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DECISION PROCESSES IN ENGINEERING DESIGN: A NETWORK PERSPECTIVE OF STAKEHOLDER AND TASK INTERACTION

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ABSTRACT

In recent years, there has been significant attention given to developing decision support methods and tools for engineering design. While advances in the formal, mathematical modeling and statistical mechanics based models have been impressive, this has not been the case for research attempting to reach beyond normative models to examine the cognitive and social factors that influence decision-making. In general advances have provided for either a top-down or bottom-up approach to decision-making; ignoring the requirements for both participant and task connectedness and dependencies. This paper describes an integrated modeling framework that uses a multi-network perspective of decision-making. The utility and extensibility of this framework are considered in discussion by way of examples from construction engineering design.

Keywords: Decision-making processes, stakeholder and task connectedness, network theory.

1. INTRODUCTION

The design decision-making process is a discourse, with its own language and structure. In designing, decision processes communicate and mediate between users and the artefact, and, at some point, involve all stakeholders in the development and delivery process. What is intriguing about decision processes in the design domain is their multi-network character, defined by both the object of decision-making i.e., the problem itself, and the subjects, i.e., the participating actor/s, who apply domain specific knowledge to create, or exert some influence on, decision outcomes. The multi-network nature of decision-making accounts for latent networks that are created or implied through uncertainties and complex interactions inherent in engineering design projects - be they construction, civil, aeronautical or automotive. Latent networks are created when, for example, actors simply do not know who or what is affected by a decision outcome; or when decisions that are taken ‘in principle’ so as to avoid disruption to work-flow; or when decisions that are influenced by varying stakeholder power and/or participation levels affect or influence other decision processes.

New advances in network theory promise to uncover the ways in which social (group, organizational and political) and technological task-based relationships shape decision outcomes. By conceiving decision processes as a complex system and modeling this system using network-theoretic principles, it is possible to include a tremendous amount of information that has remained untapped by conventional qualitative, game-theoretic, and statistical approaches. Modeling and visualization of decision processes holds the promise of uncovering not only latent networks, but also the key participants, critical tasks, vulnerabilities and dynamics that impact upon complex decision situations found across the design and delivery stages of large projects.

This paper therefore seeks to contribute to the understanding of the strategic implications of decision processes as complex systems of interacting actors and problem tasks, and demonstrate a technological means for supporting them. The objective is to allow participants of decision processes to exploit shared awareness and collaborative planning to communicate and understand decision intent and interdependencies so as to enable and enhance decision management. The logic of the approach is presented in Figure 1.

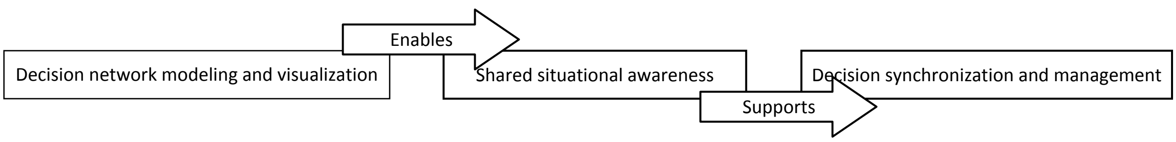


Figure 1. Logic of decision process modeling, visualization and management

Thus, the overall aim of this research is to understand the interactions of different decision processes using a "multi-network" perspective so as to identify the dynamics of decision situations and develop methods for their performance measurement and evaluation. Achieving this support presents a larger modeling challenge and progress towards this is presented here. To date, the outcomes of the experimental study of a multi-network system that adequately characterizes complex decision processes in terms of participating actors and tasks demonstrates how information technologies can be mobilized so as to facilitate the dynamic extraction, visualization and analysis of the "situatedness" of decision processes (e.g., key participants, hidden networks, vulnerabilities and changes in decision context), at varying levels of fidelity.

