SOCIAL NETWORK ANALYSIS OF INFORMATION FLOW IN AN IPD-PROJECT DESIGN ORGANIZATION

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ABSTRACT

Lean Construction recommends concurrent development of product and process by bringing Last Planners into the design phase. While this approach offers opportunities to reduce downstream waste and improve value generation, it increases coordination complexity during design due to the increased number of participants in the design team. In large projects, this increased number of participants can demand a multi-team structure with roles and mechanisms to coordinate the work between teams. In a case study we document the coordination mechanisms of a design organization on a large-scale construction project, being delivered under an Integrated Project Delivery (IPD) type contract, the Integrated Form of Agreement (IFOA). We conduct a Social Network Analysis (SNA) of information flow between people on the project, who work in a big-room environment. Analysis of this IPD-based social network with indices of degree centrality, betweenness centrality, and clustering, yields the following results: (1) the Chief Engineer and leaders of cross-functional teams play key roles in the coordination between teams, (2) people take on coordination jobs, even if it is not part of their formal role, and (3) IPD projects foster cross-functional collaboration. We conclude the paper with managerial recommendations for the efficient and effective coordination of IPD-based design project organizations and ideas for future research.

KEYWORDS

Integrated Project Delivery (IPD), Integrated Form of Agreement (IFOA), Design Management, Information Flow, Social Network Analysis, Organizational Structuring.

INTRODUCTION

A key principle in lean construction is to concurrently develop product and process during the design phase. This is enabled by bringing Last Planners from construction into the design phase, while aiming at achieving a common understanding about the project early on between all involved parties. At the same time, this approach increases the number of people involved during design, and thus increases the need for coordination. During the design phase, coordination means management of the

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information flow. To manage information flows, specifically on IPD projects, the team can apply specific mechanisms and roles, for example, cross-functional teams, cluster leaders, Chief Engineer position, collocation, Big Room, and Core Group.

Braha and Bar-Yam (2004) have shown that the connectedness of tasks in product development projects follows a power law distribution, i.e., few tasks are highly connected with other tasks, while many tasks are sparsely connected. This network characteristic implies that connectedness between people in the network is not evenly distributed. Instead, few very well-connected people control the information flow within the organization. These people are critical for the success of the project, because their position within the network gives power and influence. Social Network Analysis (SNA) has been successfully applied to identify these critical people based on indices, such as centrality, betweenness, and clustering.

Using SNA in a case study, we apply these indices to analyze an IPD-project's design organization. The goal of this research is to evaluate the use of aforementioned IPD-specific mechanisms and roles. Specifically, we test hypotheses regarding cross-functional teams, and the roles of cluster leaders and the chief engineer.

The paper is structured as follows: First we review the literature regarding SNA, characteristics of information flow in design organizations, and specifics of IPD projects. Second, we analyze 3 IPD-specific coordination mechanisms and roles and present SNA indices for their assessment with hypotheses. Third, we present case study and research methodology. Fourth, we present our findings based on the data gained in the case study. Fifth, we present managerial recommendations for coordination of information flow on IPD-projects. Sixth and last, we close the paper with conclusions and recommendations for future work.

LITERATURE REVIEW

SOCIAL NETWORK ANALYSIS OF DESIGN PROJECT ORGANIZATIONS

Moreno (1934) introduced Social Network Analysis (SNA) by using sociograms, which are formal representations of social relationships between people visualized through graphs. The sum of relationships between two actors constitutes the connection, or tie, between them, and the sum of ties between all actors constitutes the social network (Wasserman and Faust 1994). The goal of SNA is to build the social network empirically based on observed interaction. Based on these interactions the informal structure of the network unfolds. This approach differs from the defining the formal network structure prior to interactions, for example by creating the organizational structure of a company or project.

Ties between actors can be defined as existing vs. non-existing, or each tie can receive a value to reflect a weight. SNA devotes special attention to the role of weak ties. Granovetter (1973) sees infrequent and distant relationships as sources for diverse information through remote people, who are more probable to have new knowledge.

