

Figure 3.8c
Community structure in interpersonal communication network – Stage 1

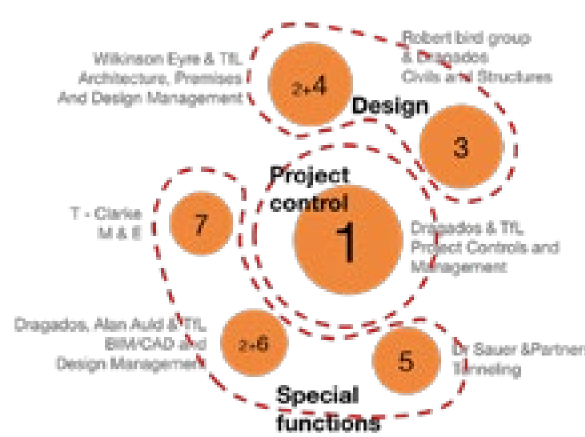


Figure 3.8c
Community structure in interpersonal communication network – Stage 2

Functional and Contractual Reporting Networks

Color – Organisation, Size - Connectivity

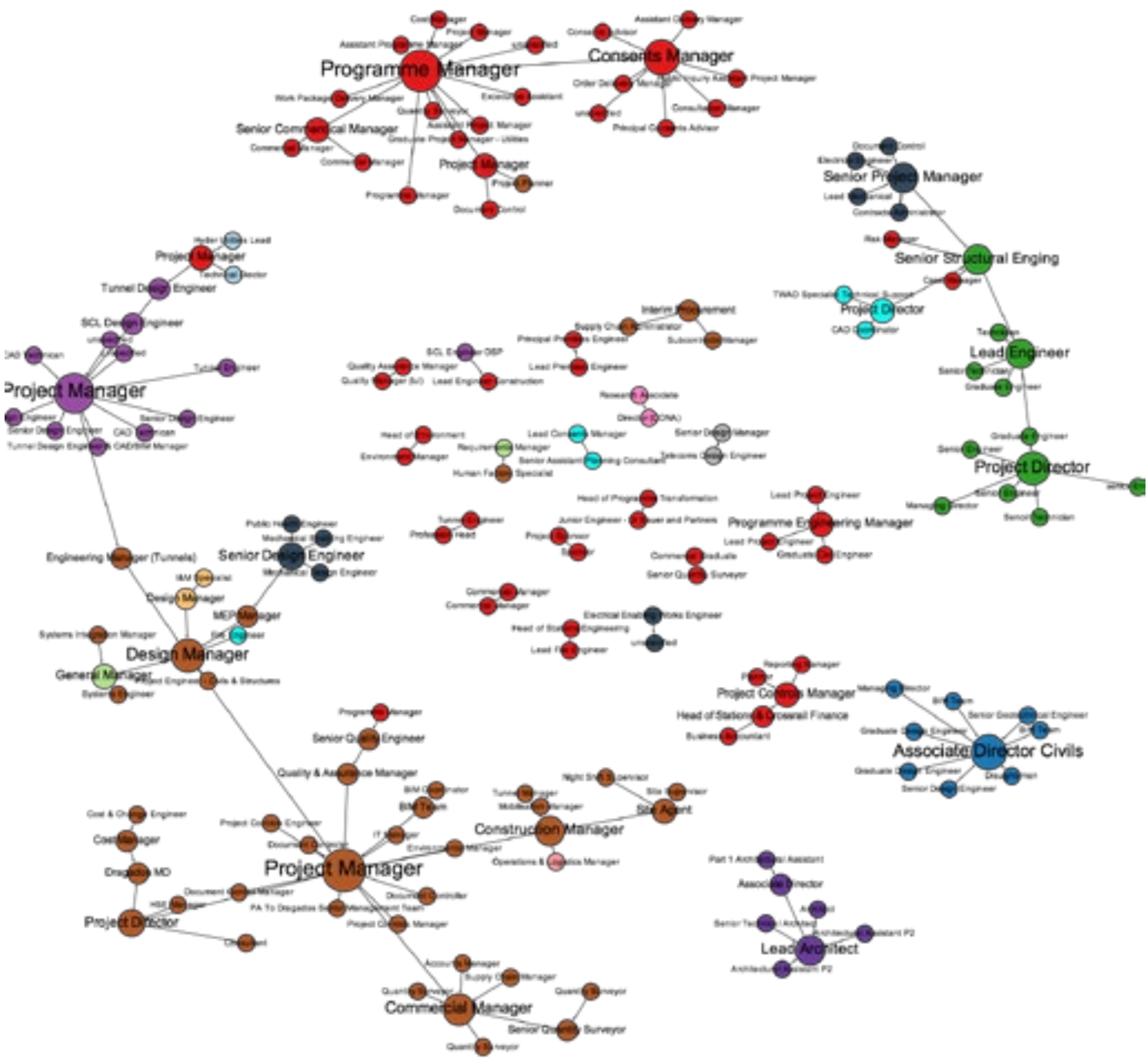


Figure 3.2
Functional Hierarchy

Figure 3.3
Contractual Hierarchy

Connectivity (Degree Centrality) of a person is <u>the number of people</u> who <u>he/she communicates with</u> and the number of people who <u>communicate with him/her</u> with respect to scope of the study.

e.g. Connectivity of A in the figure is 4 compared to connectivity of B which is 1.

Less Connectivity · More Connectivity

Transport for London · URS Infra & Env. Ltd. · T Clarke · Wilkinson Eyre · Robert Bird Group · Hyder Consulting
Dragados · Mc Nicholas · Dr Sauer & Partners · Geocisa · Alan Auld Engineering · Others

Inter Personnel Communication Networks

Color - Organisation

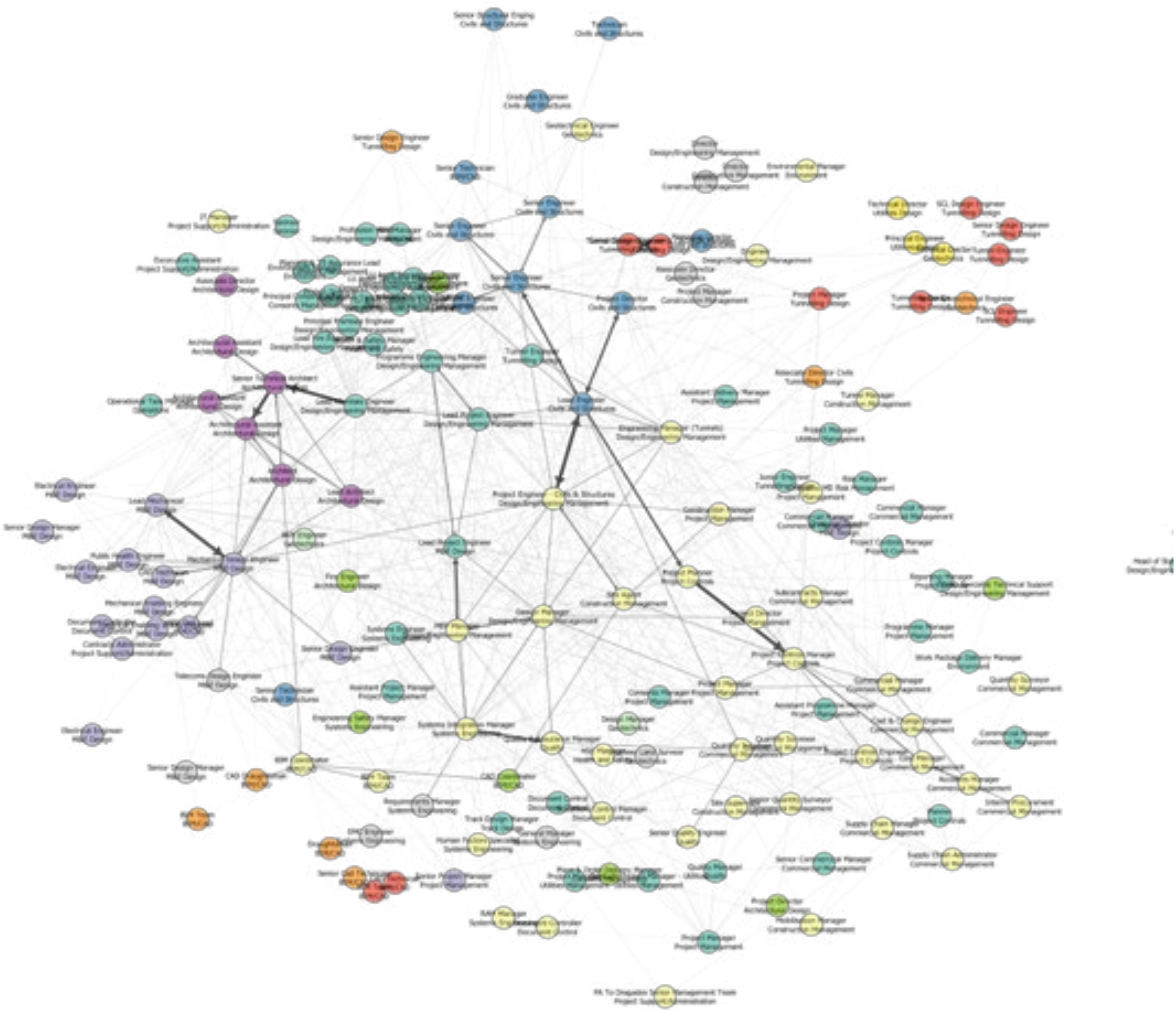


Figure 3.4a
Communication Network - Stage 1

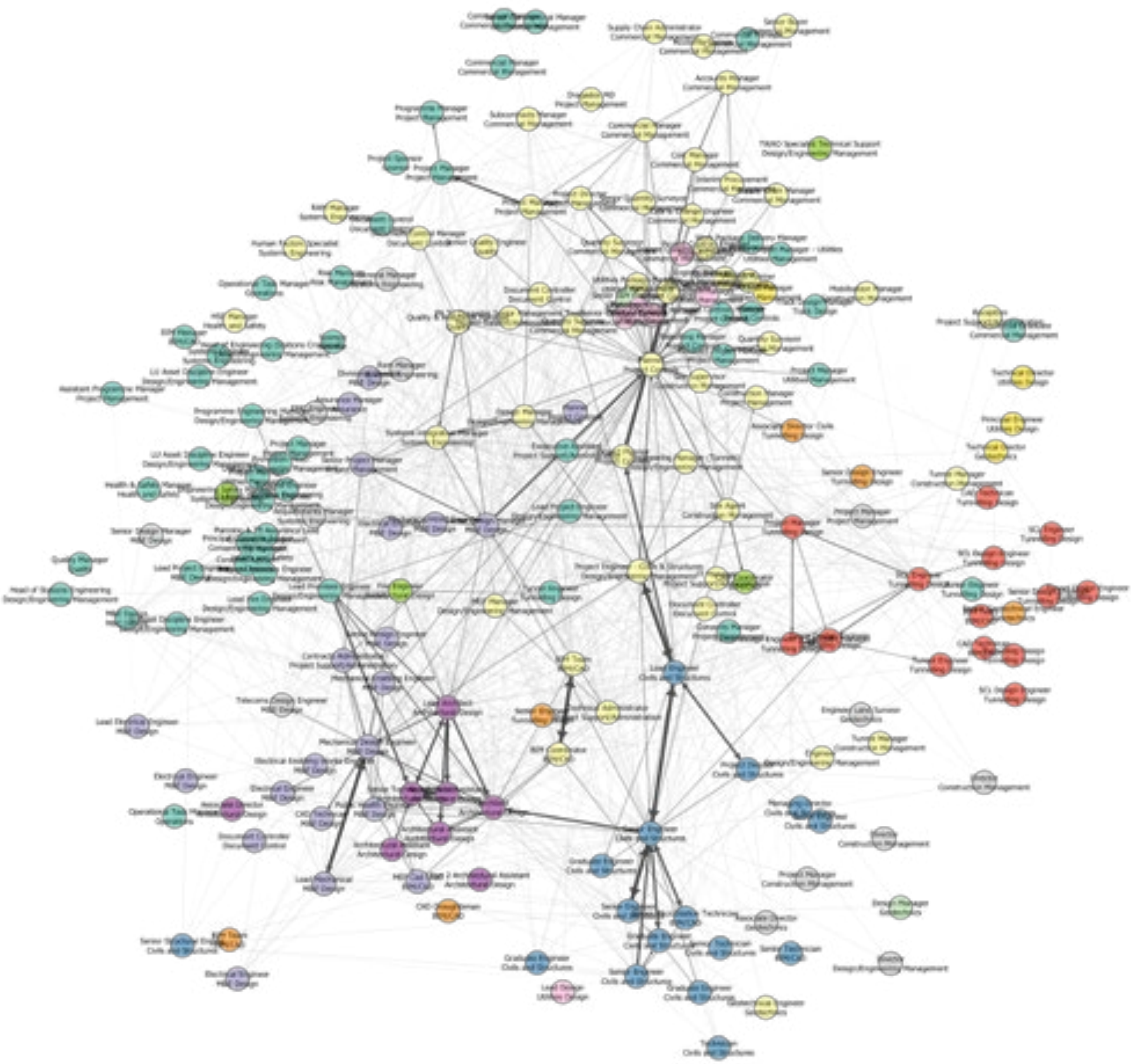


Figure 3.4b
Communication Network - Stage 2

Transport for London · URS Infra & Env. Ltd. · T Clarke · Wilkinson Eyre · Robert Bird Group · Hyder Consulting
Dragados · Mc Nicholas · Dr Sauer & Partners · Geocisa · Alan Auld Engineering · Others