2. NATURE OF DECISION-MAKING IN ENGINEERING DESIGN PROJECTS

Decision-making across the design and delivery stages of projects is an omnipresent activity. Stakeholders such as architects, engineers, project managers, manufacturers, contractors, clients, and end users make decisions continuously throughout each project stages. While some decisions seem simple or trivial, others can have far-reaching consequences. Some decisions are of the one-shot type, while others involve a sequence of actions constrained by previous decisions or influenced by feedback of results (Sarma 1994). Many decisions in projects are influenced by the coalition of stakeholder groups in unanticipated ways. Selection amongst alternatives may be made under high levels of uncertainty, amid competing decision makers, or involve a complex of interconnected components where decision outcomes may result in unforeseen knock-on effects.

The variety of stakeholders required to collaborate in engineering projects can be seen to stem from product complexity. Stakeholder groups will therefore come in different sizes and forms involving e.g. a variety of design and delivery teams, consultant groups, end user committees, and a host of strategic partnerships throughout the supply chain. Groups of project stakeholders are connected through membership of the same, associated, or aggregated decision problems and sub-problems. These connections span not only between individuals within the same organization, or functional business unit, but also across organizational boundaries. Furthermore, coalitions of stakeholders in many large projects, in particular construction engineering projects, are temporary. Thus relationships in such cases are seldom stable and often only last for the project's duration.

2.1 Background and Related Work

Whilst the problematic social characteristics of the different design domains have been documented (see e.g., Green et al. 2004 for an overview of construction), the effect of differing levels of stakeholder participation, power, and value propositions, combined with their impact on dynamic and interconnected problem tasks is still relatively unknown. Hierarchical levels of decision problems and the interdependencies between problem tasks means that a design change that has a knock-on effect may be obscured by the complexity of the product, by the lengthy design and development stages, or by the complex of social actors working in isolation prior to, during or after working in collaboration. Further, the hierarchical levels and interdependencies of decision tasks related to the overall design problem, or sub-problems, may be ignored or overlooked due to complex technical relationships which were not obvious to decision-makers. Crucially, the solution of one problem may be inter-related with another task but at a different level of abstraction. That is, e.g, the outcome of a decision at the strategic level (e.g, broader planning based decisions) may have knock-on effects at the systems level or at the component level – and vice versa. Any one specific decision outcome may have knock-on effects on tasks at either of the other levels and may be furthermore bi-directional. Seen from this perspective, decisions can depend upon information generated from previous decisions, e.g., made when solving a different problem tasks and/or by different actors. Such 'interconnectedness' can be further complicated when decisions are made "in principle", which is often the case when time constraints dictate the need to maintain work-flow. In such cases, work is continued whilst approval is sought from e.g., a client, regulatory or advisory group. Therefore, concurrent with the problem of decision-making is forecasting the effects of decisions.

Current decision-theoretic characterizations of decision processes are therefore incomplete (Shaffer 2008) as they fail to adequately account for knowledge concerning the causal connections between acts, states, and outcomes so as to account more fully for both the objects and subjects of decision situations. Consequently, the support of collaborative decision processes via computational tools is inadequate since a tool must meet the needs of the situation it is used in. Development of decision support systems is often focused exclusively on one type of problem and ignores many factors that can affect continuous, dynamic decision processes, their behavior, the different actors that influence their resolution, and crucially their implementation. Consequently, such reductionist approaches neglect many of the interconnections between objects and subjects that make up a decision situation.

It is therefore desirable to examine simultaneously both the interconnections of actors and problem tasks quantitatively (which may change throughout project stages as relationships are defined, developed and redefined), to determine whether any additional structures might relate to and influence collaborative decision-making efforts. However, there is no consensus explanation of how different actors, groups of actors and problem task structures influence decision-making, how they are initially determined, how the decision process itself is affected and how decision alternatives are modified from one decision situation to another.

In addressing these issues, this research draws on network theory, which provides powerful tools for representing and analyzing complex systems of connected actors and tasks. The quantitative study of real-world networks has a long history in the social sciences (see, for example, Newman 2003 and Watts 2004) and among the topics studied are evolving social groups (Kossinets and Watts 2006), collaborations (Guimera et al. 2005), community detection (Danon et al. 2005), hierarchical organization (Sales-Pardo et al. 2007) and communication (Monge and Contractor 2003). These studies have generated important insights into the effects of network topology on individual behavior, including community formation, and hierarchical and modular organization. However, such investigations in the application domain of engineering design are nascent and modeling the modular, hierarchical and community structures of both actor (social) and problem (task-entity) networks can further understanding of decision processes in this important domain.