Need for Communication in Design

Designers often deal with 'wicked problems:' these are indeterminate problems, i.e., problems that have 'no definite formulation' (Rittel and Webber 1973). While solving wicked problems, designers face complexity. Wicked problems are often split into chunks that are manageable by an individual or small group of people, but the chunks of the problem are often interdependent. Thus, designers must communicate in order to jointly solve the overall design problem. Galbraith (1974) explains the need for frequent communication between actors when solving complex problems. We assume that integrated teams are better than non-integrated teams at solving wicked problems.

Efficiency and Effectiveness of Communication in Design

Chinowsky et al. (2008) highlight the importance of communication, and trust as an enabler for communication, to achieve high performance teams. Eckert et al. (2001) explain the need for a targeted information flow among members of a design team in order to avoid information overload. Nonaka (1990) explains the positive effects of excess information on design team creativity. Kratzer et al. (2008) show that excess information flow increases creativity only until designers suffer from information overload. In this case, designers will cut some information flows, which increases the risk of missing important information and which in turn might lead to wasteful rework (Mihm et al. 2003).

To summarize, a conflict exists between efficiency and effectiveness in organization structuring: Increased information flow may lead to increased effectiveness by fostering higher creativity, and thus possibly to better delivery of customer value. At the same time, increased information flow reduces efficiency. When designers suffer from information overload, increased information flow reduces both efficiency and effectiveness.

CHARACTERISTICS OF IPD PROJECT ORGANIZATIONS

Projects are temporary social systems, completed usually not by an individual, but by a group of people who must interact. This interaction is driven by the characteristics of the project delivery system, namely the ‘project organization,’ the ‘operating system,’ and the ‘commercial terms’ (Thomsen et al. 2010). Thus, project organizations cannot be analyzed independently from their context, namely operating system, and commercial terms (Howell et al. 2011).

Commercial Terms and specifically the relational contract terms used to define IPD projects promote collaboration between project members by including mechanisms such as pain-and-gain sharing, collective risk management, and contingency sharing. These mechanisms affect the relations between project members and promote strong collaboration. (Howell et al. 2011; Thomsen et al. 2010)

The operating system of IPD projects is based on the principle of reliable workflow (Howell et al. 2011). Key practices for increasing the reliability of information flow in design use, e.g., learning through PDCA thinking and root-cause analysis, look ahead planning with the Last Planner System™, Value Stream Mapping, and Target Value Design. These practices build on small batches of information in design and a high frequency of information transfer.

Project organizations that follow an IPD agreement integrate owners, designers, and contractors. Contractors join the design team early and all partners work from a collocated office. Cross-functional teams consisting of individuals from the relevant companies find innovative and efficient solutions through their diverse set-up. An executive committee consisting of members from the involved companies manages the teams, makes decisions unanimously through consensus, and creates an open, collaborative culture. This model creates a 'virtual company' (Thomsen et al. 2010) with members employed by their home companies but trusting each other strongly. The resulting collaboration fosters the behaviour that the best qualified person does a job, regardless of their home company.

NETWORK PROPERTIES AND HYPOTHESES

Wasserman and Faust (1994) list a number network properties with corresponding indices to assess a social network. In this research we focus on centrality and component aspects of the network. In the following paragraphs we explain how these aspects relate to coordination mechanisms and roles in design organizations.

CENTRALITY ASPECTS OF A NETWORK

An individual is called 'central' when they are connected to a large number of other people in the network, either directly or indirectly. Opsahl et al. (2010) describe centrality using four different indices: (1) degree centrality, (2) closeness centrality, (3) betweenness centrality, and (4) eigenvektor centrality. In this paper we apply indices (1) and (3). Figures 1 and 2 illustrate individuals with respective centralities; a circle represent an individual and a connection represents communication.