Inter Personnel Communication Networks

Color - Organisation, Size - Connectivity

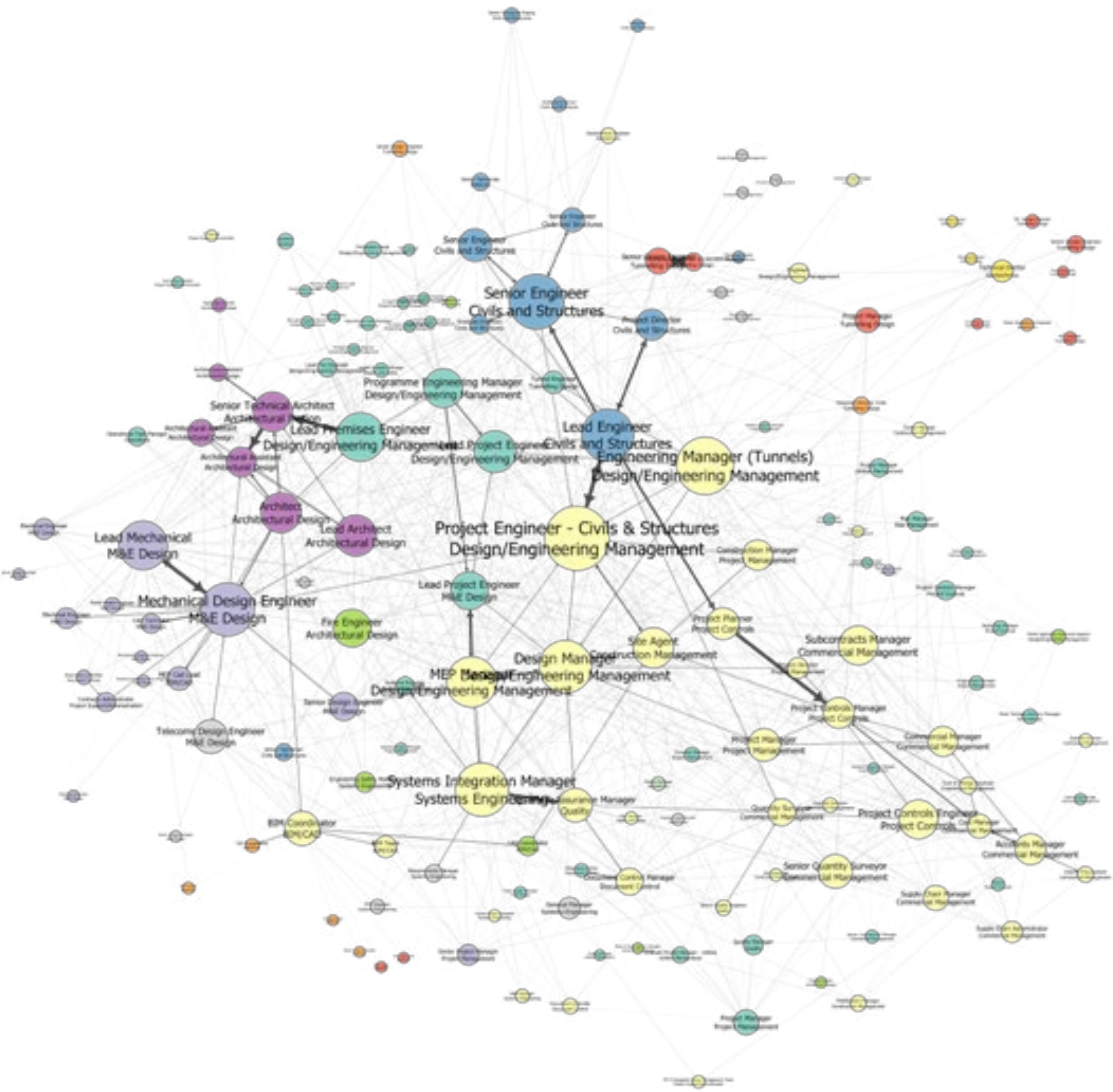


Figure 3.5a Communication Network -
Stage 1 - Connectivity

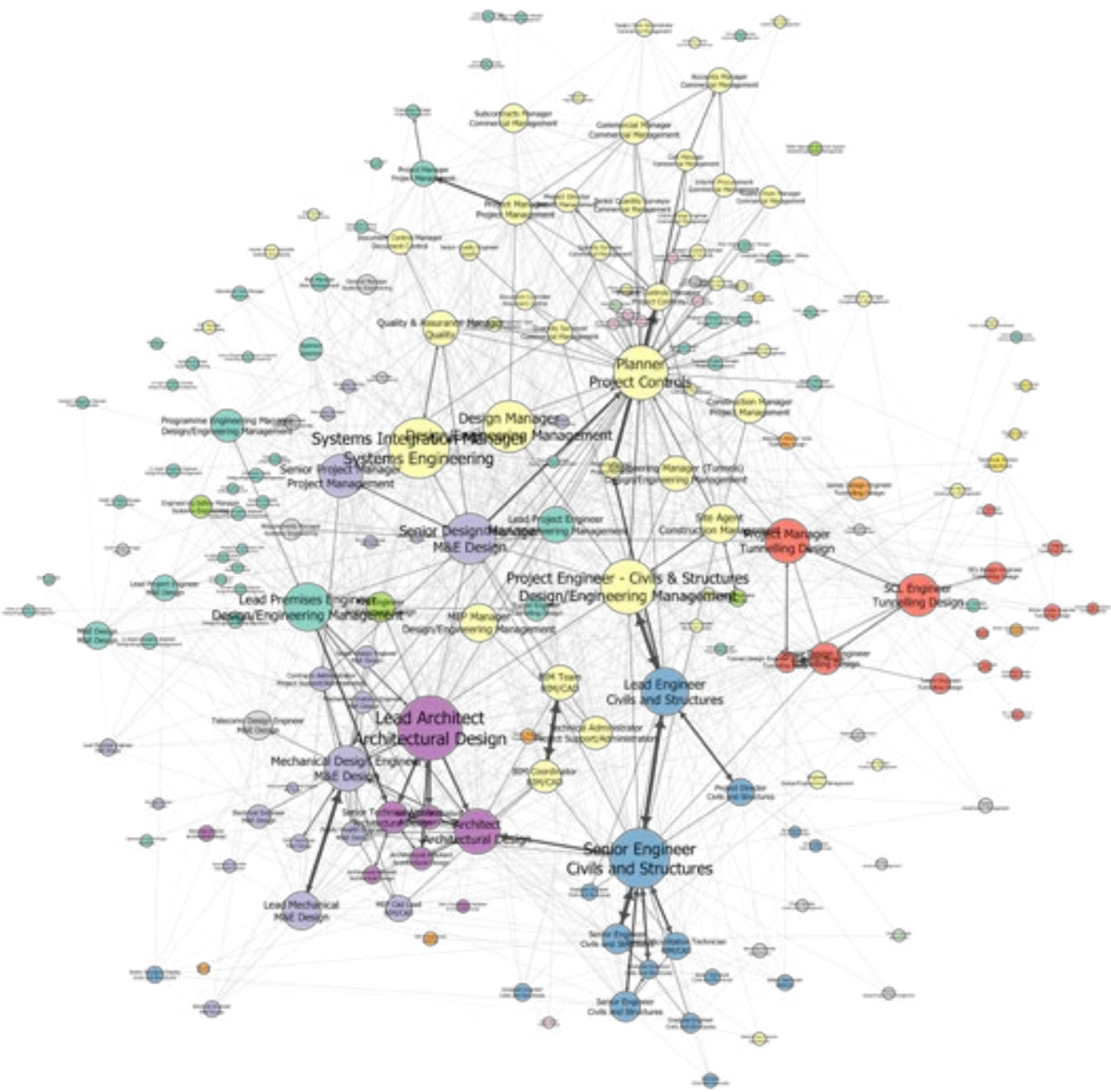


Figure 3.5b Communication Network -
Stage 2 - Connectivity

Connectivity (Degree Centrality) of a person is <u>the number of people</u> who <u>he/she communicates with</u> and the number of people who <u>communicate with him/her</u> with respect to scope of the study.

e.g. Connectivity of A in the figure is 4 compared to connectivity of B which is 1.

Less Connectivity — More Connectivity

Transport for London · URS Infra & Env. Ltd. · T Clarke · Wilkinson Eyre · Robert Bird Group · Hyder Consulting · Dragados · Mc Nicholas · Dr Sauer & Partners · Geocisa · Alan Auld Engineering · Others

Inter Personnel Communication Networks

Color - Organisation, Size - Influence

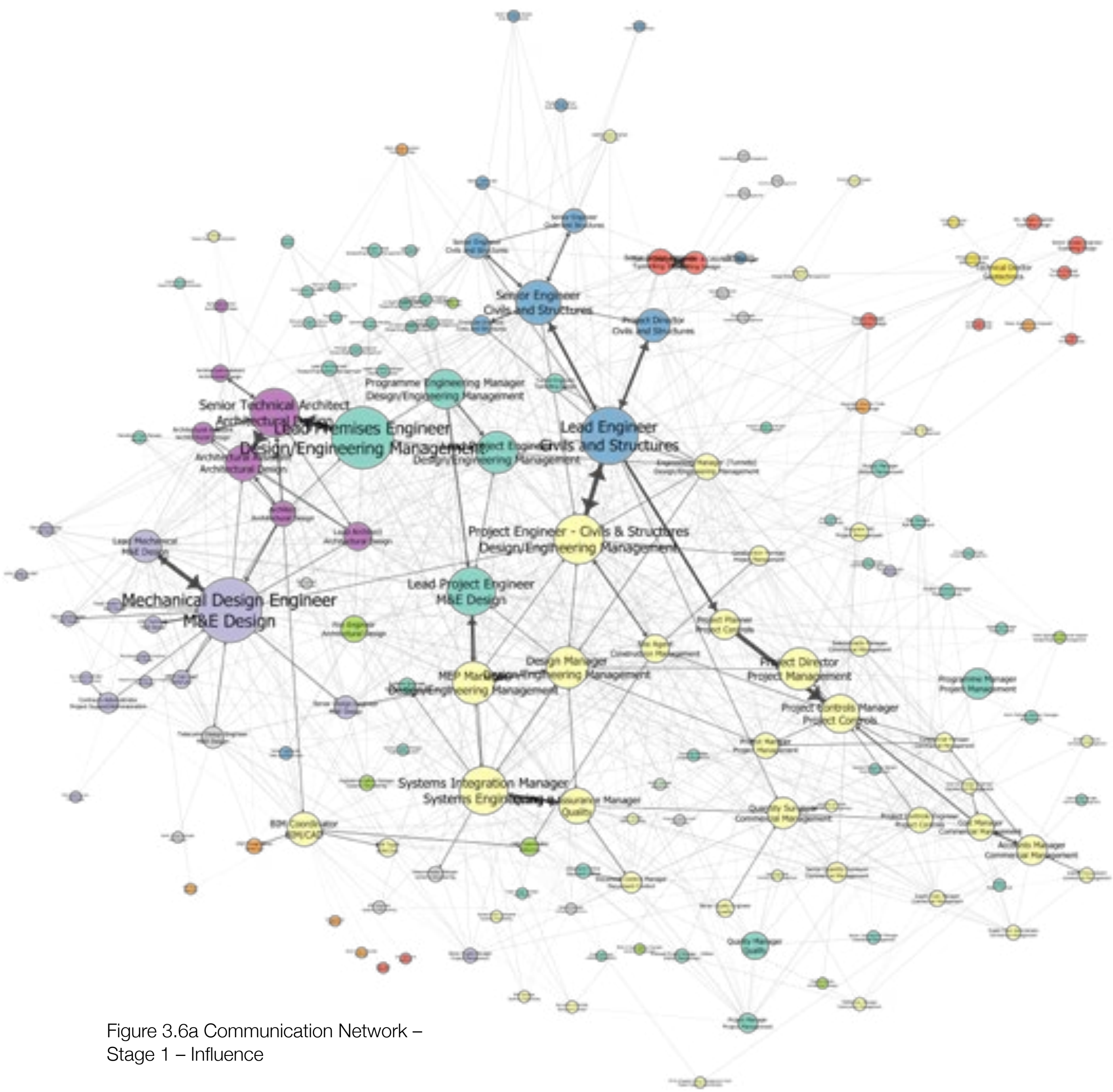


Figure 3.6a Communication Network – Stage 1 – Influence

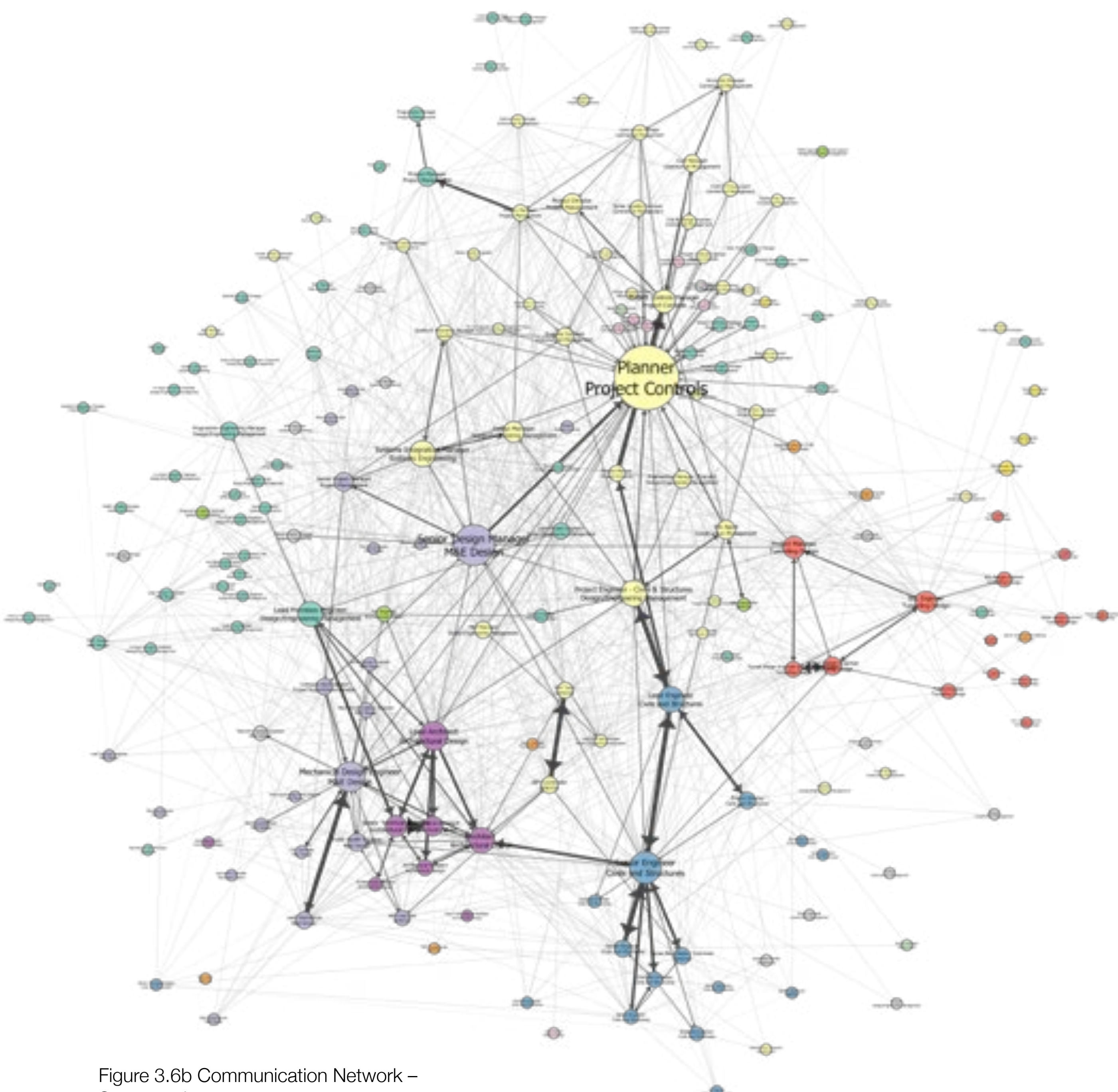
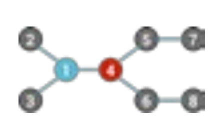


Figure 3.6b Communication Network –
Stage 2 – Influence

Influence (Eigenvector Centrality) is the measure of the number of people a person is connected to <u>weighted by the relative importance</u> of those connections.

e.g. In spite of having same connectivity, the influence of 4 in the figure below is greater than that of 1 since it connects to 5,6 which have more connectivity than 2,3.



Less Influence | More Influence

Transport for London · URS Infra & Env. Ltd. · T Clarke · Wilkinson Eyre · Robert Bird Group · Hyder Consulting
Dragados · Mc Nicholas · Dr Sauer & Partners · Geocisa · Alan Auld Engineering · Others

Inter Personnel Communication Networks

Color - Organisation, Size - Brokerage

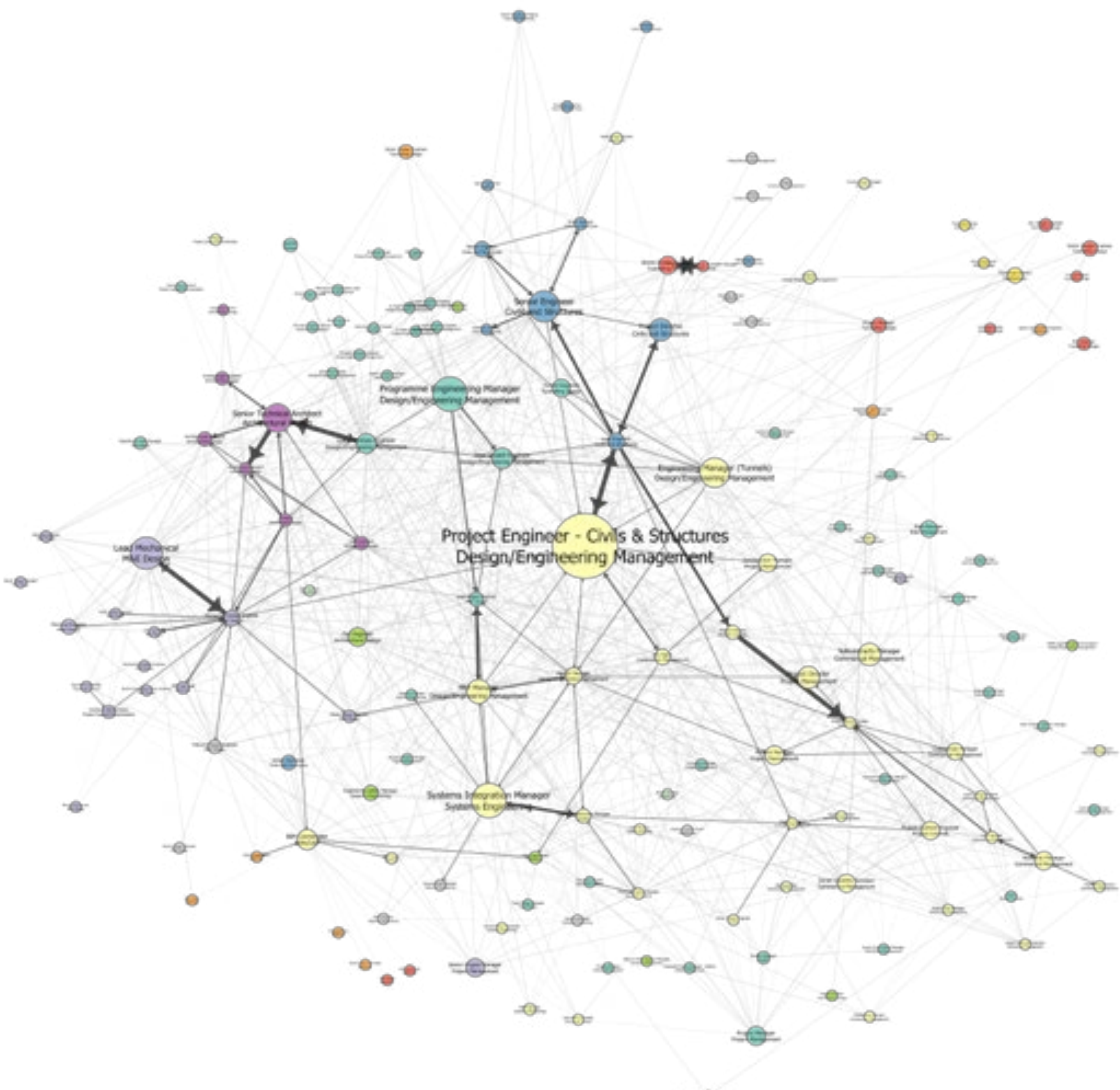


Figure 3.7a Communication Network –
Stage 1 – Brokerage

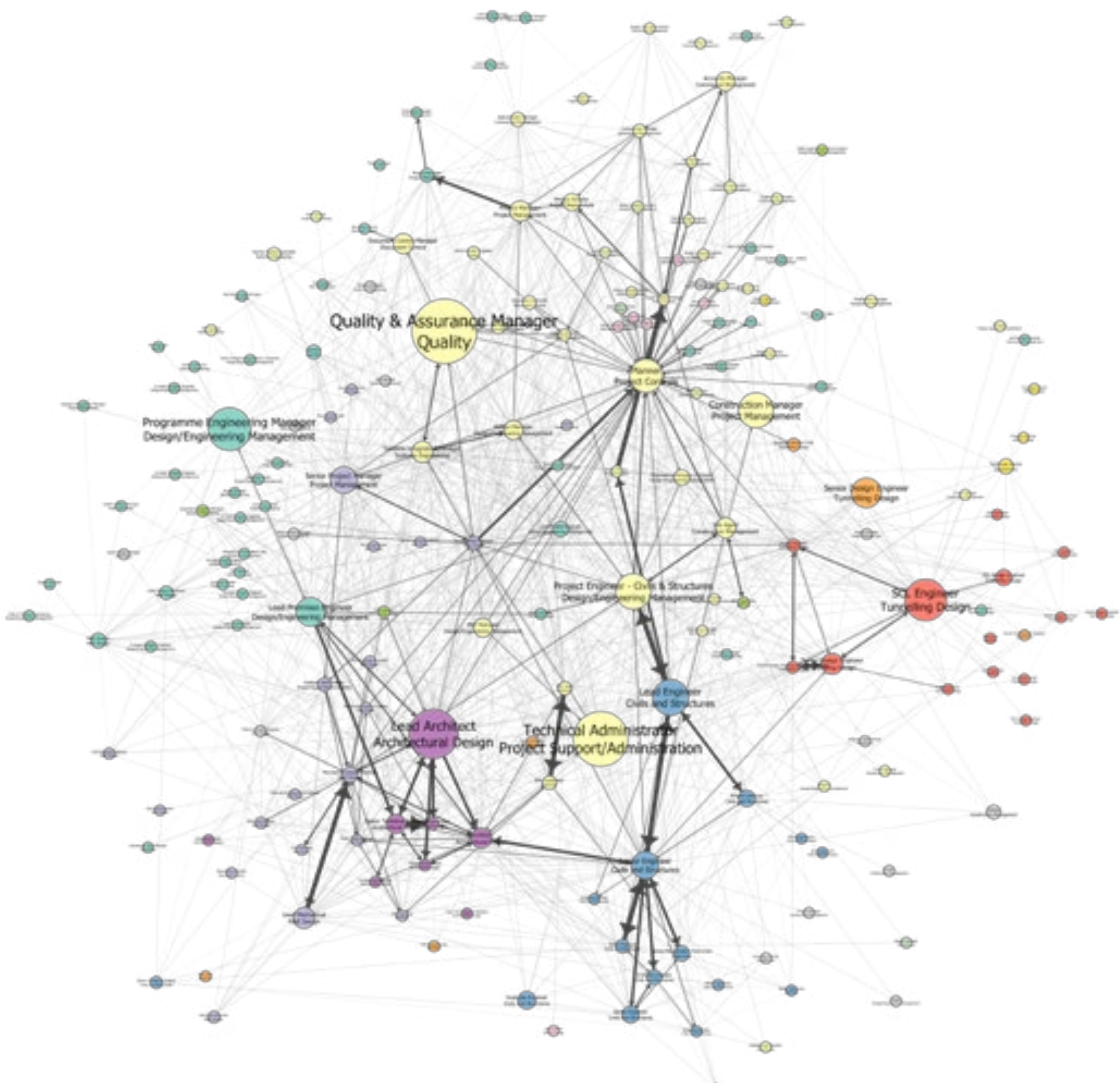


Figure 3.7b Communication Network – Stage 2 – Brokerage

Brokerage (Betweenness Centrality) A person is a broker to the extent that the <u>communication is likely to flow through</u> him.