Over the past few years, a number of researchers investigating complex projects have led a nascent effort to develop the understanding of the interconnections of decision processes of complex engineering design projects (Jupp 2010). This work primarily builds on the author’s previous interdisciplinary research with UK companies conducted from 2006-2009 under the EPSRC-funded Knowledge and Information Management (KIM) Grand Challenge project and more recent research with Australian companies conducted in 2010. Completed case studies on complex projects have captured detailed information on decision-making across collaborating stakeholder organisations, and found that individual actor preference and value assignments, as well as associated value timescales, yield multiple families of social and task-entity networks (multi-networks). Further, related macro analyses based on a variety of factors that are endogenous and exogenous to the project and which influence each stage of the decision process has also been undertaken (Jupp et al. 2007).

This previous research has therefore considered decision structures composed of ties based on stakeholder value assignments and value timescales (Jupp et al 2009). What this work shows is that network methods would be particularly effective at uncovering structures among stakeholder group memberships and inter-related problems tasks. Utilisation of such case study data in a network theoretic approach would enable a more in-depth analysis to be undertaken.

3. RESEARCH FRAMEWORK

The difficulty in understanding decision processes of engineering design projects surrounds the interconnectedness of the key actors, hidden groups and technological component interdependencies. To enhance current understanding of these aspects this research has developed a three stage approach. The first stage commences with examination and analyses of case study observations. The second stage consists of the reconstruction of observations using formal modeling techniques derived from network theory, which includes network visualization and formulation of hypotheses. The final stage relies on building a visualization framework where the key characteristics identified in the previous stages will become variables and parameters of behavior for the computational visualization of dynamic social and task-entity networks.

3.1 Stage 1

In-depth examinations of architectural, engineering and construction (AEC) design actors and activity task processes utilized in-situ case study methods, semi-structured interviews and focus group workshops (Yin 2009). The main objective was to utilize data derived from the two building projects so as to reconstruct and describe social group memberships (committees, teams, interest groups, etc.) and task entities (hierarchical breakdowns as decision chains generated as a result of problem decomposition). Project actors were asked to describe their role and responsibility in each project stage and identify tasks and activities they were involved in directly and indirectly. Once this high-level actor and activity 'map' was derived project actors were then asked to identify key attributes in relation to themselves and other actors as well as their activity tasks, including: (i) participation levels, (ii) perceived level of power and influence, (iii) value proposition, (iv) types and frequency of formal and informal information exchange, and (iv) activity task hierarchies. All interviews will be taped and transcribed. The thematic analysis techniques were followed for coding and interpreting primary data, using manual methods of sorting and categorising and the software package QSR NVivo 7. Case study data was therefore subject to coding and analysis with reference to three areas: (i) actor-actor connectedness, (ii) activity-activity connectedness, and (iii) actor-activity connectedness.