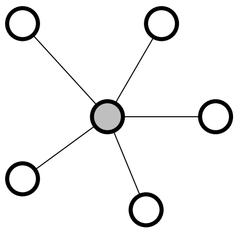

Figure 1: Person with high degree centrality

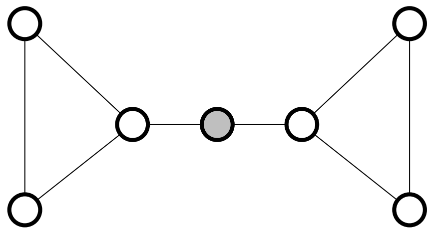

Figure 2: Person with high betweenness centrality

Degree Centrality

An individual with a high degree centrality is very communicative and directly relates to a large number of other people in the network. Their centrality presumably corresponds to the power and influence they have in the network. Leaders of cross-functional teams are highly connected to the members of their team, but also coordinate with leaders of other teams. Thus, we propose hypothesis 1: *leaders of cross-functional teams have a high degree centrality.*

Betweenness Centrality

A person with high betweenness centrality is in a brokerage position and can exercise strong power and influence in the organization. In design organizations s/he is a broker for information and acts as a gatekeeper or mediator between otherwise disconnected parts of the network. Burt (2004) claims that a person in this position on average has more creative ideas than other people have, and their ideas are more likely to be accepted by others in the network.

The Chief Engineer coordinates work between cluster groups and, while not having formal authority, s/he is highly respected by all members of the project team, i.e., s/he has a very powerful position within the organization (Morgan and Liker

2006 p. 132). Thus, we propose hypothesis 2: *the Chief Engineer has high betweenness centrality.*

COMPONENT ASPECTS OF A NETWORK

Clustering

Networks can be segmented into clusters. People inside the cluster are highly connected to each other but sparsely connected to people outside the cluster. In a design organization such clusters represent teams, in which people frequently exchange information with each other while they do less so with people outside their team. Thus, clustering of design organization reveals the structure of collaboration, i.e., how the people structure themselves within the informal organization.

IPD projects apply the coordination mechanism of cross-functional teams. This structure breaks the traditional three-silo-structure between owner, designer, and contractor, thus enabling global optimization of the design through integration of requirements from all three perspectives (Thomsen et al. 2010). Thus, we propose hypothesis 3: *Clusters of the informal IPD organization consist of owners, designers, and contractors.*

CASE STUDY DESCRIPTION AND RESEARCH METHODOLOGY

Data was collected at the Cathedral Hill Hospital (CHH) Project in San Francisco, California, USA. This project is well documented through prior research regarding:

- Operating System (Hamzeh et al. 2009; Lostuvali et al. 2012)
- Commercial Terms (Heidemann and Gehbauer 2010; Lichtig 2005)
- Project Organization (Hamzeh et al. 2009; Lostuvali et al. 2012)

The CHH project applies a relational contract that falls into the category of IPD contracts, called the Integrated Form of Agreement (IFOA). The project members use apply numerous lean principles and tools, among others: Target Value Design, Last Planner System^{TM}, and A3 Reports. Project members are collocated in an office and operate in cross-functional teams, called 'Cluster Groups,' under the supervision of a Chief Engineer and an Executive Committee called 'Core Group.'

We conducted a survey on communication between people working in the collocated office. Through an online survey each person could indicate the level of information received from and sent to others in the office. Possible levels for information flow were 'never,' 'less than once per month,' 'monthly,' 'weekly,' 'daily,' and 'several times per day.' We collected data regarding the information flow between 99 people in the design organization.

Based on the information gathered through the survey, we built a social network model. People are represented as nodes. Information flow between them is shown through weighted edges between the nodes. Table 1 shows the translation from levels of information flow into weighting of edges. The Social Network Model combines the 'Give' and the 'Receive' perspective of information flow: in case both perspectives differ for a relationship between a pair of persons, we assume that the higher of the two levels of information flow is correct.