e.g. the node 1 has the most brokerage potential as it sits between most of the paths between members in the network

Less Brokerage · More Brokerage

Transport for London · URS Infra & Env. Ltd. · T Clarke · Wilkinson Eyre · Robert Bird Group · Hyder Consulting · Dragados · Mc Nicholas · Dr Sauer & Partners · Geocisa · Alan Auld Engineering · Others

Communities in Communication Networks

Color - Organisation, Size - Influence

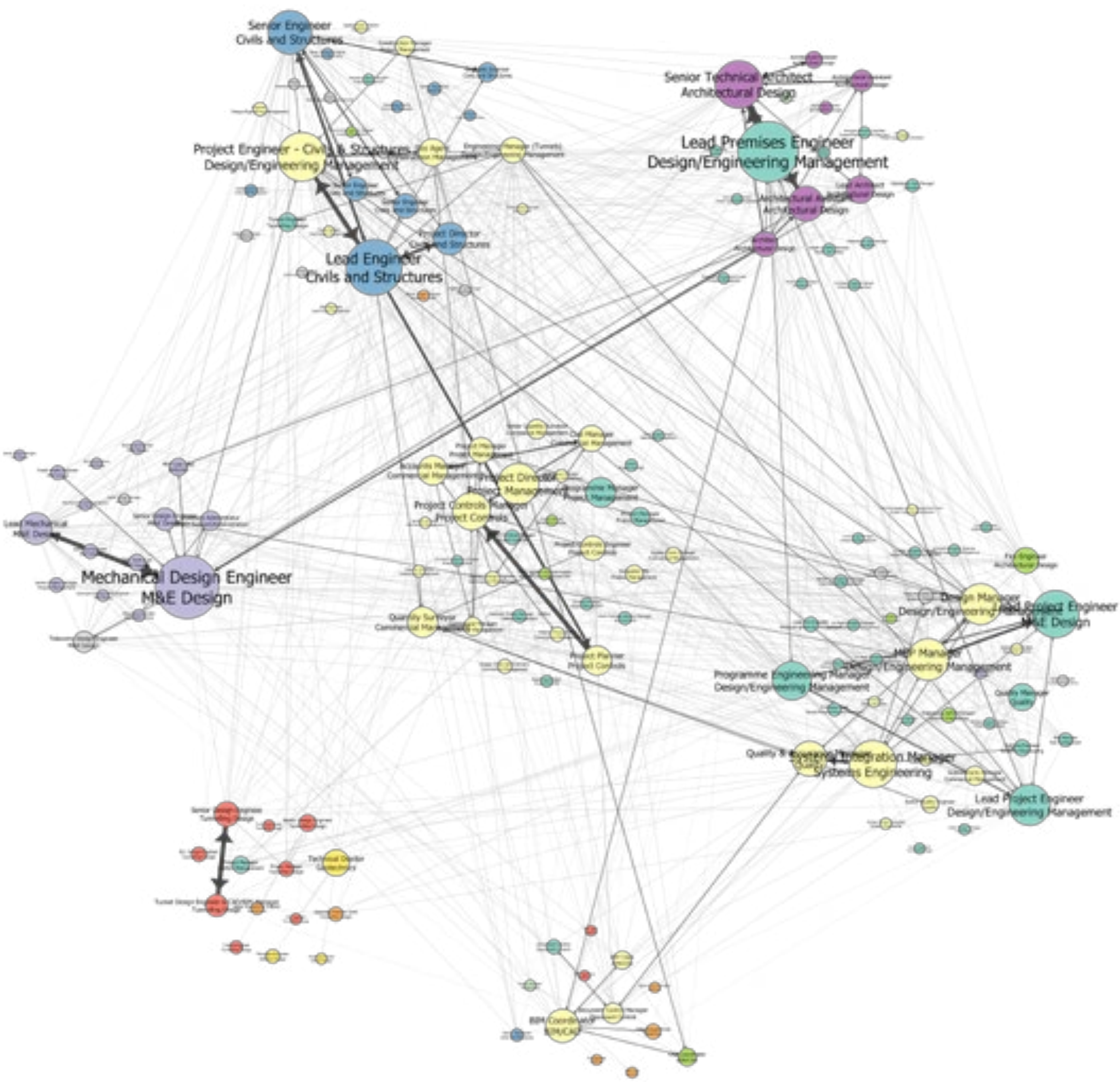


Figure 3.8a Communication Network –
Stage 1 – Communities

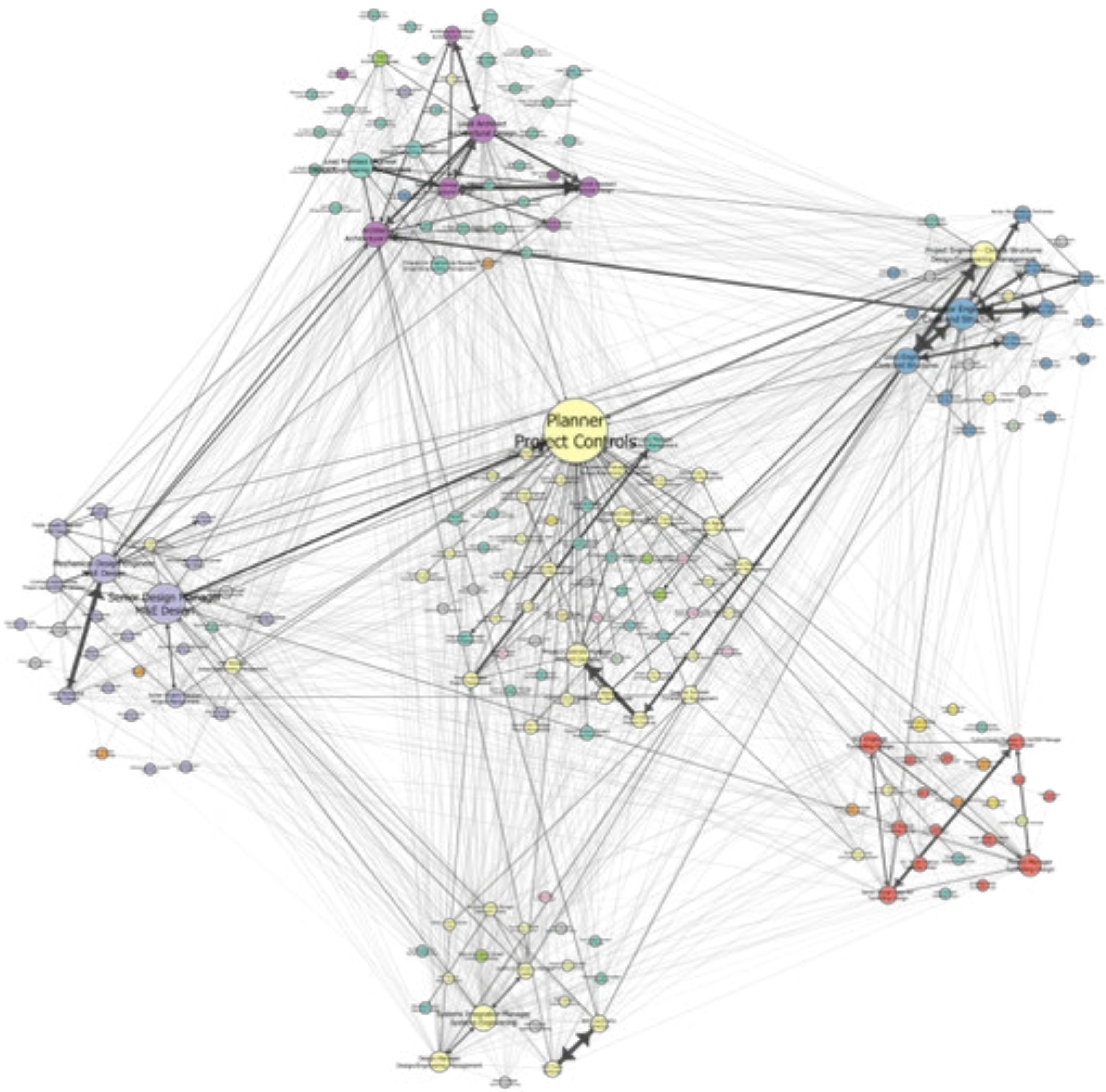
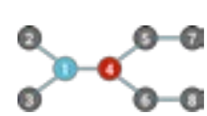


Figure 3.8b Communication Network – Stage 2 – Communities

Influence (Eigenvector Centrality) is the measure of the number of people a person is connected to <u>weighted by the relative importance</u> of those connections.

e.g. In spite of having same connectivity, the influence of 4 in the figure below is greater than that of 1 since it connects to 5,6 which have more connectivity than 2,3.



Less Influence · More Influence

Transport for London · URS Infra & Env. Ltd. · T Clarke · Wilkinson Eyre · Robert Bird Group · Hyder Consulting · Dragados · Mc Nicholas · Dr Sauer & Partners · Geocisa · Alan Auld Engineering · Others

Hammersmith Flyover Strengthening Project

An innovative structure in its time, the 16-span, 622m long Hammersmith Flyover is generally considered to be the first major segmental precast post-tensioned highway structure in the UK. It has formed a key part of London's major A4/M4 link to Heathrow Airport and the West of England since it opened in 1961.

In its design and construction, grout was intended to protect the prestress tendons (which are partly internal and partly external) from corrosion. The Hammersmith Flyover was not originally designed to be subjected to de-icing salt. Instead, its designers, G Maunsell & Partners, provided electric deck heating, but this was disconnected when electricity prices rose in the mid-1960s.

The Highways Agency revealed in 1999 and 2000 that the post-tensioning tendons holding the precast concrete structure together were corroding and work began by the new bridge owner, Transport for London (TfL), to slow down the corrosion process. However, in 2009, further inspections revealed significant deterioration in the tendons which resulted in TfL establishing one of the largest structural monitoring programmes in Europe, with 400 acoustic sensors on the eastern section. This proved vitally important in highlighting the urgency of works required. For example, the system picked up about one break a month on the Huntingdon flyover; but the Hammersmith flyover had one wire break a day. There was no doubt that the situation was critical.

When inspections in December 2011 discovered extensive voids in the grout and active corrosion of the tendons, TfL took the unprecedented step of closing the Hammersmith Flyover immediately. This led to emergency (Phase 1) strengthening to ensure the bridge, which was a key part of the 109-mile Olympic Road Network, could be re-opened ahead of the 2012 Olympic and Paralympic Games.

<u>The Structures and Tunnels Investment Programme (STIP)</u>

Following the 2012 games, TfL decided significant capital expenditure was required on infrastructure and assets to ensure they were fit for the future, which led to TfL's Structures and Tunnels Investment Programme (STIP).

The objective of the STIP was to replace, strengthen and refurbish key bridges, tunnels and other structures on the Transport for London Road Network (TLRN) to ensure network safety and reliability, while considering the needs of other transport modes. The STIP schedule began by delivering three discrete packages of work within an Early Contractor Involvement (ECI) Framework to improve the following structures:

1. Work Package 1 (WP1) consisted of Upper Holloway Railway Bridge and Highbury Corner Bridge on the A1, the A127 Ardleigh Green Railway Bridge and the A406 Power Road Railway Bridge.
2. Work Package 2 (WP2) consisted of the A406 Fore Street Tunnel, Chiswick Bridge on the A316 and the reconstruction of the woodlands retaining wall on the A406 near Golders Green.
3. Work Package 3 (WP3) consisted of the second phase of improvement works on the Hammersmith Flyover, following the successful Phase 1 strengthening works during Spring 2012.

TfL appointed Ramboll and Parsons Brinckerhoff in a joint venture to begin design work across the portfolio, which was to cost around £200m to deliver. The three Tier 1 contractors appointed later by TfL were Hockteif (WP1), BAMNuttall (WP2) and Costain (WP3).

Phase 2 – strengthening Hammersmith Flyover

TFL's key objective for Work Package 3 was a programme of works which would see the Hammersmith Flyover through at least 60 years without requiring major maintenance. Ramboll and the rest of the team began the remedial works in October 2013, which included simultaneously:

1. New surfacing, waterproofing and drainage system;
2. Making the structure independent of the original prestress with the installation of a new prestressing system that could be replaceable in the future; and
3. Replacing the bearings upon which the entire structure sits and replacing the massive central expansion joint with a new comb joint.

Work was undertaken on a '24/7' basis and any activities requiring road closures above or below had to be scheduled outside the working week and after hours to minimise disruption to the traffic flowing along the A4/M4 link to Heathrow and the West of England.

Scope

The scope of this study was the finalisation of the detailed design in the HFO project. The specific research question asked to the participants was as follows:

"With respect to the finalisation of the detailed design, specifically, the expansion joints, the permanent monitoring, the bearing pit covers and the pavement reinstatement, please identify those people with whom you have exchanged information with (either received or sent) within the last four weeks. Once identified, please describe the predominant nature of the information exchange within the last four weeks. Please then go on to describe the quality of information that you 'receive' from that person."

Context

Since the project was in its final stages of design and construction, the issues were activities that were ongoing around the period of data collection and as part of the final issues and learnings report prepared during the project closure and handover. These are issues and learnings related to: organisational maturity; programme management team; business case, requirements specification and role of the client sponsor team; governance; management and reporting of cost; value for money; application of project process; collaboration; client alignment; early contractor involvement; appointment of a single designer; management of design; sub-contracting arrangements; and stakeholder engagement. They are not described in detail in this report but were used as a contextual understanding for the networks.

Networks

The data collected was collated and combined to produce four different types of networks for the HFO project. The communication network was created and is compared with the BSCU project.

Organisational Network

The HFO project involved around 12 organisations connected to each other contractually. The structure is hierarchical with Transport for London at the top as the client, and three tiers of contractors who were connected with the tier immediately before or after them. With this network, we can see that the Tier 1 contractor (Costain) has the most connectivity, brokerage and influence.

Functional Reporting Network

The functional reporting network between people is shown in figure 4.2. In this network, we can see a lot of disconnected hierarchies, which are homogenous in terms of the membership organisations. This is not unsurprising, recognising that 'functional' leads often reside in the individual's host organisation. The connectivity analysis of this network shows that the functional leads of these organisations have the most connectivity with a relatively large number of people reporting to them. This is unsurprising in a functionally structured organisation. The distribution of connectivity within the functional reporting network therefore results in a few heavily connected nodes (hubs) and lots of low connectivity nodes.

The client and supply chain organisations show similar distribution to that of the Bank Station Capacity Upgrade. One notable difference seems to be that the contractor organisation is slightly more fragmented in terms of functional reporting. This may not necessarily be a negative issue. Further investigation and comparison between the two contracting organisations would be needed to determine any logic behind this in relation to size, age, maturity in the market place, etc.

There is also a difference in the distribution of the client's functional leads - in the Bank project, where the dyads were much more central to the network and more numerous in number. Although they have the same client (Transport for London), the two projects are different business units within the client organisation. This is not specifically investigated within this study but further investigation would be warranted around this in terms of approach to supply chain procurement and project management organisational and governance structures between the two business units.

Contractual Reporting Network

The contractual reporting network between people is shown in figure 4.3. Compared to the functional reporting network, there are many more disconnected components in this network. This shows that the contractual/line reporting within the project is much less cohesive and collaborative. There are significant disconnected components from the client (TfL) and within the Tier 1 contractors. This was very different from the Bank project which showed a much more connected network in terms of contractual reporting.

Interpersonal Communication Networks

The communication networks between people is shown in figure 4.4 and the key global parameters are given in table 6.1 along with a comparison to the global parameters of the communication network in the Hammersmith Flyover strengthening project.

	BSCU Stage1	BSCU Stage2	HFO
Size (Actors/Links)	162 & 1440	197 & 2207	57
Building Cost	£ 0.72 m	£ 1.10 m	£ 0.12 m
Operating Cost	£ 0.78 m	£ 1.16 m	£ 0.10 m
Total Cost	£ 1.50 m	£ 2.26 m	£ 0.22 m
Per unit link Cost	£1,043	£1,025	£902

Table 4.1
The global parameters of the Interpersonal communication networks

Size, Cost and Efficiency

The network started at a size of 57 actors which is small compared to the size of teams in the BSCU project. The network has a building cost of £0.12m and an operating cost of around £0.10m per month. It also has a density of 7.4%. This shows that the network is significantly matured in terms of density and was still within the optimum density range as shown in figure 6.1d.

The network had a per capita total cost of £902. Considering the network density of 7.5% and size of the team and compared with BSCU project, this is only marginally more efficient. This shows that although the network was very efficient in terms of density it was only marginally more efficient in terms of per capita cost.