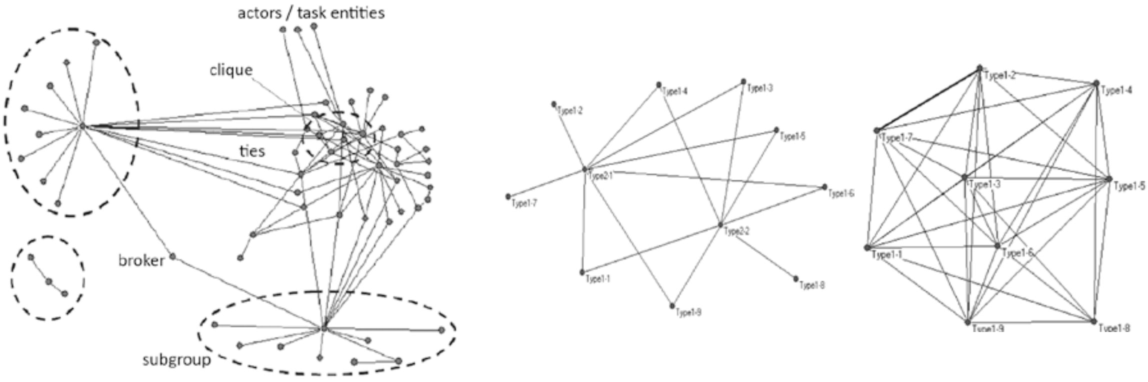
3.2 Stage 2

Based on the data analyzed in Stage 1, this research utilizes a 'complete network analysis' approach (Wasserman and Faust, 1994, Hanneman 2001). Complete network analysis attempts to capture all the relationships among a set of entities. Through complete network analyses, this research explores both the social structures, i.e. "patterns of connectivity and cleavage within social systems" (Wellman, 1988) as well as problem task structures derived from the architecture of the object, i.e., patterns of connectivity and cleavage within technological systems, which may be defined by e.g, physical, mechanical, or electrical connections between components.

One of the key challenges in using network analysis as a research tool is its diversity in application. Even with relatively limited number of project actors, large numbers of actor and activity networks were identified. For the purpose of this paper, 'systems level decision activities' were analyzed to examine the nature of actor and activity relationships and non-hierarchical decision process patterns in the two case projects during project implementation stage. Further, most of the terms used in network analysis are based on complete networks and well-known network techniques like cluster analysis and measures like density. Concepts central to our discussion of network analysis in Section 4 are presented in Table 1 and Figure 2 (adapted from Wasserman and Faust (1994) and Nugroho and Ozcan (2009)).

Table 1. Key concepts in multi-network analysis for complex decision processes. Adapted from Wasserman and Faust (1994); Nugroho and Ozcan (2009)

Concept	Description
Actor	Social entities are referred to as actors, i.e., discrete project, organisation or collective social units. Actor is depicted as a 'node' or 'vertex' in network
Task entities	Problem tasks defined by product architecture. Entities may be components or task activities.
Relational tie	In the case of a social network, what establishes a linkage between a pair of actors; and in the case of a task-entity network, what establishes a linkage between a pair of task entities and may specify the criticality of the interconnections
Group	The collection of all actors or task entities on which ties are to be measured. A group consists of a finite set of actors or task entities. Groups are defined as: 'cliques' if every node is directly tied to every other node 'social circles' or 'task circles' if there is less stringency of direct contact, which is imprecise or as structurally cohesive block if precision is wanted
Subgroup	A subgroup (of actors or task entities)
Relation	The collection of ties of a specific kind among members of an actor or task entity group
Broker	Individual actors or task entities that connect two otherwise disconnected cliques or by bridging from one group to which it belongs to another that may join them
Social network	Social network consists of a finite set of actors and the relation or relations defined among them
Task-entity network	Task network consists of a finite set of task entities and relation or relations defined among them



(a) *(b)* *(c)*

Figure 2. Multi-Network Map (a) One- and Two-mode multi-network (links between actor and task nodes); and Network modes (b) One-mode (c) Two-mode

In social network analysis, researchers have explored emergent structures by comparing them with other structural maps of the same actors to determine the degree of overlap between "observed" structure and "theoretical" structure (Kilduff and Tsai, 2003). Research related to task entity networks and product architectures is however by comparison a nascent area of research in the domain of construction research. Engineering design researchers from aerospace and automotive design domains have developed these networks in relation to Change Prediction Methods (CPM) - developing tools for identifying relationships among entities, which may be based on physical components or tasks, so as to determine criticality of interconnections (Eckert et al. 2006). Such methods can be used to create task- and component based networks and record information about component connectivity, change impact types, likelihoods, and display change prediction result. By uniting these approaches in a multi-network approach, we are able to define network nodes by actors and problem tasks and network ties as attributes defining the relationship between them. Studying social and task entity structures simultaneously helps to reveal two important features of decision processes: (1) how actors cluster or group in social space, and (2) how tasks are grouped in the problem space. Consequently, attention of analysis during this stage of the framework includes examination of "community", hierarchical structures of networks and hidden or latent networks.

3.3 Stage 3

Modeling and visualization enables the conversion of the descriptive models generated in the previous stages into formal models to describe the dynamic nature of decision processes. The strength of network analysis is that it can analyze both the whole system of relations and parts of the system at the same time. Researchers are therefore able to "trace lateral and vertical flows of information, identity sources and targets and detect structural constraints operating on flows of resources" (Wellman, 1988). The ability to capture the structure of the whole, or parts, of interacting systems makes the two-mode approach to network analysis particularly interesting for research on complex decision-making processes. It is this particular ability that we feel is important in making the combination of decision processes and a network-theoretic perspective so attractive.