Table 1: Weighting of Information Flow for SNA

Level of Information Flow	Weighting of Edge	Rationale
Never	0	-
Less than once per month	1	Max. once every 2 months
Monthly	2	[scale factor]
Weekly	9	4,5 weeks / month
Daily	45	5 days / week
Several times per day	90	At least twice per day

We analyzed the resulting weighted directed social network with the software Gephi (Bastian et al. 2009). These weighted information flows represent integration of people into the design organization and they enable analysis of peoples' informal role within the organization.

RESULTS AND FINDINGS

Distribution of connectedness between people in the design organization shows a pattern similar to Braha and Bar-Yam's (2004): a large number of people exchange relatively little information with others in the organization (left side of Figure 3), whereas a small number of people act as information hubs transferring large amounts of information (right side of Figure 3). One may assume that information transfers between people on an IPD project are evenly distributed for 2 reasons: (1) the IPD contract fosters trust between all members of the organization, and (2) the workplace enables easy access to all people on the project. However, the analysis shows the existence of information leaders, who are highly influential in the project organization. The questions "Why is information flow unevenly distributed on this IPD-project?" and "Are other distributions of information transfers beneficial?" remain for future research.

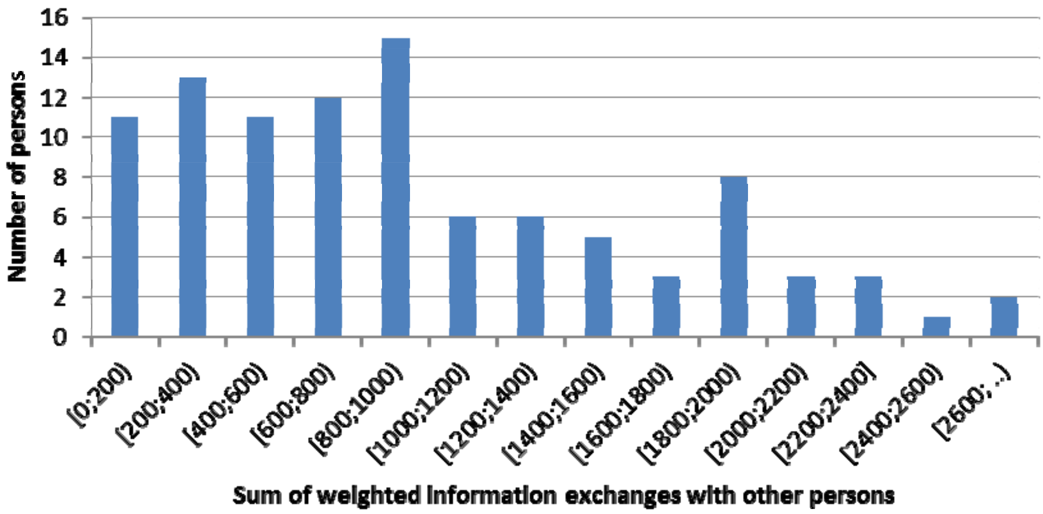

Figure 3: Weighted Degree Distribution of People in the Project Organization

Next, we analyze the mechanisms of information flow within the design organization using degree centrality and betweenness centrality. Table 2 shows the highest ranking people for weighted degree centrality and betweenness centrality.

Table 2: People with 10 highest respective centrality indices in descending order

Weighted Degree Centrality	Betweenness Centrality
PM Mech. Plum. Contractor	GC - Chief Engineer / Cluster Leader 4
Mech. Plum. Contractor	Owners Rep
Electr. Designer	GC - Chief Engineer Staff
GC - Chief Engineer / Cluster Leader 4	GC - Cluster Leader 1
GC BIM Expert - Cluster 3	GC - Cluster Leader 3
GC - Cluster Leader 3	GC - BIM Expert Cluster 4
GC - Cluster Leader 2	PM Mech. Plum. Contractor
Arch	GC
Electr. Contractor	GC - Cluster Leader 2
Arch	GC

Data supports hypothesis 1, 'leaders of cross-functional teams have a high degree centrality.' Three of the four leaders of the cluster groups (at the CHH Project called cluster leaders) lie within the 10 people with the highest weighted degree centrality. In this case study, the Chief Engineer has a double role, since he acts also as Cluster Leader 4.

