Modelling Information Flow for Collaboration

Christopher Durugbo, Ashutosh Tiwari, Jeffrey R. Alcock

Modelling Information Flow for Collaboration

Christopher Durugbo, Ashutosh Tiwari, Jeffrey R. Alcock

School of Applied Sciences, Cranfield University, MK43 0AL, United Kingdom
{c.durugbo, a.tiwari, j.r.alcock}@cranfield.ac.uk

Abstract. This paper describes a case study involving the use of a proposed model of information flow, based on complex network theory, to study delivery information flow within a microsystem technology (MST) company. The structure of the company is captured through decision making, teamwork, and coordination networks. These networks were then aggregated and analysed from a sociological and an organisational perspective through measures that reflect connections, interconnectedness, and activity of individuals.

Keywords: information flow, complex networks, conceptual modelling, collaboration, delivery phase, microsystems technology.

1 Introduction

Recently, the study of social networks has offered a useful avenue for the analysis of information flow with a view to improving organisational factors and requirements such as capacity, productivity, efficiency, flexibility, and adaptability [1, 2]. Consequently, models of information flow of social networks have been proposed by analysts to explore minor and major roles of individuals in an organisation [3].

This research is motivated by the need to enhance collaboration during delivery phases for production through a model of information flow. Collaboration is an important organisational requirement that means working together in group(s) to achieve a common task or goal through teamwork, decision-making and coordination [4]. Enhancing collaboration during delivery offers opportunities for improving the efficiency, quality and sharing of information, leading to sustainable operations [4, 5].

The aim of this paper is to model complex networks for collaboration during delivery. In order to accomplish this, a case study of complex networks for the delivery of MST, will be undertaken to analyse information flow. §2 and §3 present the contribution of the paper to sustainability and the research background respectively, whereas §4 introduces a model of information flow used in §5 for a case study within an MST firm.

2 Contribution to sustainability

This paper seeks to contribute to sustainable operations for organisations through a case study that makes use of a conceptual model of information flow to study the relationship between collaboration and delivery information flow. Sustainability is used here, from an economic perspective, to mean maintaining profitable operations.

3 Research background

In [4], the state-of-the-art in the use of social network analysis (SNA) for modelling collaboration was analysed and the authors concluded that current models lacked visualisations for characterising formal relationships that symbolise collaboration roles and responsibilities. This is because SNA only considers individuals or groups of individuals as entities within social networks in terms of relationships, social roles and social structure [5, 6]. However, during collaborations, people/ teams are interconnected and tasks/processes are linked [4].

Interconnections for social networks have been the subject of research that have been used to model scale-free, hierarchical and random [7] properties and networks of organisations and communities. Social networks are also characterised by quantities that distinguish between structural interconnectedness and prominence of vertices. These quantities include [4]:

1. *Distance* - sum of links along the shortest path between vertices,
2. *Reachability* - establishes if vertices are linked directly or indirectly,
3. *Density* - compares number of actual links to possible links between vertices,
4. *Degree centrality* - number of vertices directly connected to a vertex,
5. *Closeness centrality* - inverse of the distance between a vertex and vertices in a network, and
6. *Betweenness centrality* - amount of times a vertex connects vertices to each other.

The need to include and analyse networks made up of tasks is evident in current studies by authors such as Batallas and Yassine [8], in which the analysis of social networks is complemented with design structure matrices for analysing tasks and Collins *et al.* [9] that examined task networks for product development. These studies have mainly concentrated on isolating and analysing social and task networks separately or making use of one technique to analyse the other. An inspection of these techniques suggests that potentially some links and flows may be omitted. For instance, a human operator working as part of a team may access or transfer some information necessary for collaboration (such as number of products to be manufactured) with a manufacturing process. This interaction may not require the participation of a team member or may be accessed by another team member through the process without a direct link to the original source of the information i.e. the first human participant.

4 A model of information flow for organisational collaboration

The focus of this paper is to make use of a model of information flow, shown in Fig. 1, to analyse collaborative delivery in an MST company.