By utilizing and customizing advanced visualization techniques for decision networks the intention is to enhance understanding of these structures and behaviors and how they change over time so as to study their dynamics and extract general principles. Dynamic visualization is considered appropriate because the target system is complex and there are important nonlinearities between variables that can be identified via visualization methods that enable the dynamic patterns of networks to be mapped. This will enable the extraction of principles and patterns of decision processes by simultaneously observing and manipulating variables in both social and task entity networks.

4. RESEARCH FINDINGS

Whilst our incorporation of a network perspective into the study of decision processes is still in its early stages, the remainder of the paper presents some preliminary findings which have revealed some valuable insights so far.

4.1 Case studies and initial discoveries

The first stage of this research has conducted analyses of the case study data that describes hundreds of decision situations and processes which occurred during the design and delivery stages of complex construction projects. Data was captured with the primary focus on describing decision processes as they occur in practice; it includes the type of design decision problems, identified tasks, decision protocols, decision support tools and detailed variables surrounding those actors involved in collaborative decision-making situations (e.g., their goals, preferences and unique value propositions) that are routinely seen in construction engineering projects.

Although project stakeholders do not broadcast lists of their values and attributes by which they individually or their organizations measure the project's success, their decision preferences and choices provide a paper trail so as to identify relationships. This first stage has therefore examined these connections by analyzing hundreds of collaborative and independent design decisions made during project implementation. Based on preliminary analyses of four detailed cases for completeness of available data and unique decision-making contexts, two case study projects were identified as containing sufficient and detailed data to support in-depth analysis; they included two UK projects:

- Case 1 - The Curve, Performing Arts Theatre. This study tracked the decision-making processes across the main design and construction stages of this state-of-the-art centre.
- Case 2 - The Royal London and St. Bartholomew's Hospital. The case study documents the late detailed design, documentation and construction stages of Britain's largest hospital.

Data captured across both case studies provided the adequate level of detail in their descriptions of the actors and task entities surrounding numerous decision situations across four of the main stages of the RIBA Plan of Work (RIBA 2007), including schematic design, detailed design, construction documentation and construction. Each data set was 'cleaned', 'coded' and mapped into matrices to present information relating to stakeholders and their organizations (with detailed data on the 10-12 most active firms), contractual and governance based relationships, project mission, identified problem tasks, their interdependencies, suggested solutions, decision opponents and proponents and the unique value propositions of decision participants. The case studies were also mapped in terms of how tasks related to product hierarchy, such as system or component levels. Interconnections between actors and actor organizations were then mapped in further detail in relation to their participation in identified decision processes. This data was derived from their involvement in both face-to-face decision situations (which was recounted in case study interviews), and also through a variety of electronic forms of communication (captured through emails, faxes, etc).

Social and task based relations were then reviewed based on documentation covering specifications of roles and responsibilities, contractual arrangements, and the information exchange protocols. For example The Royal London and St. Bartholomew's provided a rich data source in relation to the documentation covering this complex Private Finance Initiative contractual form and the information exchange protocols established to support Building Information Modeling. Detailed information relating to politically oriented or audit committees surrounding these projects also provided a rich source of information to review our initial social and task network maps.

Mapping of the object and subject characteristics across multiple decision processes has therefore resulted in re-constructed decision process matrices for each of the stages studied. Changes in social group memberships that occurred both within and across each project stage have been tracked and mapped. However smaller changes in stakeholder group memberships that occurred within a project stage have been ignored as they have been captured as they alter across stages. Taking 'The Curve', Performing Arts Theatre case study as an example of our findings thus far, the descriptive mappings of actor and task-entity connections into the matrix includes approximately 84 individual actors (including stakeholder replacements), 21 stakeholder organizations, comprising of three different coordinating and audit committees, more than 40 different functional business units, with an average of seven actor memberships per decision situation. For the descriptions of task-entity interrelations, on average approximately 960 problem tasks (including sub-problems and sub-sub-problems) across strategic, systems and component level interconnections have been mapped.