Data also supports hypothesis 2, 'the Chief Engineer has high betweenness centrality.' The Chief Engineer lies within the 10 people with the highest betweenness centrality.

Table 2 also shows that information leaders outside the assigned coordination staff exist, for example 'PM Mech. Plum. Contractor,' 'Mech. Plum. Contractor,' and 'Electr. Designer'. This finding highlights that IPD projects encourage people to do what is necessary to make the project successful, regardless of their formal role.

Figure 4 shows a force-directed graph of the design organization (labels represent people, arrows represent information flow between them). In a force-directed graph, connections between a pair of nodes can be seen as springs that try to pull the pair closer together. The algorithms used to lay out this graph (namely Gephi's 'Force-Atlas 2' and 'Label Adjust') minimized the sum of spreads of all springs in the graph. These algorithms considered only information flow levels 'weekly,' 'daily,' and 'several times per day,' and accordingly Figure 4 shows only these levels.

Data partially supports hypothesis 3 'Clusters of the informal IPD organization consist of owners, designers, and contractors.' Figure 4 shows the 4 distinct clusters Gephi's clustering algorithm found. Designers and contractors highly interact inside these 4 clusters; however 3 of the 4 clusters do not include owner representatives. Further research is necessary regarding the need for owner involvement, specifically regarding the frequency of interaction with designers and builders but also regarding the frequency of coordination between owner representatives.