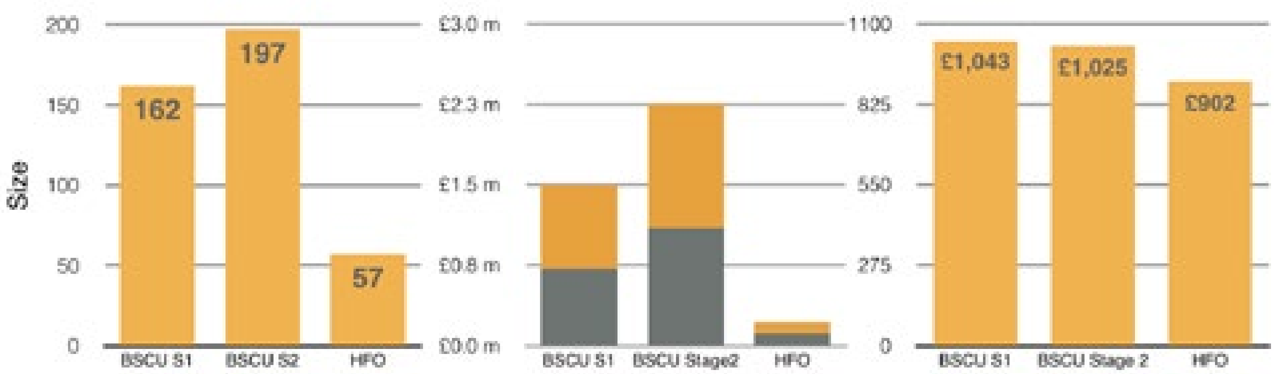


Figure 4.1b (left) The size of the communication networks; Figure 4.1c (middle) - The cost of the communication networks (Stage 1 and Stage 2); Figure 4.1d (right) The cost of the communication networks with respect to random network HFO

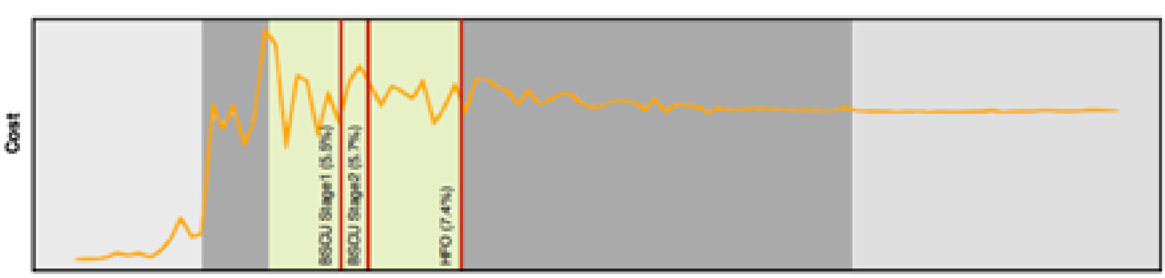
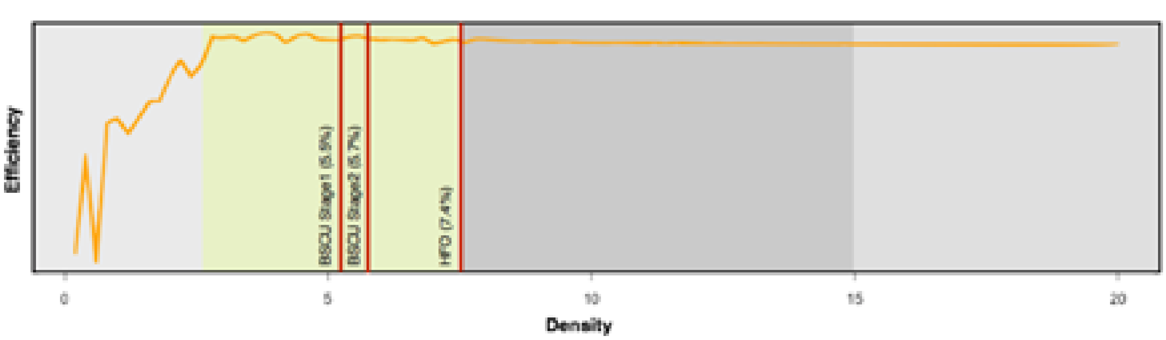


Figure 4.1e
The efficiency of the communication network – HFO

Figure 4.1f
The efficiency of the communication networks with respect to the random networks – HFO



Analysis

Connectivity

When we look at the network in terms of connectivity (figure 4.5), we can observe that actors from the Tier 1 contractor had most prominence. Having the densest links in the network these actors form the core group of the network. The Construction Manager from the Tier 1 contractor was the most connected actor in the network. We also observe that the client is less prominent compared to the Tier 1 contractor which might show a lesser involvement of the client in the design work. There is less homophily - clustering of actors from the same organisations - in the network which shows that all the organisations are well embedded within the Tier 1 contractor.

Influence

When we look at the network in terms of influence (figure 4.6), the actors who are from the client organisation have more prominence than connectivity. Even within the Tier 1 contractor, the project manager has more influence compared to connectivity. This shows that the decision-making process is more concentrated within the project management cluster between the Tier 1 contractor and the client. We can also observe that there was more prominence in terms of connectivity in design finalisation activities and more prominence in terms of influence in the project management activities. Though this may be intuitive to the design of the team, it might be an indicator of less connected networks and there is further discussion of this point when we look at communities below.

Brokerage

While looking at the brokerage (Figure 4.7) of the actors we noticed that every organisation/activity had a prominent actor who acted as the broker for the cluster. The client organisation did not have a prominent broker within the network. This indicates a distinct 'structural hole' in the network which was confirmed by the intuition of the senior management team and the corresponding recommendations from the project.

Communities

As shown in figure 4.8, there were five distinct clusters within the network. The project management cluster was the largest and most influential in the network. There was also a second parallel project management cluster. This, along with the difference in connectivity and influence, might indicate the presence of a structural hole in the network. All the other communities were multi-organisational except for the quality and assurance cluster within the client organisation. This might have been because of the changes in the estimates and commercial changes in the project.

Functional and Contractual Reporting Networks

Color – Organisation, Size - Connectivity

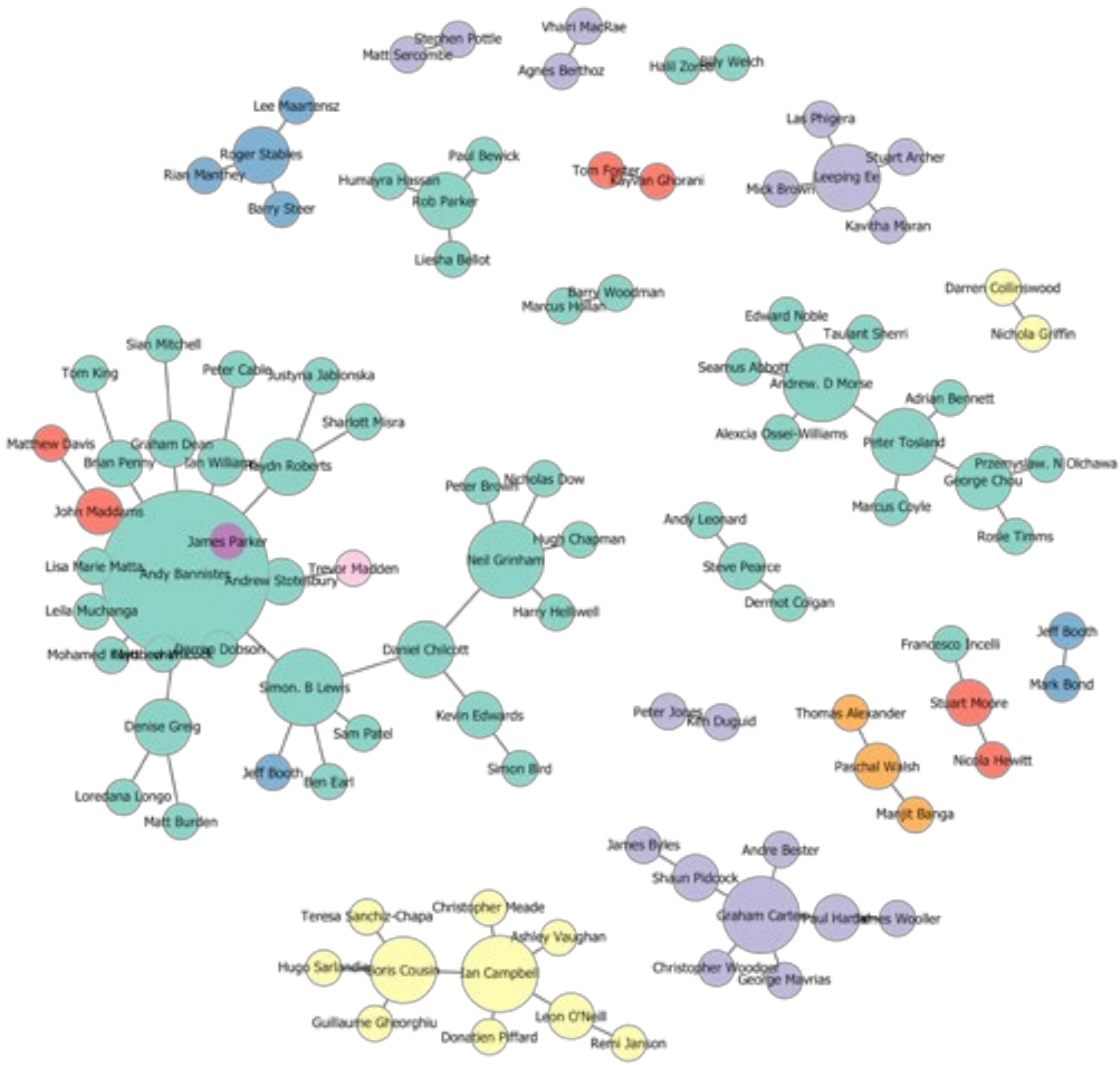


Figure 4.2
Functional Hierarchy – HFO

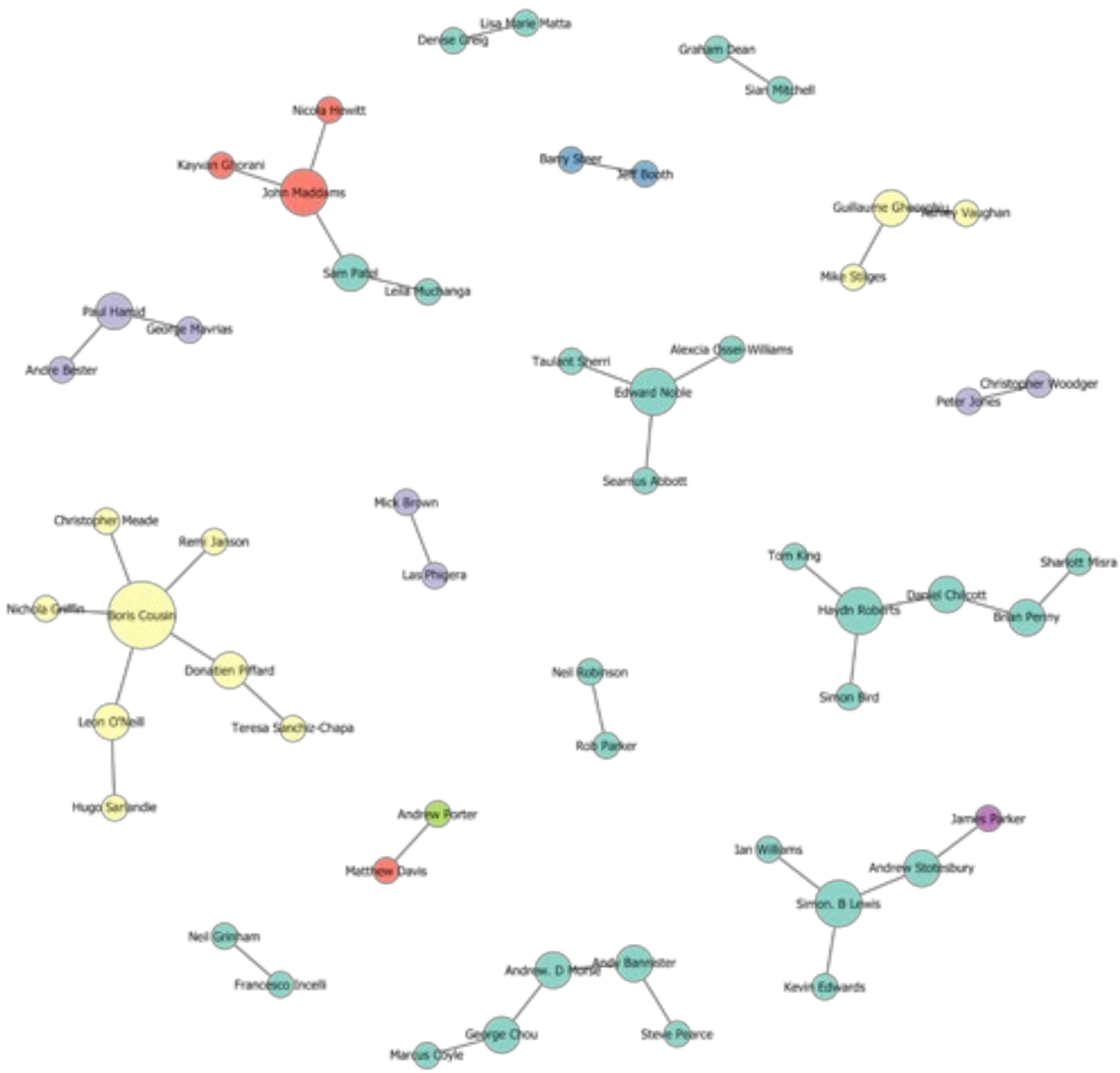


Figure 4.3
Contractual Hierarchy – HFO

Connectivity (Degree Centrality) of a person is the number of people who he/she communicates with and the number of people who communicate with him/her with respect to scope of the study.

e.g. Connectivity of A in the figure is 4 compared to connectivity of B which is 1.

Less Connectivity ● ● ● More Connectivity

Costain | Freyssinet | Parkinsons Brinkr. | Atkins | Transport for London | Ramboll | Structural Systems | Buro Happold | Others

Inter Personnel Communication Networks

Color - Organisation

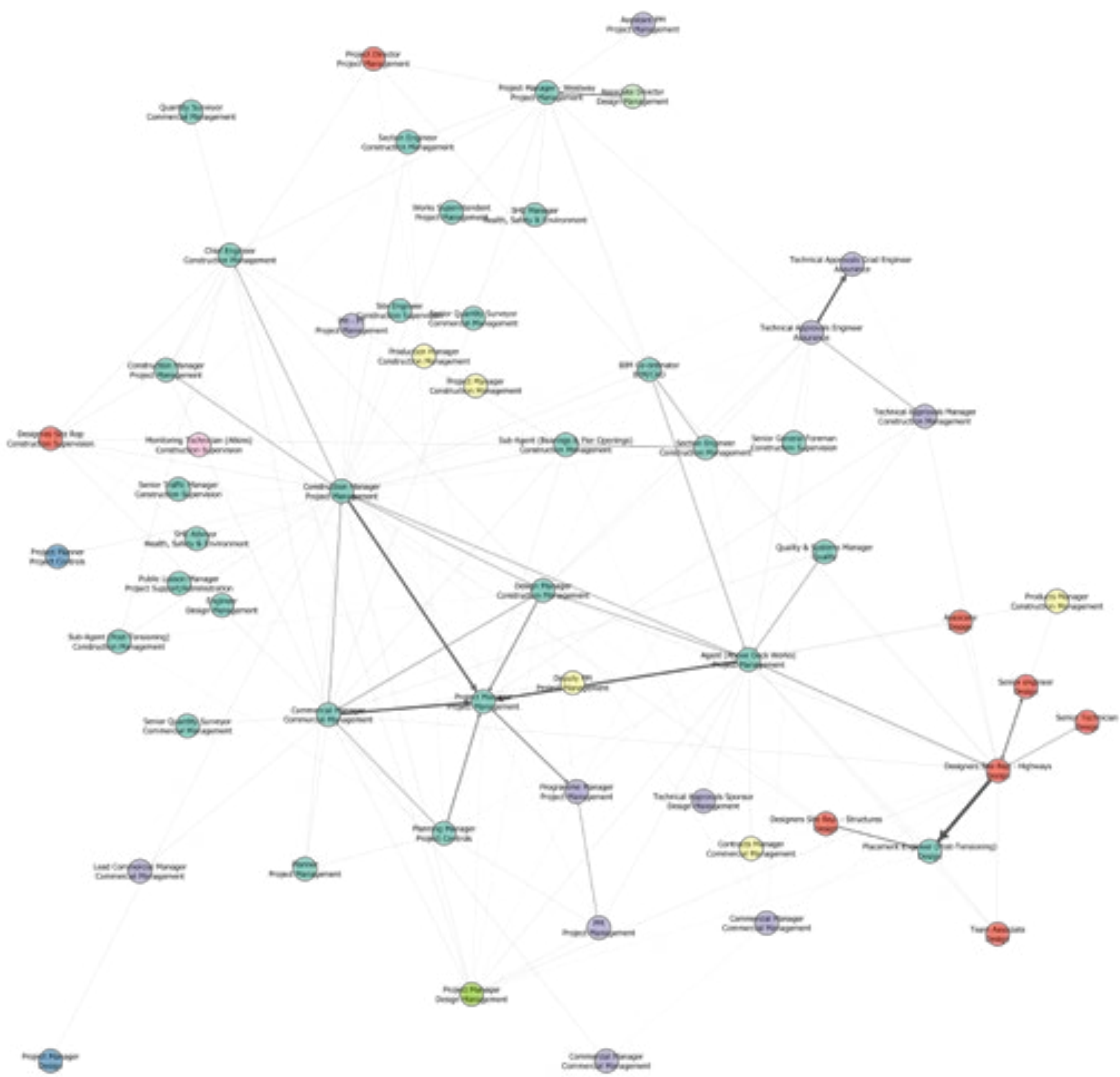


Figure 4.4 Communication Network
HFO

Costain · Freyssinet · Parkinsons Brinkr. · Atkins · Transport for London · Ramboll · Structural Systems · Buro Happold · Others