These preliminary findings have produced a matrix based mapping of actors, actor groups, task entities and chains of task entities. From this map it is predicted that the top five to seven groups or clusters of actors will reflect the dominant levels of stakeholder power and participation (a traditional project management measure of decision influence). These social groups may be consistently successful in influencing decisions and will be among one of the many hypotheses tested in future research stages.

4.2 Experimental network visualization

Some basic modeling and visualization of the social and task-entity matrices described in the previous section have been undertaken. This stage has utilized and customized tools from network analysis to visualize group memberships, problem decomposition, and the alignments and realignments of preferences and values, which affect decision process behavior. As an experimental study, the complex interactions that underlie the myriad of decisions processes that can be defined across project stages, this research has so far drawn on single and multi-network approaches to better understand the role of actor groups, task interdependencies, and their structures throughout dynamic decision situations. However, what this experimental modeling stage has revealed via the exploitation of the fact that nodes are typically embedded in the two types of networks (with multiple ties of differing strengths, either between individual actors, clusters of actors, problem tasks or chains of tasks), is that within the unique structures of networks, the relational attributes of actors and tasks are interdependent and subject to change across project stages.

However it should also be noted that while rich in their data content, two-mode networks are difficult to visualize and interpret. This experimental visualization method has therefore utilized a common strategy to manage such cases of visualization in a one-mode "projection" of the network onto either the individual actor and actor groups, or the tasks and sets of task entities. Taking the collective of stakeholder organizations within 'The Curve' case study as an example, the projection of the groups were modeled, in which nodes show groups of actors, i.e., organizations, and ties represent common membership or "interlocks" (Robins and Alexander 2004) - both between organizational groups and between task entities. Figure 3 shows this experimental visualization using an adaptation of the Visone network modeling software (Baur 2008).