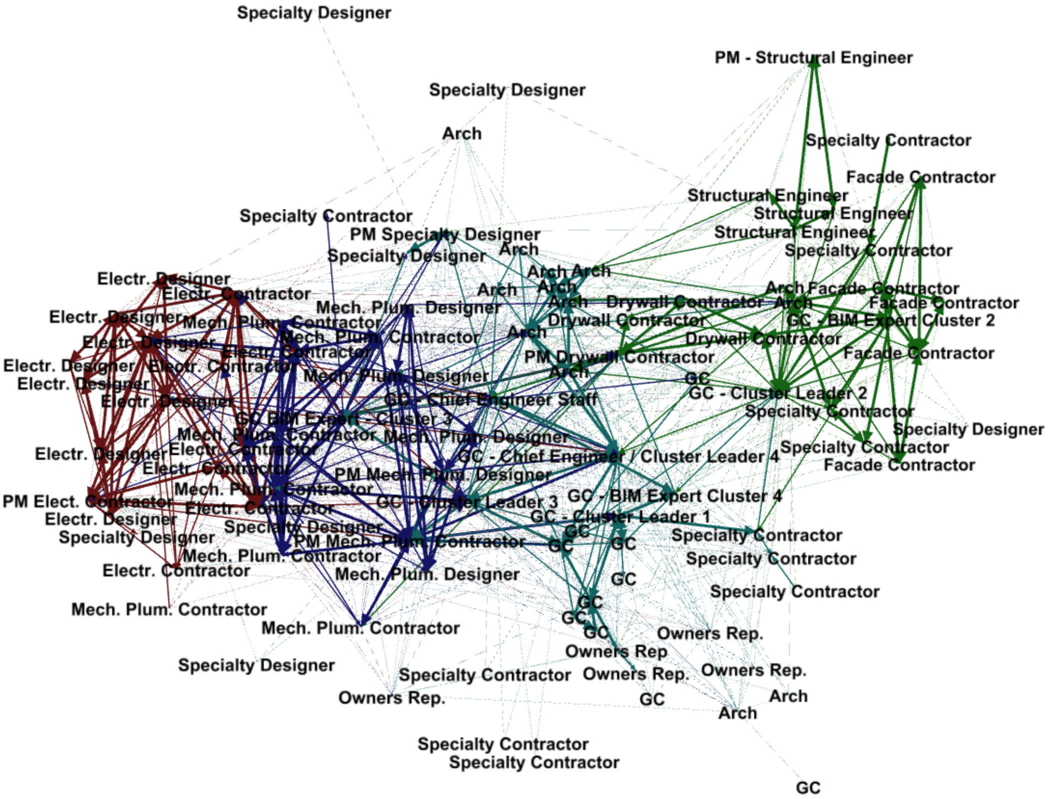

Figure 4: Force-directed graph of project team - colors indicate clusters as found through clustering algorithm.

MANAGERIAL RECOMMENDATIONS

As shown, this IPD project encourages people to get involved for the benefit of the project. People who see themselves as capable, coordinate work between others, regardless of their formal role. This bottom-up approach to managing information flow is beneficial for coordination efficiency. However, if people who coordinate information flow are not qualified for the job, coordination may not be effective.

For example, BIM Experts have an important role during detailed design. The high centrality of BIM Experts in Table 2 shows their importance in the design organization. Not only do they coordinate within others in their own clusters, they also coordinate between groups and act as information brokers. This job increases the requirements on the role: in order to recognize potential for innovation and savings, BIM experts need expertise in building systems and technology on top of their expertise in BIM.

We recommend that such information leaders in the informal organization be identified through SNA, and that those people be trained to qualify for the job of coordinating teams. Information leaders will most probably change during the different phases of a project, so we recommend that the search for information leaders be repeated.

CONCLUSION

At the risk of over-generalizing from the set of data collected on CHH, we draw the following conclusions; additional data collection efforts will be most welcome.

IPD practices promote an increase in the number of people involved in design and thus IPD increases the need for coordination of the larger design team. The data we collected showed that the distribution of information flow between people involved during design is uneven: Many people exchange information sparsely, while a few individuals act as information hubs between separate parts of the network.

The bottom-up approach used on IPD projects encourages people to become information hubs, even when this kind of coordination is not part of their formal job description. This effect confirms the relation between commercial terms, operating system, and project organization. Commercial terms foster collaboration and the open collaborative culture of IPD projects fosters trust. Collaboration and trust make bottom-up management possible, which encourages people to do what is best for the project. This finding highlights the importance of combining the right people, operating system, and project organization to make an IPD project successful.

IPD projects run the risks of missing opportunities for innovation and cost savings, when people gain influence and power in the informal organization, without having the necessary qualifications. SNA is a powerful tool to identify these people, so that they main gain qualifications necessary to fill this informal role.

SNA achieves transparency about the informal organization, which is the first step to managing it. As shown, a trade-off between efficiency and effectiveness exists when structuring the information flow. Weak ties between people are an efficient mechanism to build an integrated organization (Granovetter 1973). The trustful environment of IPD projects offers good conditions for the development of weak ties. Thus, IPD projects seem ripe for research on organizational structuring in collaborative environments.

The presented analysis has strong limitations. We analyzed only one phase of one project, so the significance of results is limited. Application of SNA on more projects and in different phases will help to build a frame of reference for comparison of organizational structures between different project phases and between projects.

ACKNOWLEDGMENTS

We thank Paul Reiser and all members of CHH for their support in researching and documenting this case study. Research for this paper was supported in-part, financially by the Fulbright Program, as well as in-kind by members of- and financially by gifts made to the Project Production Systems Laboratory (http://p2sl.berkeley.edu/) at UC Berkeley. All support is gratefully acknowledged. Any opinions, findings, conclusions, or recommendations expressed in this paper are those of the authors and do not necessarily reflect the views of contributors to the Project Production Systems Laboratory or the Fulbright Program.