Inter Personnel Communication Networks

Color - Organisation, Size - Connectivity

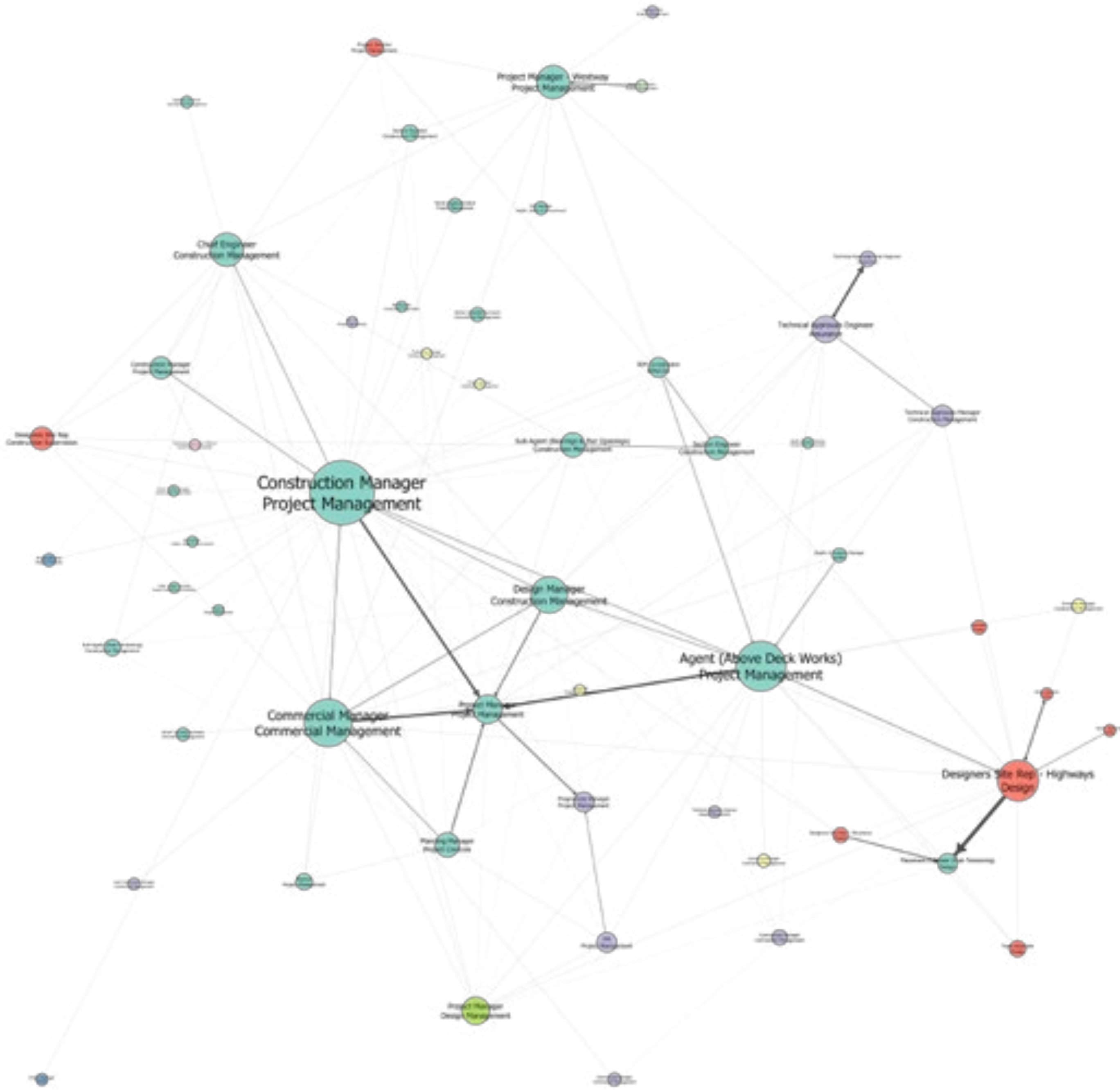
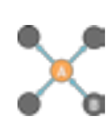


Figure 4.5 Communication Network - HFO - Connectivity

Connectivity (Degree Centrality) of a person is the number of people who he/she communicates with and the number of people who communicate with him/her with respect to scope of the study.

e.g. Connectivity of A in the figure is 4 compared to connectivity of B which is 1.



Less Connectivity ● ● ● More Connectivity

Costain, Parkinsons Brinkr., Transport for London, Structural Systems, Others, Freyssinet, Atkins, Ramboll, Buro Happold

Inter Personnel Communication Networks

Color - Organisation, Size - Influence

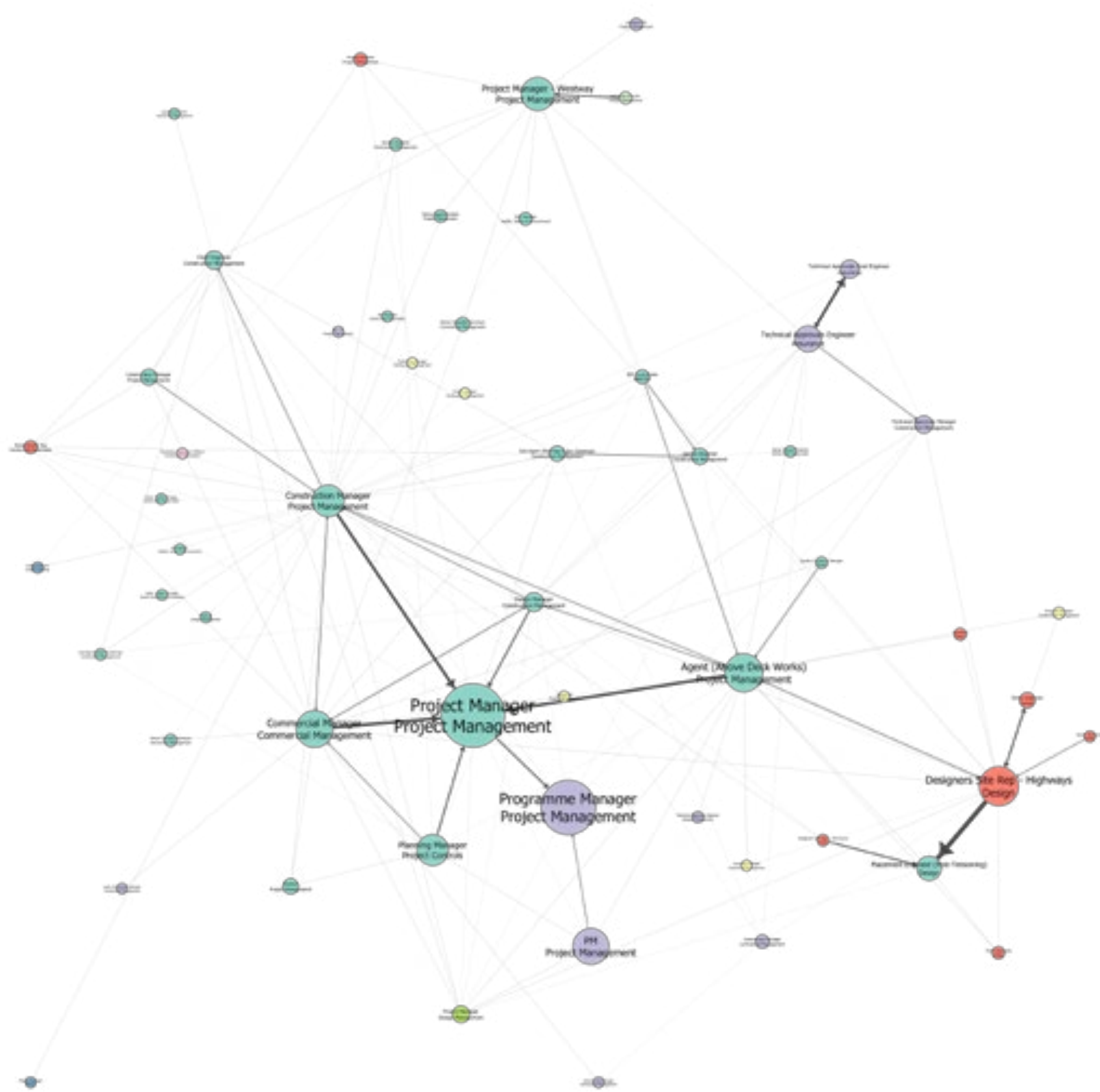


Figure 4.6 Communication Network - HFO - Influence

Influence (Eigenvector Centrality) is the measure of the number of people a person is connected to <u>weighted by the relative importance</u> of those connections.

e.g. In spite of having same connectivity, the influence of 4 in the figure below is greater than that of 1 since it connects to 5,6 which have more connectivity than 2,3.

Less Influence · More Influence

Costain · Freyssinet · Parkinsons Brinkr. · Atkins · Transport for London · Ramboll · Structural Systems · Buro Happold · Others

Inter Personnel Communication Networks

Color - Organisation, Size - Brokerage

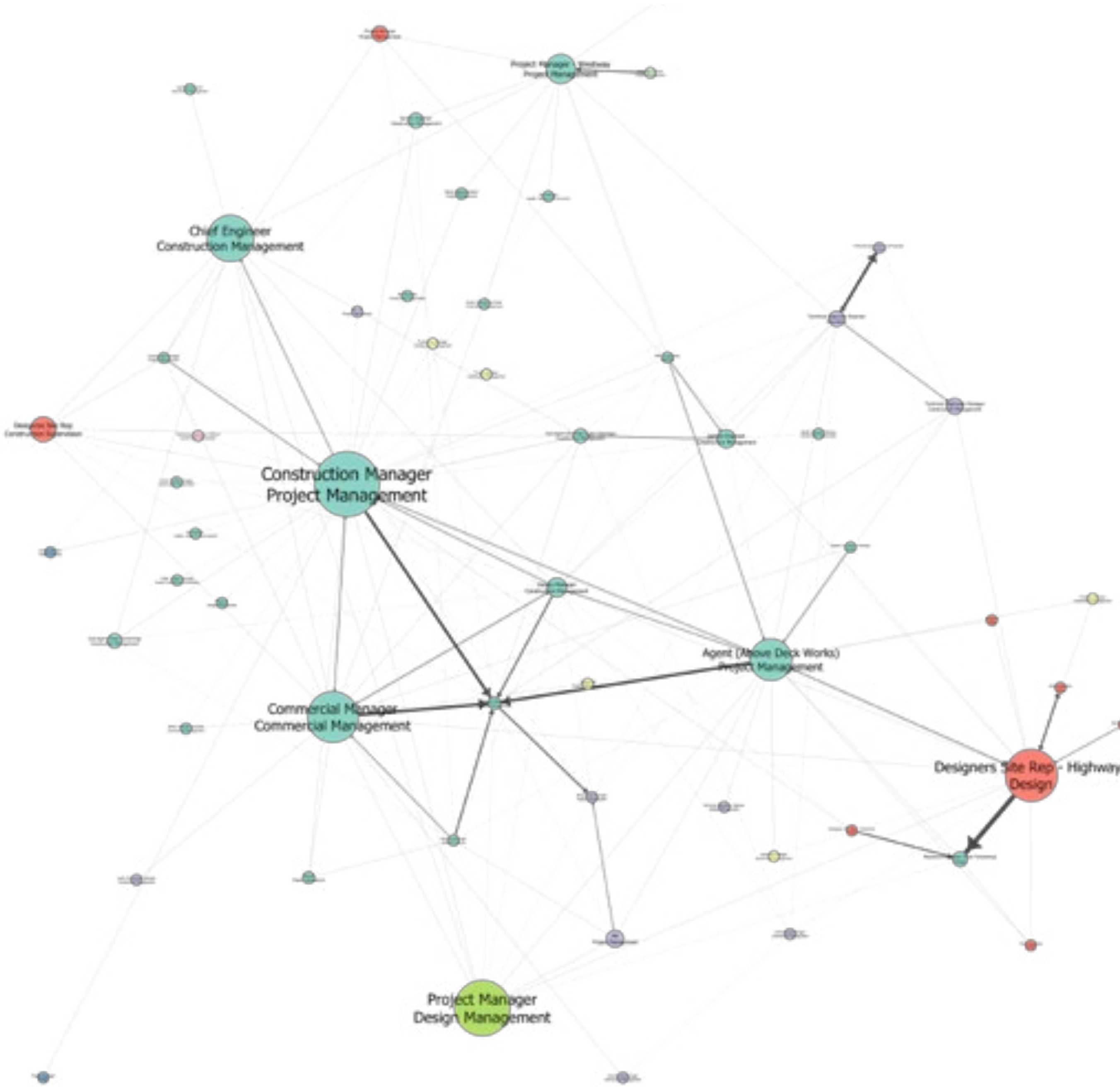
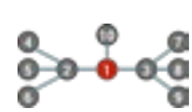


Figure 4.7 Communication Network - HFO - Brokerage

Brokerage (Betweenness Centrality) A person is a broker to the extent that the communication is likely to flow through him.

e.g. the node 1 has the most brokerage potential as it sits between most of the paths between members in the network



Less Brokerage ● ● ● More Brokerage

Costain · Parkinsons Brinkr. · Transport for London · Structural Systems · Others · Freyssinet · Atkins · Ramboll · Buro Happold

Inter Personnel Communication Networks

Color - Organisation, Size - Influence

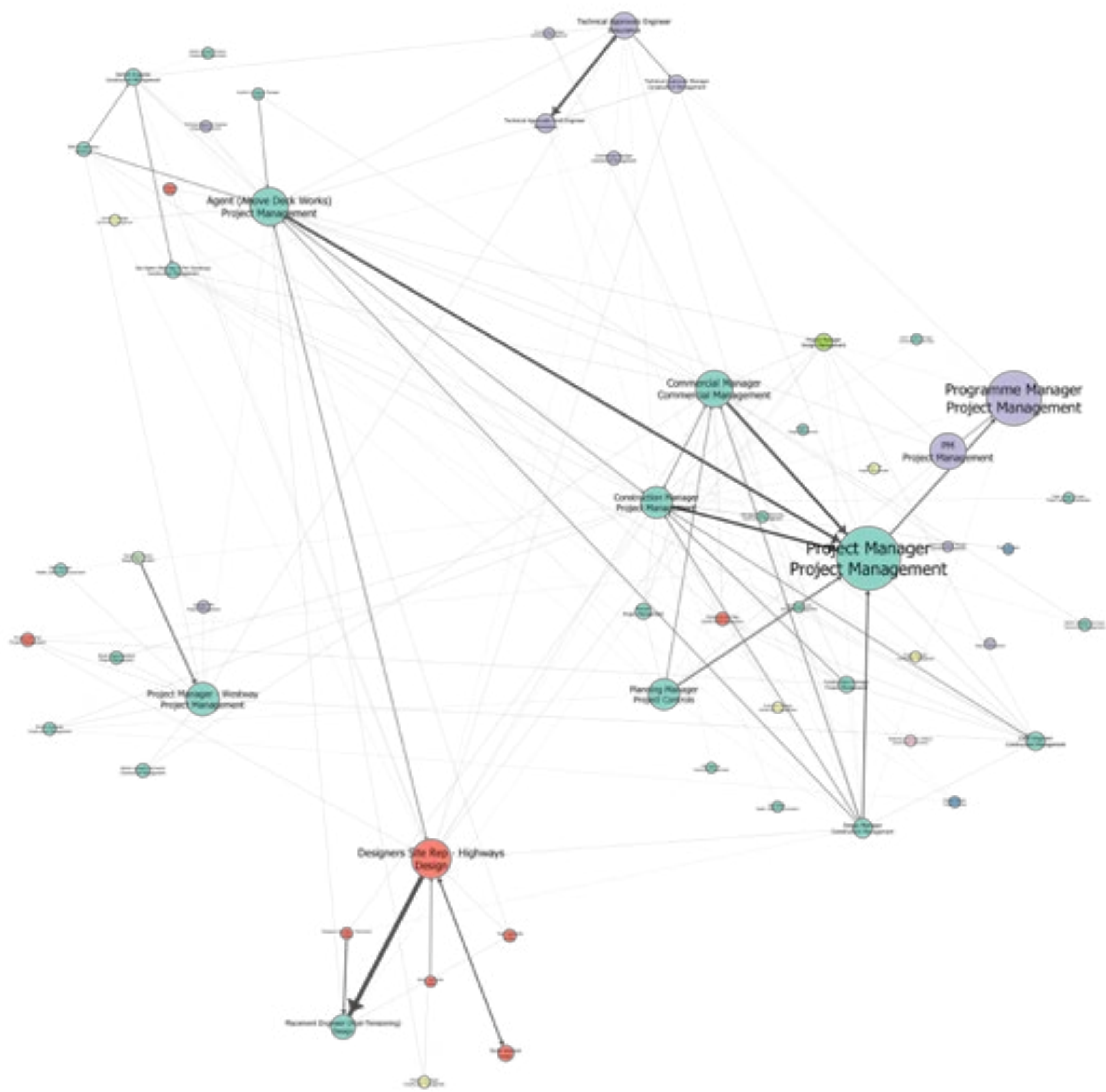


Figure 4.8 Communication Network -
HFO - Communities

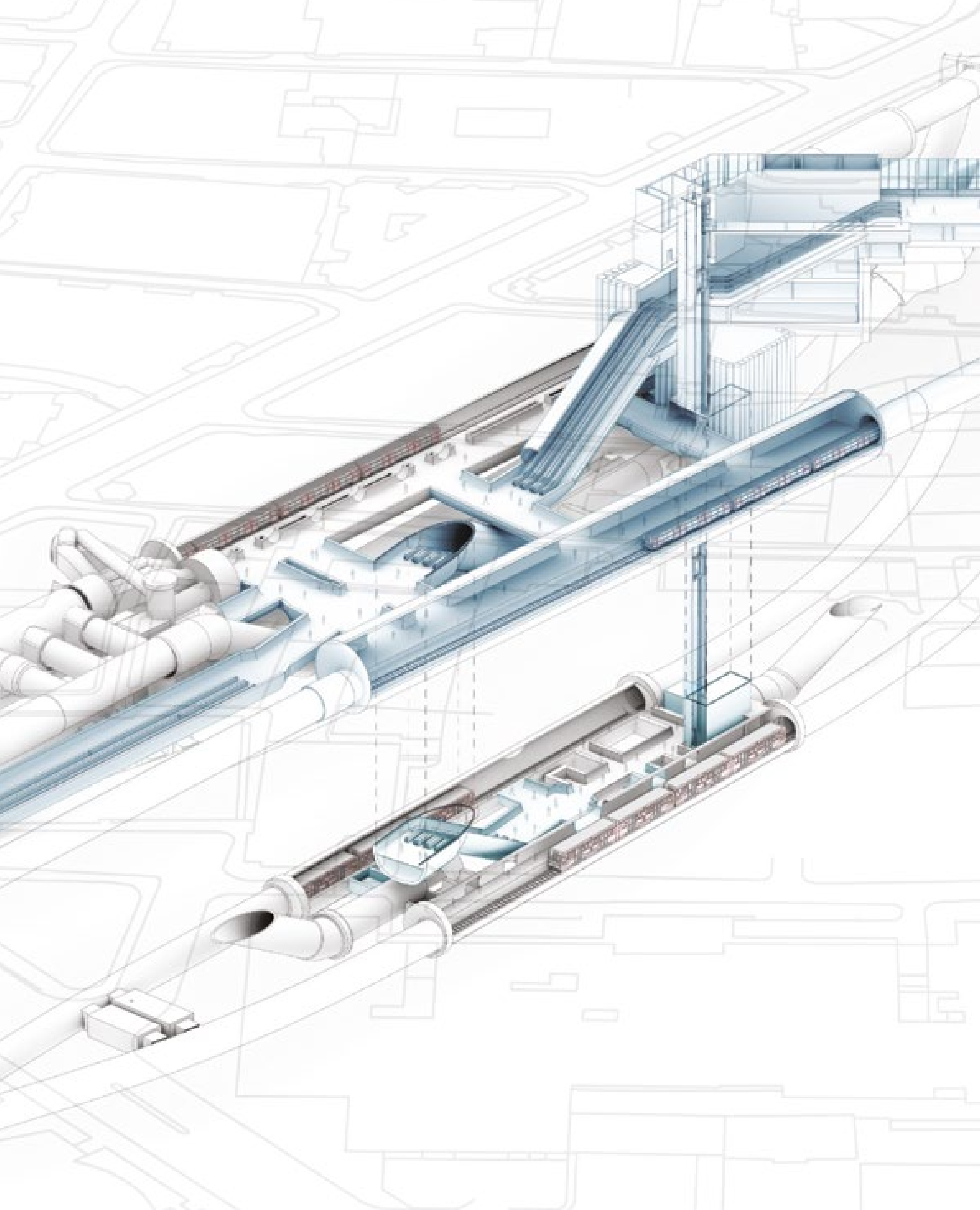
Influence (Eigenvector Centrality) is the measure of the number of people a person is connected to <u>weighted by the relative importance</u> of those connections.

e.g. In spite of having same connectivity, the influence of 4 in the figure below is greater than that of 1 since it connects to 5,6 which have more connectivity than 2,3.