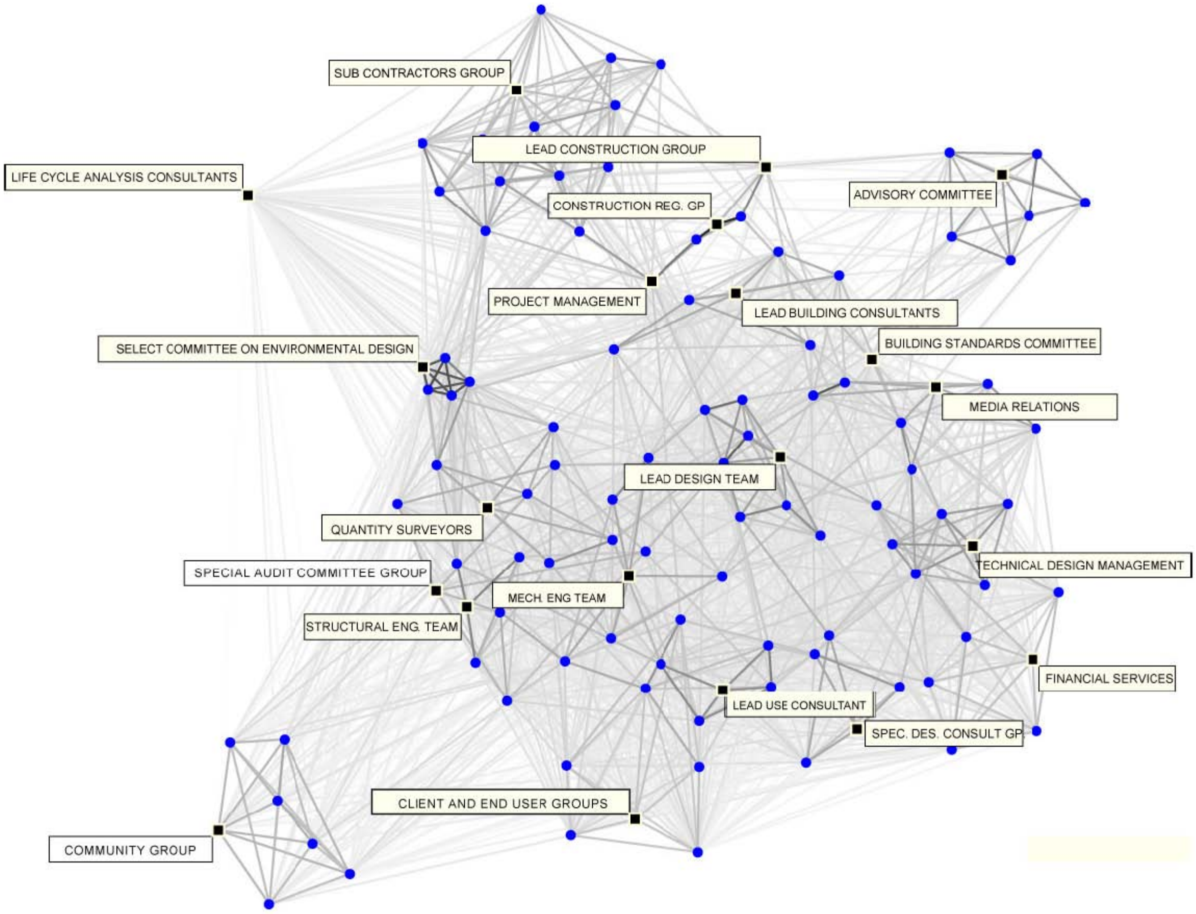


Figure 3. Network visualization: one-mode projection of a two-mode network. SQUARES indicate the network of social groups, while individual actors (stakeholders) are shown as CIRCLES. Each link between two groups or individuals is assigned a strength (indicated by the link's darkness) equal to the normalized interlock (where the "interlock" between two groups is equal to the number of their common members.

The experimental network visualization in Figure 3 illustrates that the more common members of two types of actor groups have, the stronger their connection is in the network. The strength of the connection can be quantified by the ‘normalized interlock’ (Porter et. al 2007, Robins and Alexander 2004). Using this experimental network and developing the analysis method makes possible the utilization of this weighting in the visualization of a network by darkening the links between nodes accordingly. Using this mode of analysis to the decision networks as they are developed, it is anticipated that whilst some of the connections that can be identified may be unsurprising, other connections between stakeholder groups will be much less obvious. Further, thus far the multi-network approach has enabled these early stages of research to simultaneously consider multiple ties between different actors and task entities, and in future research will enable us to take advantage of the enormous amount of information that has consequently become available that describes these entities.

5. DISCUSSION AND FUTURE WORK

By way of the research framework and preliminary application and findings of the multi-network approach to modeling decision processes, this paper has shown that the challenge of supporting complex decision situations is a significant problem for the construction industry. With the tremendous impact that complex development projects have on the economy, it is crucial that we better understand how social and task entity networks influence project success. Decision-making across lengthy design and delivery efforts involves multiple organizations and occurs in what are essentially temporary project-form organizations, where no single corporate structure or strategy dominates throughout all stages of the development process. An understanding of decision processes, much as network theory has already yielded a better understanding of other corporate practices, will result in their effective ICT-based support, facilitated by increased understanding of their dynamics, hidden networks, hierarchical structures, key actors, vulnerabilities and changes.

This research takes the important step of explicitly considering the interconnection, dynamics and potentially the co-evolution of social and task entity networks simultaneously. Despite advances made in the study of real-world networks in other domains, there are few results on the dynamics of networks in the context of actors collaborating on inter-related tasks and their bi-directional influences, which are exemplified in complex construction projects. With the longitudinal data obtained from previous case studies of complex construction projects, this research is well placed to provide important insights on the dynamical evolution of the microscopic (individual actor and tasks), and macroscopic (collective behaviors of actors and tasks), structures in these networks. The approach presented here therefore addresses a gap in research which has important strategic implications for the development of knowledge in academia and effectiveness of design and management practices in construction.

The multi-networks approach is a conceptual innovation that adds a level of sophistication to the modeling of actor and task structures and behaviors. It is well known that personal relationships greatly affect group decisions and outcomes, but these relationships are difficult to observe and quantify in large groups such as those which occur in complex engineering design projects whose development phase may span several years. Further, due to the complexity of the product, intricate groups of inter-related decision problems and sub-problems are generated. It is common practice in network studies to look at one type of connection at a time and then to make simple comparisons between the separate networks. The modeling approach will allow a direct comparison between different social and task networks that arise from complex architectural and engineering design problems.