REFERENCES

Bastian, M., Heymann, S., and Jacomy, M. (2009). “Gephi: An open source software for exploring and manipulating networks.” *International AAAI conference on weblogs and social media* (Vol. 2). Menlo Park, CA: AAAI Press.

Braha, D., and Bar-Yam, Y. (2004). "Topology of large-scale engineering problem-solving networks." *Physical Review E*, 69(1), 016113.

Burt, R. (2004). "Structural Holes and Good Ideas." *Am. J. of Soc.*, 110(2), 349–399.

Chinowsky, P., Diekmann, J., and Galotti, V. (2008). "Social network model of construction." ASCE, *J. of Constr. Engrg. and Mgmt.*, 134(10), 804–812.

Eckert, C., Clarkson, P., and Stacey, M. (2001). "Information flow in engineering companies: problems and their causes." *International Conference on Engineering Design*, Glasgow, UK, 43–50.

Galbraith, J.R. (1974). "Organization Design: An Information Processing View." *Interfaces*, 4(3), 28–36.

Granovetter, M. (1973). "The strength of weak ties." *Am. J. of Soc.*, 78(6), 1360–1380.

Hamzeh, F.R., Ballard, G., and Tommelein, I.D. (2009). "Is the Last Planner® System applicable to design?-A case study." *Proc. 17th Annual Conf. of the Int'l. Group for Lean Construction (IGLC-17)*, Taipei, Taiwan, 165-176.

Heidemann, A., and Gehbauer, F. (2010). "Cooperative project delivery in an environment of strict design-bid-build tender regulations." *Proc. 18th Annual Conf. of the Int'l. Group for Lean Constr. (IGLC-18)*, Haifa, Israel, 581–590.

Howell, G., Ballard, G., and Tommelein, I. (2011). "Construction Engineering—Reinvigorating the Discipline." ASCE, *J. of Constr. Eng. and Mgmt.*, 137(10), 740–744.

Kratzer, J., Gemuenden, H.G., and Lettl, C. (2008). "Balancing creativity and time efficiency in multi-team R&D projects: the alignment of formal and informal networks." *R&D Management*, 38(5), 538–549.

Lichtig, W.A. (2005). "Sutter health: Developing a contracting model to support lean project delivery." *Lean Construction Journal*, 2(1), 105–112.

Lostuvali, B., Alves, T., and Modrich, R.-U. (2012). "Lean Product Development at Cathedral Hill Hospital Project." *Proc. 20th Ann. Conf. Int'l. Group for Lean Constr. (IGLC-20)*, San Diego, CA, USA, 1041-1050.

Mihm, J., Loch, C., and Huchzermeier, A. (2003). "Problem–Solving Oscillations in Complex Engineering Projects." *Management Science*, 49(6), 733–750.

Moreno, J.L. (1934). "Who shall survive?: A new approach to the problem of human interrelations." *Psychological Abstracts*, vol. 8, p. 5153.

Morgan, J.M., and Liker, J.K. (2006). *The Toyota product development system*. Productivity Press: New York, 363 pp.

Nonaka, I. (1990). "Redundant, overlapping organization: a Japanese approach to managing the innovation process." *Calif. Management Review*, 32(3), 27–38.

Opsahl, T., Agneessens, F., and Skvoretz, J. (2010). "Node centrality in weighted networks: Generalizing degree and shortest paths." *Soc. Networks*, 32(3), 245–251.

Rittel, H. and Webber, M. (1973). "Dilemmas in a general theory of planning." Policy Sciences, 4(2), 155-169.

Thomsen, C., Darrington, J., Dunne, D., and Lichtig, W. (2010). "Managing integrated project delivery." *White paper of the Construction Management Association of America*. McLean, VA, USA, 52 pp.

Wasserman, S., and Faust, K. (1994). *Social network analysis: Methods and applications*. Cambridge University Press: Cambridge, UK , 825 pp.