Less Influence · More Influence

Costain · Parkinsons Brinkr. · Transport for London · Structural Systems · Others

Freyssinet · Atkins · Ramboll · Buro Happold



Discussion of main findings

The BSCU project went through a significant change in the detailed design of the station box over the course of late 2014 and early 2015 during which we captured, in two stages, the communication network between actors involved in this issue. The HFO project was in the final stages of design finalisation during early 2015. We captured the communication network involved in this stage.

In analysing these networks, we observed the following:

Organisational, functional and contractual networks

The *organisation* in BSCU was defined by a hierarchical organisational network with 18 organisations, with Tier 2 contractors having most influence in terms of information exchange. The organisation for HFO consists of around 12 organisations with the Tier 1 contractor having the most influence. The functional and contractual networks in HFO were more disconnected, having a larger number of dyads. This may show the maturity of the organisation and the late stage of the design

The differences in *organisational*, functional and contractual network structures between the two projects and between the client, tier 1 and tier 2 contractors warrant further research and analysis. This would offer interesting insights into the differences between contingency factors such as age, size and technology that influence the more formal hierarchical organisational structures and the resulting information exchange networks, especially with respect to how these networks are seen to self-organise. The impact of environmental factors upon organisational, functional and contractual networks are important. The influence of these structures on the exchange of information within project networks is fundamentally important to improving the effectiveness of project organisations.

Communication networks

The *communication* network with respect to BSCU started with 162 actors and grew 21% to Stage 2 which increased the building cost by 38% and increased the operational cost by 48%. Although the costs increased, the network became 2% more efficient over time and optimised itself for the best density. The communication network in HFO consisted of 57 actors, and was significantly more efficient in terms of density and marginally more efficient in terms of per capita cost. Due to the life-cycle stages of each project, we believe that this could indicate that the communication network optimises itself for more efficiency as the project matures.

In BSCU, connectivity in the network was more evenly distributed and reflected 'homophily' (the tendency for actors to associate and bond with similar others). It shows a presence of strong hubs within the network. There is an overall role of the hub which is performed by Tier 1 contractor, Dragados. There is a design management cluster which connects the design functions and 'business as usual' activities. These two activities show significantly different distribution of connectivity locally.

Influence within the network is exponentially distributed compared to connectivity but shows that higher influence nodes occur within project-specific disciplines and actors actively involved in a particular issue. The distribution of influence also shows a hierarchy within itself. There is limited evidence of some key actors having extremely high brokerage potential compared to the rest of the network, which could be interpreted as a sign of more distributed decision-making across the project. The communication network also shows a self-organised community structure with 7 distinct clusters formed around influential people. The communities were multi-disciplinary and multi-organisational.

As we moved towards stage 2 in BSCU, both connectivity and influence became more concentrated and shifted towards the project controls discipline from design management which was intuitive to the context of the project, as the design issue was resolved and the design work was completed. In terms of brokerage, the network became more distributed with more equally prominent actors with brokerage potential. The communities also merged to result in fewer, more closely connected, communities. This shows that the network matured over time and changed according to the context of the project.

In HFO, connectivity in the network was evenly distributed with a more prominent Tier 1 contractor which formed the core group. The client organisation exhibited less involvement in the design finalisation. There was less homophily and greater embeddedness of organisations within each other. The client organisation had more influence than connectivity, showing a more active involvement in decision-making processes, although there might have been a ‘structural hole’ in the network affecting the lack of strong brokerage from the client organisation. The community structure in the network is less defined than BSCU. It also shows parallel, multi-organisational communities performing the same functions showing possible issues. This may suggest a difference between the development and maturation of network communities at different stages of project life cycles.

Conclusion

The major inferences that can be made from the main findings are:

The **network measures** of cost and efficiency offer a significant opportunity to reflect both the project context and the life-cycle stage. It has the potential to be developed further and could be used in addition to a formal organisational resource plan to accurately measure and manage ‘the network’. This would move the project community from simply understanding the cost of resources over time towards a more efficient use of those resources over time.

The **local measures** on prominence, particularly what we have termed in this study ‘dysfunctional prominence’, shows us the places where the decision-making is happening and allows the reinforcement and change in management practices to achieve the desired outcome. There is a tendency towards becoming reliant on prominent actors as defined by formal hierarchies within organisations. This can blind us to the need to focus on actors within information exchange networks who are the ones who have the most influence (both positive and negative) over risk, uncertainty and decision-making. Network analysis allows these actors to be seen and for the roles they play to be identified and classified.

The **network changes** reflect the changes in the context and life cycle of the project. This can be used to infer problem areas in the network or to validate the effectiveness of the management measures taken within the network. Such an understanding of these network changes over time can help, in addition to the more traditional performance measures of earned value, milestone reporting, cost planning, in highlighting areas that are perhaps detrimental to the performance of the project as it highlights those areas where key elements of information exchange takes place.

The networks and communities have been shown to **self-organise and optimise** themselves for efficiency over time, successfully solving project issues, which can result in monetary savings through efficient team working. Unmonitored, self-organising could not be suggested to be efficient and cost saving, but being able to measure and visualise these communities, their make-up and most influential actors can help project organisations in a way that cannot be seen through formal hierarchies.

The most important implication of this research is that organisations know relatively little about the effectiveness of their employees and suppliers in designing and delivering projects. Fundamentally, large project organisations are essentially ‘self-organising’ leading to the formation of some important clusters that do not reflect the systems presumed in the procurement of project resources.

Areas for further research

As with all studies of this nature, time permitted us to only ‘scratch the surface’ of the data collected. Even then, time only allowed for limited inference of the data’s meaning. Potential areas for further research include:

Network costs – to the best of our knowledge, this report is the first time that understanding the costs of networks has been introduced. It has offered an opportunity, considering the industry’s current focus on collaboration and relational contracting, to understand the associated costs of an efficient organisation. This is different from just looking at ‘costs saved’ or ‘benchmarking’, which have been traditional views of the financial benefits of collaboration. Further work should be done to build on and develop both quantitatively and qualitatively the notions of network ‘cost’ and its relationship to the measures of costs within a project cost plan (i.e. day rates) and the measures of a network (i.e. density).

Networks over time – the two studies on BSCU and the different stage of HFO showed that there is further potential in exploring the relationship between network structures and project life cycles. This would require a longitudinal study. It would offer the opportunity to better understand the project actor roles over time in terms of their influence, connectivity and brokerage as a project moves from stage to stage. A multi-project environment for project-based organisations, as in this study, provides the opportunity, for example, of enhancing the resource allocation. This could result in more cost-efficient project (temporary) organisations.

Networks and routines – further data that was collected but not analysed within this study identified the opportunity to explore the relationship between network structures and the organisational routines enacted by the multiple project participants. Issues such as cost reporting, risk management and project planning are embedded within organisational routines and grounded in interdependent patterns of action forming the basis of organisational capability. Further analysis on the ‘networked’ nature of these interdependent patterns of action is worthy of exploration.

Hierarchies vs organisational, functional and contractual networks – the data on the organisational, functional and contractual networks in both BSCU and HFO showed that further work is required to understand any relationships between the hierarchical structure of the host organisation (client, Tier 1 or Tier 2), the project-specific procurement model and contract structure and the resulting network formation. This could offer further insights into such issues as interdependencies between critical actors within functional departments and project organisations where corporate governance or statutory regulations influence these structures and the resulting information exchange needs.

Appendices

Appendix 1 Literature Review

Large infrastructure projects are characterized by technical, organisational and environmental complexity (Bosch-Rekveldt et al., 2011). Organisational complexity particularly arises from the need to manage the relationships among many actors with multiple interests and objectives (Flyvbjerg, 2009). Infrastructure projects are also subject to a diverse range of uncertainties: internally – including cost and duration estimations, firm's financial capacities, and effectiveness and behaviour of human resources; and externally – such as governmental and regulatory change, economic variance in interest rates and inflation, legal changes, and acts of God (Love et al., 2002). To manage project uncertainty, clients tend to allocate risk in accordance with functional contract transactions, which often results in situations where behaviours become more aligned with resolving contractual obligations than the resolution of the key issues. Traditional organisational and contractual models of infrastructure project delivery simply accept this situation, which often results in limitations in achieving radical and sustained improvements in performance.

While traditional project management literature has placed great emphasis on technical issues such as planning, scheduling, risk analysis and project management techniques (Winter et al., 2006), there have been recent calls for more attention to be placed on the 'relational', 'human' and 'social' dimensions of project management (Winter et.al., 2006; Hanisch and Wald, 2011). This is largely driven by the growing recognition of 'informal' and relational forms of governance in projects. Increasingly, contemporary management scholars are viewing projects as complex networks of multiple interdependent actors (Dubois and Gadde, 2000). Indeed, despite the significant attention placed on establishing formal organisational and contractual hierarchies in large, complex infrastructure projects, much of the decision-making related to project uncertainties are made through non-contractual, multi-functional networks of individuals temporarily brought together through project-related common interest or tasks.

Network theory is a dominant theoretical paradigm in management research as well as other disciplines including communication, knowledge transfer, marketing, economics, anthropology, epidemiology and organisational studies (Borgatti and Foster, 2003; Brass et al., 2004; Freeman, 2004; Contractor et al., 2006). Network theory offers a powerful analytical tool for capturing, analysing and visualising complex infrastructure projects and their interacting organisations. In the construction industry domain, Loosemore (1999) was among the first to adopt SNA in his study of communication networks under situations of crisis in UK construction. Likewise, Pryke (2005; 2012) applied SNA within construction projects in the UK, France and China, examining the effects of changes in procurement strategy on project governance and project management systems. Pryke and Ouwerkerk (2003) used SNA to map project relationships for effective risk identification and management, while in the work of El-Sheikh and Pryke (2010), SNA supported the identification of communication gaps in a construction project. More recently, Chowdhury et al. (2011) used a representative single case study of a Public Private Partnership (PPP) project to highlight the benefits of using SNA in deepening the understanding of the structuring of PPP arrangements and how the structure of the network emerges from the relationships between project stakeholders. Hossain and Wu (2009) also used SNA to examine the relationship between an actor's structural position in the communication network and his or her ability to coordinate project activities. His findings highlighted the importance of centrally-positioned actors performing a large proportion of the coordination activities within the network.

Taken together, the studies discussed above underline the benefits of taking a network perspective to the study of construction projects. A network perspective allows the comparison of the formally-prescribed project organisation with the actual organisation and underlines the importance of the informal social structures that operate "behind the chart" in large infrastructure project organisations. It also provides a deeper understanding of the various informal network roles that actors play depending on their network position. Having said that, studies adopting a network-analytical perspective remain scarce in the project management domain (Hossain and Wu, 2009; Kratzer et al., 2010) compared to other management disciplines (Balkundi and Harrison, 2006). Therefore, there is a need for more empirical studies on project networks. This study extends previous work on project networks (Pryke, 2005; 2012) and is based on a pilot study conducted on a large and complex infrastructure project, the Bank Station Capacity Upgrade Programme, with the purpose of obtaining initial understanding of the structure and the functioning of the network. Based on quantitative network data collected through an online questionnaire with 63 project participants, the study examined the structure of the network and the existence of communities. The study demonstrates the usefulness of SNA in facilitating a better understanding of the functioning of infrastructure project networks and providing valuable information to project managers. It reveals dysfunctions in the project network and allows for the development of network-based interventions to design team structures that facilitate successful collaboration.

We begin this paper by introducing SNA and outline the main structural elements and analytical measures. We then describe the case study and discuss the findings of the empirical investigation. The conclusion summarises the findings; discusses the contribution of the approach to management practice and underlines directions for future research on project networks.

Wasserman and Faust (1994) describe a social network as a set of actors connected through a set of clearly specified relationships. These relationships can be directed in that they flow from one actor to the other, such as information, trust and affection, or undirected; sharing an office for example. Network theory attempts to explain the effects that different structural properties can have on the actors. A key dimension of social networks is density, which represents the proportion of all possible ties that are actually present, calculated by the number of ties divided by the total number of possible ties. The values range between 0 and 1 where 0 denotes that network actors are unconnected whilst 1 indicates full connectivity. Density is an indicator of the speed at which information diffuses in the social network and the extent to which network actors can reach each other. It also represents 'cohesion' - a reflection of redundancy taking place within a group. Higher cohesion, which is the existence of a large proportion of redundant ties between actors, is often associated with increased team performance (Beal et al., 2003; Evans and Dion, 2012). This is explained by cohesion representing many trusted relationships through which valuable resources such as knowledge, information and opportunities can flow. The work of Wise (2014), however, has contested this view, following a study of 180 teams of travel agents. His findings suggested that an inverse curvilinear relationship may exist between team cohesion and team performance. Group performance was found to be maximised at an optimal point of group cohesion, any decrease or increase beyond this point will result in suboptimal performance. He argues that too much team cohesion can lead to negative results, such as 'group think' and limited innovation.

Geodesic distance is another network analytical measure that indicates the distance between two nodes in the network in question, calculated by the minimum number of ties that must be crossed to get from one actor to another. A large geodesic distance between two actors would indicate that several intermediary actors would have to transfer information between the communication originator and the receiver. This may result in extended time periods for processing the information, higher potential for miscommunications and an increase in the boundaries between the two actors.

Finally, the property of community structure identifies network actors that are joined together in densely-connected groups with looser connections to other parts of the network. Communities may form based on common interest, occupation or co-location and identifying these sub-structures can offer insight into how network function and typology may affect each other. This is particularly important for project managers as previous research, such as that of Donaldson (2001), have shown that social network typology can be optimised to improve the functioning of the network and increase its overall performance. In this research study we propose that the three concepts of connectivity, geodesic distance and the existence of communities of densely connected actors outlined above are instrumental in enabling a better understanding of the functioning of large infrastructure project networks. The network along with the communities will show the overall network structure and determine whether the communication routes, strengths and direction are optimum in relation to the functions of the network.

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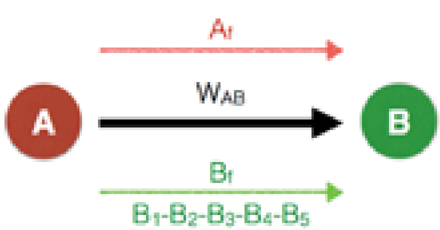
Appendix 2
Methodology for calculating link weights

Overall Framework

To create a weighted information exchange network for a flow of information from actor A and actor B, we collected the following information.

- A Says – Existence of information flow (Ae)
- B Says – Existence of information flow (Be)
- A Says – Frequency (Af)
- B Says – Frequency (Bf), Importance (B1), Accuracy (B2), Timeliness (B3), Clarity (B4), Trust (B5)



Combining A's version and B's Version:

The combined weight WAB is the result/combination of some or all this information based on the values of Ae and Be. The possible values for Ae and Be can be 'true', 'false', 'NA'.

If Ae is 'true' then Af exists and if Be is 'true' then Bf, B1, B2, B3, B4, B5 exist. Otherwise these values are not available. The combining process for various scenarios of these values is given in the table below.

		A_e		
		1	0	NA
B_e	1	Scenario 1 A_f, B_f, B_1, B_2, B_3, B_4, B_5	Scenario 2 C, B_f, B_1, B_2, B_3, B_4, B_5	Scenario 3 B_f, B_1, B_2, B_3, B_4, B_5
	0	Scenario 4 C, A_f, A_q	No Link	No Link
	NA	Scenario 5 A_f, A_q	No Link	No Link

Where C and Aq are assumed values, C is the % of loss of trust we have in a data when its counterpart contradicts it. For example, if A says that he sends information to B and B denies it (Ae is 'true' and Be is 'false') then the strength of the link reported by B is reduced to a significant percentage of the original. We are assuming this to be 10%. This prevents people from linking a large number of other people to gain abnormal significance in the network.