It is also anticipated that visualization will shed light on the effects of “in principle” decision-making – a particular decision process phenomenon, common within complex design projects, wherein decisions are taken ahead of time prior to approval by all relevant decision-makers. Where this occurs, resulting information interdependencies increase levels of uncertainty and risk in subsequent and inter-related decision processes. It is predicted that these deviations and events may also indicate that individual stakeholders and their organizations are not the most significant communities influencing decisions across the project platform, but rather the co-evolution of different decision processes can set a “train” of actions, states and outcomes in motion.

The paper has introduced a methodological innovation in modeling decision processes by exploiting a network perspective and the fact that nodes are typically embedded in multiple types of networks. The insight presented is that not only are the problems, sub-problems and solutions inter-related but that the structure of social networks and the behavior of the actors embedded within them are often interdependent. By investigating these different networks simultaneously, this approach is able to analyze the inter-relations of organizational and political "communities" to obtain an understanding of decision processes dynamics via identification of microscopic and macroscopic structures. Connections between actors and between tasks in each network can thus be represented by many different quantities that each yield estimates for the strength of the tie between them.

5.1 Visualization techniques

Future stages of research target more advanced network analyses and visualization to provide a deeper understanding of decision networks. Further analysis involves incorporating measures associated with two-mode connections, such as Horton-Strahler numbers (Horter 1945, Strahler 1952) and modularity (Newman 2006). The modularity of each network map can be measured so as to identify its compartmentalization. Calculating modularity within the networks is needed to investigate e.g., hierarchies in actor relations via the allocation of weights to network ties. Modularity measures the difference between the total fraction of ties that fall within - rather than between - groups and the fraction one would expect if ties were placed at random. The projected one-mode networks to be constructed will be weighted and calculations will employ the weighted generalization of modularity described in Newman (2006), in which e.g., instead of counting numbers of ties falling between particular groups, the sums of the weights of those ties are counted, so that heavily weighted ties contribute more than lightly weighted ones. A longitudinal analysis of the modularity of actor and task entity networks constructed across projects stages can then be conducted. By comparing design and delivery stages analysis may reveal patterns within networks that deviate (in some cases drastically) from the same prior actor groups and/or task sets. Such techniques will enable identification of close relationships, nonlinearities and latent networks.

More advance network visualization techniques will also be targeted, including visualization of dynamic network structures and behaviors. This is considered appropriate because the target system is complex, there are important nonlinearities between variables, and this research is interested is in understanding the dynamics of the system. Visualization is also of particular relevance as a tool to discern patterns of behavior. The main concepts targeted in network visualizations relate to the effects of one and two-mode expansion and contraction within the network. Advanced network visualizations will aim to derive insights from dynamic network models and explore network dynamics by testing behavior. Since the properties of actors and tasks change over time, network nodes adapt and change propagates from one node to the next. The objective of dynamic network analysis is to study elements of both the social and task-entity networks' evolution, altering variables under which change is likely to occur. A visualization framework will be developed by specific calculations of characteristics described on network nodes and ties including clustering coefficient, average path length, shortest longest path, preferential attachment, etc. Exploring these aspects is important because they will provide greater understanding of critical variables such as time, and time-varying changes, group and network size, connectedness, density and degree, as well as provide information regarding actor and task 'embeddedness'.

6. CONCLUDING REMARKS

Engineering design projects face a variety of challenges when managing decision processes, which often stem from the geographic and temporal dispersion of project stakeholders. For participants of many and varied decision situations, making use of the visual analyses and enabling an understanding of decisions and their outcomes in relation to the project at large continues to pose a daunting challenge. An increasing trend towards distributed virtual teams linked through computer-mediated communication tools means that project stakeholders face an even greater challenge in managing decision processes effectively. Conceiving of decision processes as a complex system, and modeling this system using network-theoretic principles, so as to construct network maps 'on-the-fly', has powerful implications for supporting decision situations and managing large projects. Network modeling and visualization aims to uncover a tremendous amount of information surrounding decision situations that has remained untapped by conventional qualitative, game-theoretic, and statistical approaches. Through computational modeling and visualization of actors and tasks, this research aims to enable analyses of the inter-relations of decision-making communities to obtain a better understanding of the dynamics of decision processes.

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