The weight of an information exchange WAB from A to B is defined as the amount of useful information that is exchanged from A to B. This is measured as a counted fraction between 0 and 1, where 0 corresponds to no link and 1 corresponds to the maximum possible strength of the link. The weight, WAB is defined to be dependent on two factors, Frequency of information exchange FAB (counted fraction between 0 and 1) and Quality of Information exchange QAB (counted fraction between 0 and 1). It is also assumed that the high-quality information exchanged less frequently is proportionally equivalent to low quality information exchanged more frequently. Keeping this in mind and since both FAB and QAB are counted fractions, the value WAB is calculated as a product of both.

$$W_{AB} = F_{AB} \times Q_{AB}$$

Scenario 1	$F_{AB} = (A_f + B_f)/2$
Scenario 2 & 3	$F_{AB} = B_f$
Scenario 4 & 5	$F_{AB} = A_f$

Where Frequency, FAB is calculated from Af and Bf depending on the scenario. Quality, QAB is calculated from Aq and Bq depending on the scenario, where Aq is assumed and Bq is a combination of B1, B2, B3, B4, B5. The rationale behind the definition of WAB is explained at the end of the section. Af and Bf are captured in a nominal scale which is converted to an absolute number and then to a counted fraction (from 0 - 1) as shown in the table right.

Code	Nominal Scale	No. of exchanges in a month	Strength of frequency (A_f / B_f)
6	More than once a day	60	1.00
5	Daily	30	0.50
4	Several times a week	20	0.33
3	A few times a week	10	0.17
2	Once a week	5	0.08
1	Less than once a week	3	0.05
0	Once or twice in total	1	0.02

Based on the scenario on the availability of Af and Bf, FAB is defined as either Af or Bf or the average of both. The scenarios and corresponding FAB is shown below. Since, in the survey, we did not ask the respondent to evaluate the information he/she is sending in terms of quality (Importance, Accuracy, etc.), we assume this to be neutral in the Likert scale. This translates to 50% of the highest possible quality. Bq is defined as the weighted average of the parameters B1, B2, B3, B4, B5 where their corresponding weights W1, W2, W3, W4, W5. The Likert scale values and corresponding ordinal scale integer values for Bn are given in the table right.

Likert Scale	Values
Completely Disagree	0
Disagree	1
Somewhat Disagree	2
Neutral	3
Somewhat Agree	4
Agree	5
Completely Agree	6

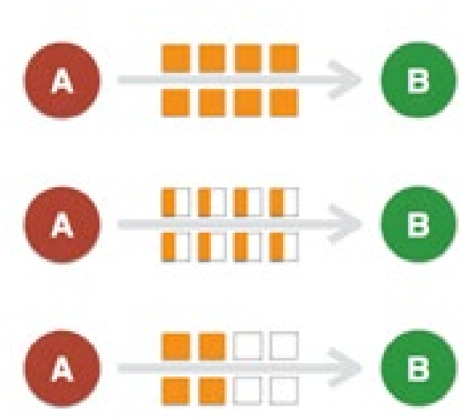
Scenario 1, 2 & 3	$Q_{AB} = B_q$
Scenario 4 & 5	$Q_{AB} = A_q$

Though the methodology allows for the possibility of varied weights for the parameters, the weights for all the parameters are kept equal. We assume that even if the parameter is marked as 0 in ordinal scale there must be some value of quality to the information exchanged for it to exist. Moreover, the incidence of 0 for Bn is very low (~5) in the data. Keeping these in mind, Bq is defined as the weighted average of Bn where the corresponding weights are Wn. The alternative method of using the product of individual parameters was evaluated and the decision is explained at the end of the section.

$$B_q = \frac{\sum_{i=1}^{5} W_i B_i}{\sum_{i=1}^{5} W_i}$$

Based on the scenario QAB is defined as either Aq or Bq. The scenarios and corresponding QAB is shown below. Simplifying all the above and substituting assumed values of C, Aq and Wi, we get the following definitions for WAB for each scenario.

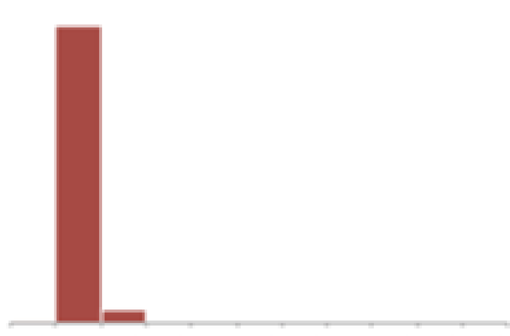
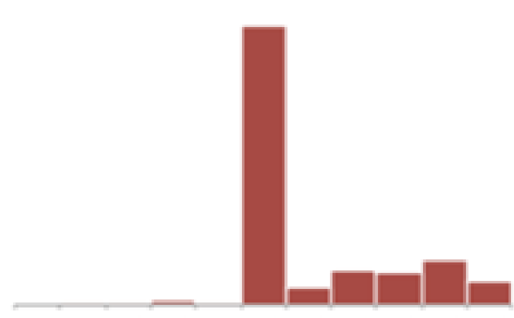
The assumption while determining the weight of information exchange link between A and B is that the weight is directly proportional to the amount of information exchanged between them and the quality of such information. We can imagine this as packets of information transferred between these nodes of certain size where FAB denotes the number of packets and QAB denotes the average size of the packets. This is illustrated in the diagram. For example, in the diagram above, if we assume the maximum possible exchange of packets is 8 and the size of the package is 1 unit, the top most exchange has a FAB of 1 and QAB of 1 so the total amount of packets sent (8) which makes the WAB = 1 x 1 = 1. In the next example, the number of packets sent remain the same while their quality is halved so that FAB = 1 and QAB = 0.5 which leads to total number of complete packets exchanged as 4 and WAB = 1 x 0.5 = 0.5. In the third example, the number of packets is halved but they have full quality so that FAB = 0.5 and QAB = 1 which leads to a total number of complete packets exchanged as 4 and WAB = 1 x 0.5 = 0.5. This is also consistent with our assumption that people who communicate frequently with low quality information should be equivalent to people who communicated less with more quality information.



Scenario 1	$W_{AB} = \frac{(A_f + B_f) * (B_1 + B_2 + B_3 + B_4 + B_5)}{10}$
Scenario 2	$W_{AB} = \frac{0.10 * B_f * (B_1 + B_2 + B_3 + B_4 + B_5)}{5}$
Scenario 3	$W_{AB} = \frac{B_f * (B_1 + B_2 + B_3 + B_4 + B_5)}{5}$
Scenario 4	$W_{AB} = 0.05 \times A_f$
Scenario 5	$W_{AB} = 0.50 \times A_f$

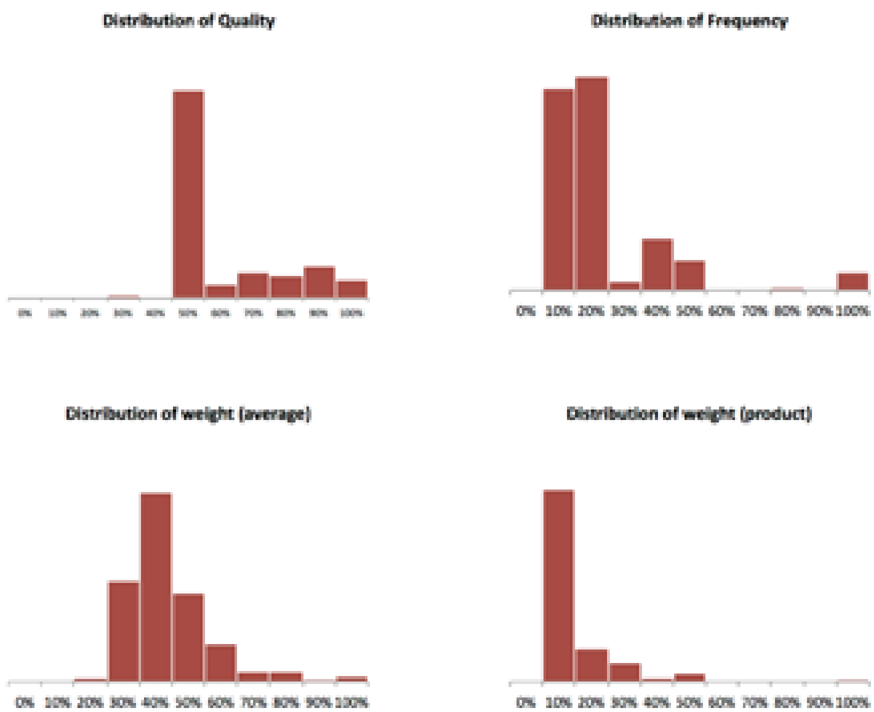
There are two possible approaches which can be taken while calculating Bq from B1, B2, B3, B4, B5. The first is considering all the parameters as different dimensions of the information exchange package and define quality as the product of all these dimensions. The second is considering the parameters as components of the information exchange package with various sizes (weights). The approaches are illustrated and the results, advantages and disadvantages of both approaches is evaluated below.

$B_q = B_1 \times B_2 \times B_3 \times B_4 \times B5$	$B_q = B_1 + B_2 + B_3 + B_4 + B_5$ (adjusted to sizes)
Advantages: The instance when one parameter is zero (i.e no value) the total output becomes zero which is consistent with the definition. But this scenario is very limited in the data and can be overcome by assuming that every exchange has some minimum value regardless receiver's perception.	Advantages: Weights give us control over the combination process and enables us to select, emphasis and isolate elements for further analysis.

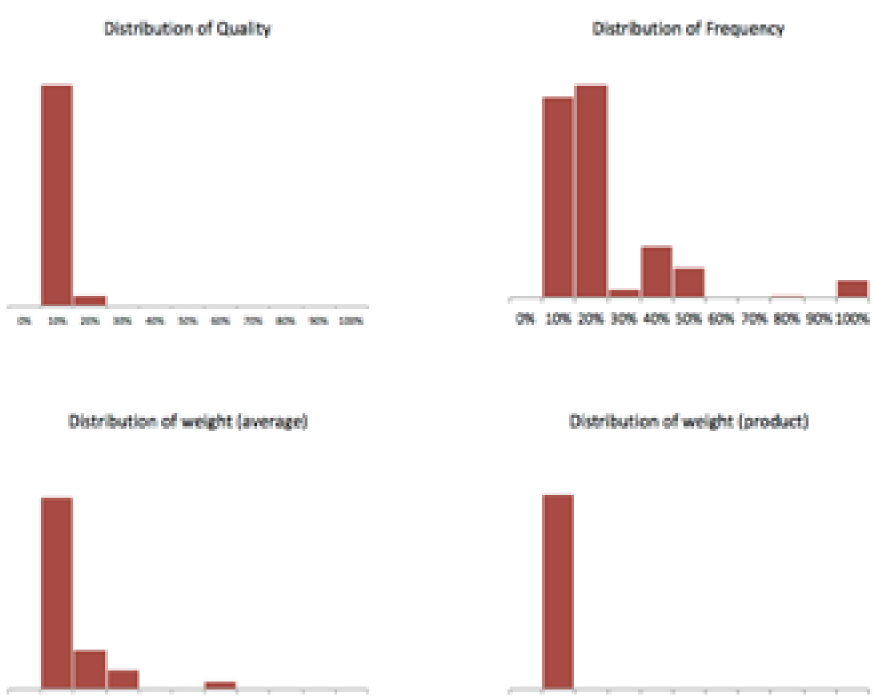
Distribution: By using this method we get the following distribution of W_{AB} in the data. 	Distribution: By using this method we get the following distribution of W_{AB} in the data. 
This shows that the variation in the final data with is method is very limited and can lead to limitation in further analysis	This distribution is in line with our understanding of the survey where most of the interactions are normal (50%) with more instances to the positive side.

Considering all the above, the methodology assuming components is chosen for the analysis. The distribution of WAB in various scenarios is show below.

Distributions when parameters are considered as components of Quality



Distributions when parameters are considered as dimensions of Quality



Appendix 3
Terms of Reference BSCU Project

This terms of reference document outlines the overall requirement for the research, aims and objectives of the study, a clear boundary to the aspect of the design process which is being studied and a data collection framework, especially the primary survey.

Requirement

The high degree of interdependency between participants within inter-organisational networks (generally termed ‘temporary organisations’ or ‘projects’) in large infrastructure projects poses difficulties in the day-to-day management of the work. Though organisational (both functional and line management) and contractual hierarchies help us manage projects, the actual work and information exchange between people and organisations has been shown to follow different organisational networks. In the case of uncertainties and issues, the traditional approach may lead to adversarial behaviour more aligned to the contractual obligations rather than the success of the project. Lack of knowledge of the actual network of information exchange in the organisation may also introduce unknown inefficiencies in the execution of the project.

In this context, through the techniques of Organisational Network Analysis (ONA), a different approach can be taken where the organisation created to plan and manage the project can be defined as a network of actors linked by contractual and functional obligations and information exchanges.

Research Aims

The primary aim of this research study is to apply ONA in the management of large infrastructure projects by studying the project in terms of contractual, functional and information exchange networks between the actors involved. It also aims to create a network based toolkit for capturing and analysing these networks in temporary organisations and to develop a suite of network based interventions for managing these networks so that effective decisions are made in the interest of successful project outcomes.

Research Scope

The entire project, stage 1 - detailed design for BSCU project, is big and complex enough to generate a complete network in terms of information exchange between actors. However, it would be a challenge to identify the cause and effect of network-based measures while dealing with such extensive organisational scope. Hence, it is essential that the scope be narrowed to restrict the study to either a work package, complex multidisciplinary problem or specific risk items identified in the design which can be clearly delineated with a determinable boundary, quantifiable and have maximum inter-organisational (multiple participant) interaction. The selected aspect should also have relevance throughout the project lifecycle.

Keeping in mind the above criteria, the detailed design of the station box and new ticket hall has been selected as the aspect to be studied. This work package has a definable boundary in terms of design accountability within design packages, is multi-disciplinary in terms of design, construction, operation and maintenance and has specific cost, time and risk codes associated with it.

The corresponding BIM/CAD model for stage 1 and stage 2 of the project are attached at the end. Though the base and secondary data will capture the entire project, the primary survey (discussed in the section below) dealing with the information exchange network will specifically focus on the communication between the multiple participants involved in all aspects of the detailed design of the station box and new ticket hall. In addition to the cost, time and risk codes, 3D CAD model data will be used to provide participants to the study with clarity on the physical boundaries of the work package.

This study will be limited to the detailed design phase of the project, which falls within the timescales of the KTP. The data will be captured at certain intervention points (see below) through the life of the design phase. The structure of this study would allow the ongoing investigation of the network through into the construction life cycle and beyond, but this will be subject to the outputs of this study and further agreements with the project participants.

Research Objectives

Having set out the aims of the research study and defined its scope, eight key objectives were identified. These are set out, in no order of priority, as follows:

1. To identify and map all the actors who constitute the BSCU project including people and organisations.
2. To understand the organisation of the BSCU project in terms of

contractual obligations between the actors identified.

3. To understand the organisation of the BSCU project in terms of functional links and hierarchies defined for the project between the actors.
4. To map the information exchange network between actors, over time, during the detailed design phase of the project.
5. To attach quantitative values in terms of time(a), money(b) and risk(c) to the contractual, functional and information exchange networks identified in the organisation.
6. To analyse the identified networks using ONA techniques to find patterns and roles emerging from the organisation overall and individual actors.
7. To analyse the identified networks using ONA techniques to find patterns and roles emerging from the organisation overall and individual actors.
8. To design and implement the improvement measures identified and track the impact the measures have in the networks and the overall project.

<u>Research Question</u>

The specific research question to be asked is:

With respect to the ongoing development of all aspects (design, commercial, planning, reporting, operation, maintenance, construction, etc.) of the detailed design of the station box and ticket hall, as defined by the boundaries in the 3D CAD model, the cost account codes, activity codes and risk codes, please identify those people with whom you have exchanged information with (either to or from) within the last four weeks.

Once identified, please describe the predominant nature of the information exchange within the last four weeks. Please then go on to describe the quality of information that you 'receive' from that person".

Note to respondents:

We do not require you to note the quality of the information that you send. It is recognised that by asking the predominant nature of the information exchange that this will in some respects be a subjective view based on your personal and professional judgement. This is not inappropriate for this study.

Data Collection - Primary Survey

The primary survey is designed to capture both the communication links between people involved in the detailed design of station box/ new ticket hall and the quality of that communication. It aims to verify and validate certain information acquired through the secondary data collection. The list of information asked in the survey and corresponding explanation is given in detail in the following table. A sample questionnaire could be found at www.ktp2014.com/sample.php.

Data Collected	Comments/ Details
Information about person filling the survey	
Name	Name of the person (verified if already exist in the database)
Organisation	Organisation with which the person contractually employed. Individual contractors will name the organisation involved in the BSCU project which contracts them.
Title	The job title of the person (verified if already exist in the database).
Photograph	Optionally uploaded by the respondent so that the questionnaire for others gets easily readable for others/ in the future. e.g. in the list people, photograph is much more readable than a name.
Email Address	Already collected - verified for convenience of the respondent and future accuracy.
Phone Number	Already collected - verified for convenience of the respondent and future accuracy.
Contractual and functional links within organisation	
Functional Discipline	Functional area or team within the BSCU organisational structure the respondent belongs to e.g. engineering , commercial, project controls etc. This is an expandable list where new categories can be added by the respondent if it is not available in the options. The Functional Discipline list can be found below.
Permanent/ Contract	Whether the person is either a permanent member of staff or are contracted in to the organisation that employes them.
Reporting Manager - Functional	The person whom the respondent reports to within the organisation which employs him/her. i.e. an Engineering Manager may report to the Head of Engineering.
Reporting Manager – Line/contract	The person whom the respondent is contractually obliged to report into with respect to BSCU project. This person may be from a different organisation to the one they are employed by. It may be the same person defined as the functional manager.
Information exchange links with other actors	
Communication w.r.t. the issue?	The respondent is given an exhaustive list of people involved in BSCU project from which they select the people they communicate with regarding the detailed design of station box/ new ticket hall. This is just a yes/no question. If answered 'yes' then for each person in the yes list is presented for detailed description of the connection. The boundary definition 3D CAD model of the activity being studied can be found below.
Description of the nature of communication. **This section is presented to all the people with whom the respondent communicates with regarding the work package.** **This is used for quantifying the quality of the communication between the person and the respondent.**	
Do you receive information from this person?	Yes or no. with respect to the particular aspect being studied. The next 7 questions are asked if the answer to this 'yes'.
Frequency	How frequently the information is received from the person?
Quality	Perceived quality of information received (in a scale of 1-6).
Importance	Perceived importance of the information received (in a scale of 1-6).
Accuracy	Perceived accuracy of the information received (in a scale of 1-6).
Clarity	Perceived clarity of the information received (in a scale of 1-6).
Trust	Perceived trust between the person and the respondent (in a scale of 1-6).
Category/ Type of information	This is a list describing the purpose of information exchange received by the respondent. The list of purposes for information exchange can be found below.
Do you send information to this person?	yes or no. with respect to the particular work package being studied. The next 2 questions are asked if the answer to this 'yes'.
Frequency	How frequently do you send information to the person?
Category/ Type of information	This is a list describing the purpose of information exchange sent by the respondent. The list of purposes for information exchange can be found below.

Functional Discipline:

Question: “Which ‘functional discipline’ do you consider yourself to belong to?”

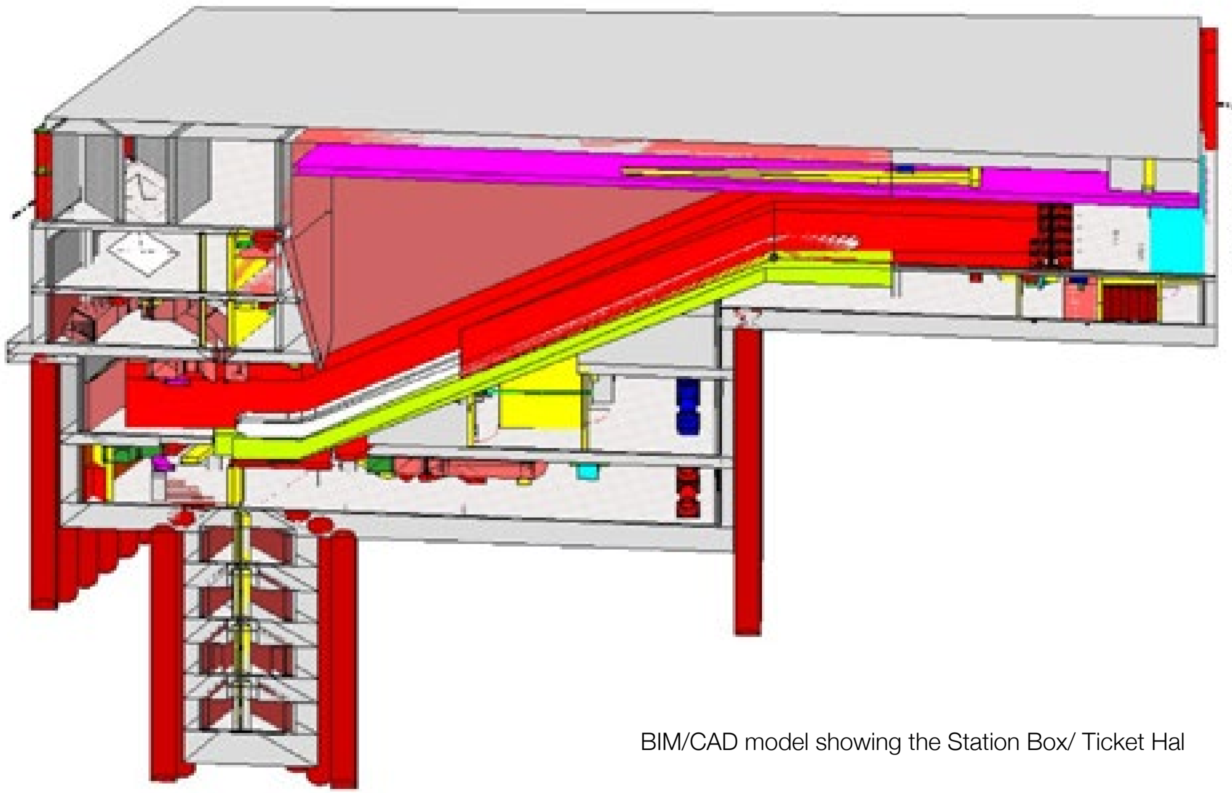
Note: This may not be specified in any of your contracts or roles and responsibilities within the project governance plans, so make a professional judgement based on your day to day role.

1. Project Management
2. Risk Management
3. Commercial Management (incl. Contract Administration & Cost Control)
4. Design/Engineering Management
5. Project Controls (incl. Planning & Reporting)
6. M&E Design
7. Architectural Design
8. Tunnelling Design
9. Civils and Structures
10. Track and Signal Design
11. BIM / CAD
12. Document Control
13. Health and Safety
14. Quality
15. Assurance
16. Systems Engineering
17. Geotechnics
18. Utilities
19. Project Support/Administration
20. Environment
21. Operations
22. Maintenance
23. Other

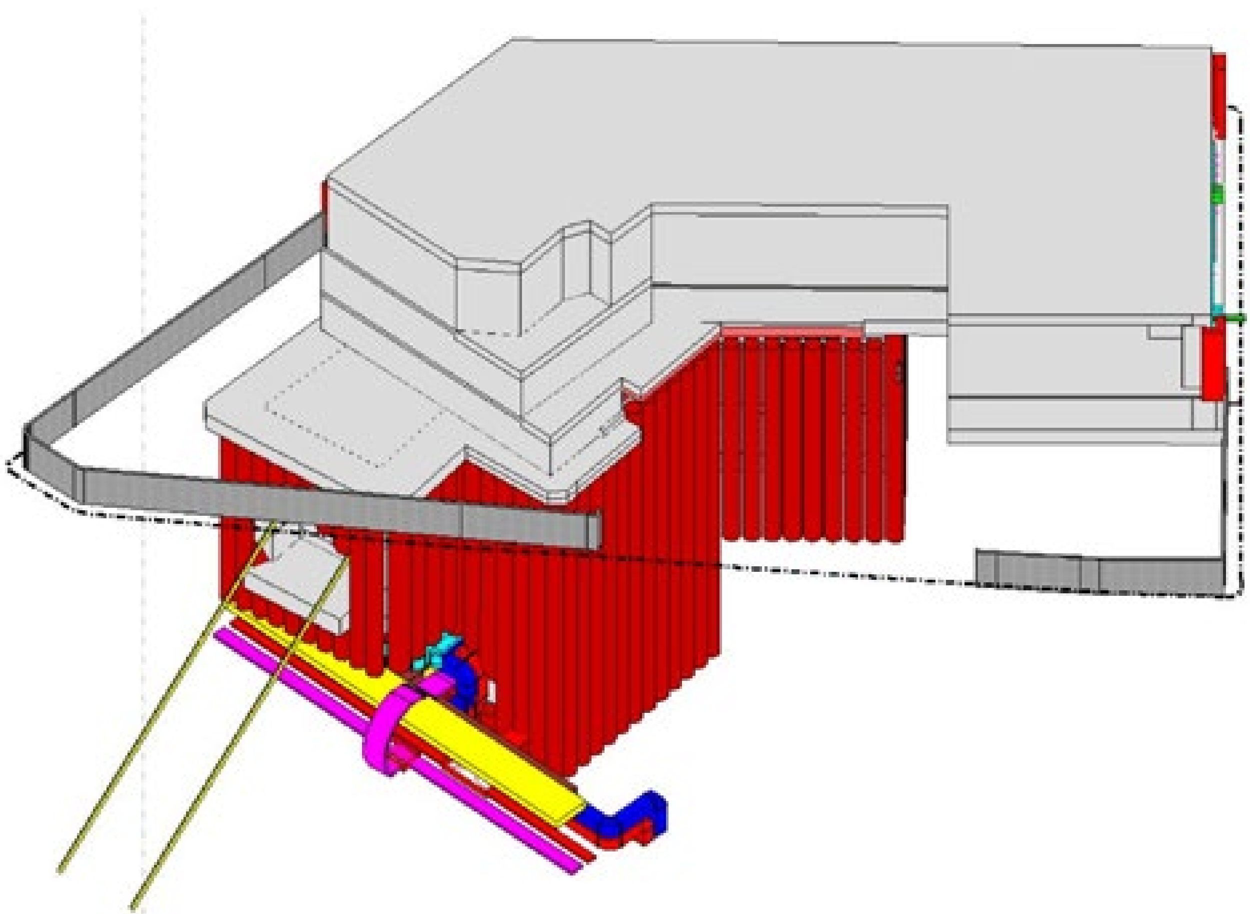
Purpose of the Communication with this person:

Question: “In the past month I have predominantly exchanged information with this person for the following purposes:” Note: This is not an exact science and you may have exchanged information in a number of ways for a number of reasons. If this is the case then make a professional judgement and select the one that has been the most dominant and directly associated with the design and planning of the ‘station box/new ticket hall’.

1. Reporting or preparing progress data
2. Understanding, updating or developing work process
3. Undertaking or participating in quality audit or assurance
4. Structuring, retrieving or archiving documents
5. Submitting, retrieving or analysing design and survey data
6. Reporting, monitoring or controlling cost information
7. Updating, modifying or controlling the schedule
8. Reporting on, updating or identifying risks
9. Preparing, identifying or instructing client change
10. Preparing, identifying or instructing third party change
11. Understanding, reviewing or developing the design within your functional disciplines
12. Understanding, reviewing or developing the design across functional disciplines to manage design interfaces
13. The escalation of critical issues or problems for discussion or resolution
14. Identifying, reporting or discussing issues of health, safety and environment in relation to design development BIM/CAD model showing the Station Box/ Ticket Hall



BIM/CAD model showing the Station Box/ Ticket Hal



Appendix 4
Terms of Reference HFS Project

Network study on the finalisation of the detailed design for works on the Hammersmith Flyover Strengthening project.

Introduction

This terms of reference document sets out details of the second full research study under the Knowledge Transfer Partnership (KTP) between Transport for London (TfL) and University College London (UCL). Details of the KTP, including its purpose and structure, can be found in document reference partnership UIN-3580. This research study builds on the Pilot Study undertaken at the commencement of the KTP and the study on the Bank SCU Programme undertaken in November 2014.

This document outlines the overall requirement for the research, aims and objectives of the study, a clear boundary to the scope of construction work being studied, a data collection framework and estimated timelines.

Requirement

The high degree of interdependency between individuals within inter-organisational networks (generally termed ‘temporary organisations’ or ‘projects’) in large infrastructure projects poses difficulties in the day-to-day management of the work.

Though organisational (both functional and line management) and contractual hierarchies help us manage projects, the actual work and information exchange between people and organisations has been shown to follow different organisational networks.

The structure and characteristics of information exchange networks may introduce imperceptible inefficiencies in the execution of the project. A more thorough understanding of these networks may allow managers to make informed and timely interventions to improve project performance (in whichever way performance is measured e.g. reliability of delivery, profit, cash flow).

In this context, through the techniques of Organisational Network Analysis (ONA), a different approach can be taken where the organisation created to plan and manage the project can be defined as a network of actors linked by contractual obligations, functional reporting obligations, and information exchanges.

Research Aims

The primary aim of this research study is to apply ONA in the management of large infrastructure projects by studying the project in terms of contractual, functional and information exchange networks between the actors involved.

It also aims to create a network-based toolkit for capturing and analysing these networks in temporary organisations and to develop a suite of network-based interventions for managing these networks so that effective decisions are made in the interest of successful project outcomes.

Research Scope

The entire Hammersmith Flyover Strengthening project is large and complex enough to generate a complete network in terms of information exchange between actors. However, it would be a challenge to identify the cause and effect of network-based measures while dealing with such extensive organisational scope.

It is therefore essential that the scope be narrowed to restrict the study to either a work package, a complex multidisciplinary problem or specific risk items which can be clearly delineated with a determinable boundary, are quantifiable and have maximum inter-organisational (multiple participant) interaction.

Keeping in mind the above criteria, the finalisation of the detailed design has been selected as the aspect to be studied. This aspect of work has a definable boundary in terms of design accountability within design packages, is multi-disciplinary in terms of design, construction, operation and maintenance and has specific cost, time and risk codes associated with it.

Though the base and secondary data will capture the entire project, the primary survey (see Section 8) dealing with the information exchange network will specifically focus on the communication between the multiple participants involved in all aspects of the detailed design of the station box and new ticket hall.

This study will be limited to the construction phase of the project, which falls within the timescales of the KTP. The data will be captured at certain intervention points (see Section 9) through the life of the construction phase. The structure of this study would allow the on-going investigation of the network through into the construction life cycle and beyond, but this will be subject to the outputs of this study and further agreements with the project participants.

Research Objectives

Having set out the aims of the research study and defined its scope, eight key objectives were identified. These are set out in no order of priority below:

1.To identify and map all the actors who constitute the Hammersmith Flyover Strengthening project including people and organisations.

2.To understand the organisation of the Hammersmith Flyover Strengthening project in terms of contractual obligations between the actors identified.

3.To understand the organisation of the Hammersmith Flyover Strengthening project in terms of functional links and hierarchies defined for the project between the individuals.

4.To map the information exchange network between actors, over time, during the design phase of the project.

5.To attach quantitative values in terms of time (a), money (b) and risk (c) to the contractual, functional and information exchange networks identified in the organisation.

6.To analyse the identified networks using ONA techniques to find patterns and roles emerging from the organisation overall and individuals.

7.To qualitatively assess the emerging networks alongside the quantitative data (objective 5) to find out those areas of the organisation which are working well or which need improvement and identify possible improvement measures.

8.To design and implement the improvement measures identified and track the impact the measures have in the networks and the overall project.

Research Question

The specific research question to be asked is:

“With respect to the finalisation of the detailed design, specifically, the expansion joints, the permanent monitoring, the bearing pit covers and the pavement reinstatement, please identify those people with whom you have exchanged information with (either received or sent) within the last four weeks. Once identified, please describe the predominant nature of the information exchange within the last four weeks. Please then go on to describe the quality of information that you 'receive' from that person”.

The notes to respondents:

We do not require you to note the quality of the information that you send. It is recognised that by asking the predominant nature of the information exchange that this will in some respects be a subjective view based on your personal and professional judgement. This is not inappropriate for this study.

Data Collection – Primary Survey

The primary survey is designed to capture both the communication links between people involved in the finalisation of the detailed design and the quality of that communication. It aims to verify and validate certain information acquired through the secondary data collection. The list of information asked in the survey and corresponding explanation is given in detail in the following table. A sample questionnaire can be found at www.ktp2014.com/sample.php.

Data Collected	Comments/ Details
Information about person filling the survey	
Name	Name of the person (verified if already exist in the database).
Organisation	Organisation with which the person contractually employed. Individual contractors will name the organisation involved in the HFO Strengthening project, which contracts them.
Title	The job title of the person (verified if already exist in the database).
Photograph	Optionally uploaded by the respondent so that the questionnaire for others gets easily readable for others/ in the future. e.g. in the list people, photograph is much more readable than a name.
Email Address	Verified for convenience of the respondent and future accuracy.
Phone Number	Verified for convenience of the respondent and future accuracy.
Contractual and functional links within organisation	
Functional Discipline	Functional area or team within the Hammersmith Flyover Strengthening project organisational structure the respondent belongs to e.g. engineering, commercial, project controls etc. This is an expandable list where the respondent can add new categories, if it is not available in the options. The Functional Discipline list can be found below.
Permanent/ Contract	Whether the person is either a permanent member of staff or contracted in to the organisation that employs them.
Reporting Manager - Functional	The person whom the respondent reports to within the organisation, which employs him/her. i.e. an Engineering Manager may report to the Head of Engineering.
Reporting Manager – Line/contract	The person whom the respondent is contractually obliged to report into with respect to the Hammersmith Flyover Project. This person may be from a different organisation to the one they are employed by. It may be the same person defined as the functional manager.
Information exchange links with other actors	
Communication with respect to the issue?	The respondent is given an exhaustive list of people involved in HFO Strengthening project from which they select the people they communicate with regarding the finalisation of the detailed design. This is just a yes/no question. If answered 'yes' then for each person in the yes list is presented for detailed description of the connection. The boundary definition 3D CAD model of the activity being studied can be found below.
Description of the nature of communication. This section is presented to all the people with whom the respondent communicates with regarding the work package. This is used for quantifying the quality of the communication between the person and the respondent.	
Do you receive information from this person?	Yes or no with respect to the particular aspect being studied. The next 7 questions are asked if the answer to this 'yes'
Frequency	How frequently the information is received from the person?
Quality	Perceived quality of information received (on a scale of 1-6)
Importance	Perceived importance of the information received (on a scale of 1-6)
Accuracy	Perceived accuracy of the information received (on a scale of 1-6)
Clarity	Perceived clarity of the information received (on a scale of 1-6)
Timeliness	Perceived timeliness of the information received (on a scale of 1-6)
Trust	Perceived trust between the person and the respondent (on a scale of 1-6)
Category/ Type of information	This is a list describing the purpose of information exchange received by the respondent. The list of purposes for information exchange can be found below.
Do you send information to this person?	Yes or no with respect to the particular work package being studied. The next 2 questions are asked if the answer to this 'yes'.
Frequency	How frequently do you send information to the person?
Category/ Type of information	This is a list describing the purpose of information exchange sent by the respondent. The list of purposes for information exchange can be found in below.

Functional Disciplines

Question: “Which ‘functional discipline’ do you consider yourself to belong to?”

Note: This may not be specified any in your contract or roles and responsibilities within the project governance plans, so make a professional judgement based on your day-to-day role.

1. Project Management
2. Risk Management
3. Commercial Management (incl. Contract Administration & Cost Control)
4. Design Management
5. Design
6. Project Controls (incl. Planning & Reporting)
7. BIM / CAD
8. Document Control
9. Health, Safety and Environment
10. Quality
11. Assurance
12. Project Support/Administration
13. Operations and maintenance
14. Construction management
15. Construction supervision
16. Other

Purpose of the Communication with this person:

Question: “In the past month I have predominantly exchanged information with this person for the following purposes:”

Note: This is not an exact science and you may have exchanged information in a number of ways for a number of reasons. If this is the case then make a professional judgement and select the one that has been the most dominant and directly associated with the finalisation of the detailed design.

1. Reporting or preparing progress data.
2. Understanding, updating or developing work process.
3. Undertaking or participating in quality audit or assurance.
4. Structuring, retrieving or archiving documents.
5. Submitting, retrieving or analysing design and survey data.
6. Reporting, monitoring or controlling cost information.
7. Updating, modifying or controlling the schedule.
8. Reporting on, updating or identifying risks.
9. Preparing, identifying or instructing client change.
10. Preparing, identifying or instructing third party change.
11. Understanding, reviewing or developing the design within your functional disciplines.
12. Understanding, reviewing or developing the design across functional disciplines to manage design interfaces.
13. The escalation of critical issues or problems for discussion or resolution.
14. Identifying, reporting or discussing issues of health, safety and environment in relation to design development.