As described in [4], mathematically, a collaborating organisation, can be modelled as a connected, partitioned, non-overlapping hypergraph $G = (V, E)$ containing a graph for characterising the collaborative social network of individuals/groups $G_s = (V_s, E_s)$ and a directed graph for characterising the collaborative activity network of processes/tasks $G_p = (V_p, E_p)$. V_s represents *social vertices* of collaborating individuals, teams or organisations, and V_p represents *activity vertices* for processes that are required to achieve a common goal that could not be achieved by the independently collaborating individuals. E_s and E_p correspond to edges between teams (or individuals) and processes. In the proposed model, processes become part of a collaboration based on the set of interface edges T showing connections between human participants and processes i.e. T associates V_s with V_p. Consequently G is defined by $V = V_s \cup V_p$ and $V_s \cap V_p = \emptyset$. Similarly, $E = E_s \cup E_p \cup T$ and $E_s \cap E_p \cap T = \emptyset$.

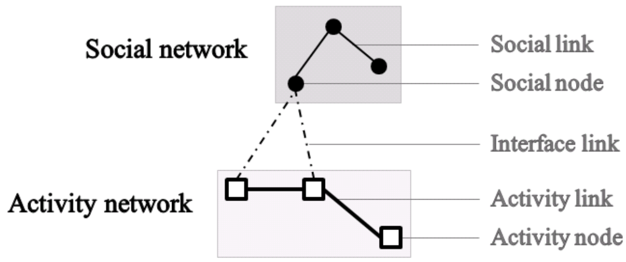

Fig. 1: A model of information flow for organisational collaboration [4]

Using the proposed information structure, the information behaviour for organisations can be characterised using key SNA measures of clustering coefficient, closeness and degree centrality. These quantities were selected because they reflect interconnectedness within groups, individual connections for relationships and activity of individuals respectively [5, 6].

The **degree centrality** (Dc_i) is a ratio of number of directly connected vertices to the number of possible vertices in a network and can be computed as:

$$Dc_i = [\deg]_i / N - 1 \quad (1)$$

Where, N is the number of vertices in the network and $[\deg]_i$ is the number of vertices directly connected to i.

The **clustering coefficient** assesses the density between vertices and represents the tendency for vertices to cluster together. If a vertex i, connects to b_i neighbours, and the number of possible edges between the vertices is given as $b_i(b_i - 1)/2$, then the clustering coefficient (Cc_i) of i can be computed as:

$$Cc_i = 2n_i / b_i(b_i - 1) \quad (2)$$

Where n_i is the number of edges between b_i neighbours.

The **closeness** between vertices defines the order with which one vertex collaborates with another vertex. It is computed as the inverse of the geodesic distance (d_{ij}) between a pair of vertices i and j. d_{ij} is the number of edges along the shortest path between i and j. Closeness (c_{ij}) can be calculated as:

$$c_{ij} = 1 \Big/ \sum_{i \neq j \in N} d_{ij} \quad (3)$$

For instance, if a vertex *i* connects directly to another vertex *j*, then the closeness of *i* to *j* is given as 1, if collaboration is established as a result of connecting to a third vertex *k* acting as a hub i.e. dictator collaboration [4], then *i* has a closeness of 0.5 to *j*.

5 Case Study

Company B is an MST company based in the United Kingdom with a targeted global market. It operates with 14 staff for the delivery of microfluidic and microoptical based products and services as business-to-business solutions for customers that are mainly original equipment manufacturers or an academic institution. Products delivered by Company B include microlens arrays for flat panel displays, and lab-on-a-chip microfluidic devices for industrial automation, cell analysis and drug delivery.

In this section, the research method and findings of the case study to analyse delivery information flow in Company B is described. The implications of the findings for sustainable operations are also identified.

5.1 Research Methodology

An analytical research methodology [10] was adopted for the case study in two steps.

Firstly, the information structure of Company B was analysed through an initial semi-structured telephone interview with the customer support manager (CSM) at Company B that lasted 25 minutes. This interviewee was provided by the company director at Company B following initial telephone conversations to request permission to carry out the study. The director designated the CSM as personnel responsible for managing the flow of information during MST delivery and the main question posed to the CSM to initiate the semi-structured interviews was: 'What are the processes and information flow for the delivery phase in your company?,

Secondly, using the data provided by the CSM, face-to-face interviews were then conducted on-site with 7 other available company personnel involved in the delivery process to analyse information flow using the proposed model. In other to populate the model, interviewees were asked to validate the description provided by the CSM. Interviewees were also asked to identify processes and other personnel that they were connected to during delivery for decision making, teamwork, and coordination.

5.2 Research Findings

The interviews with personnel at Company B revealed that decision-making within G_s is a directed graph that involves the entire social vertices within V_s. Incident edges are mainly outwards from the subset of V_s containing social vertices of the management group (Ba to Bd) as shown in Fig 2a.

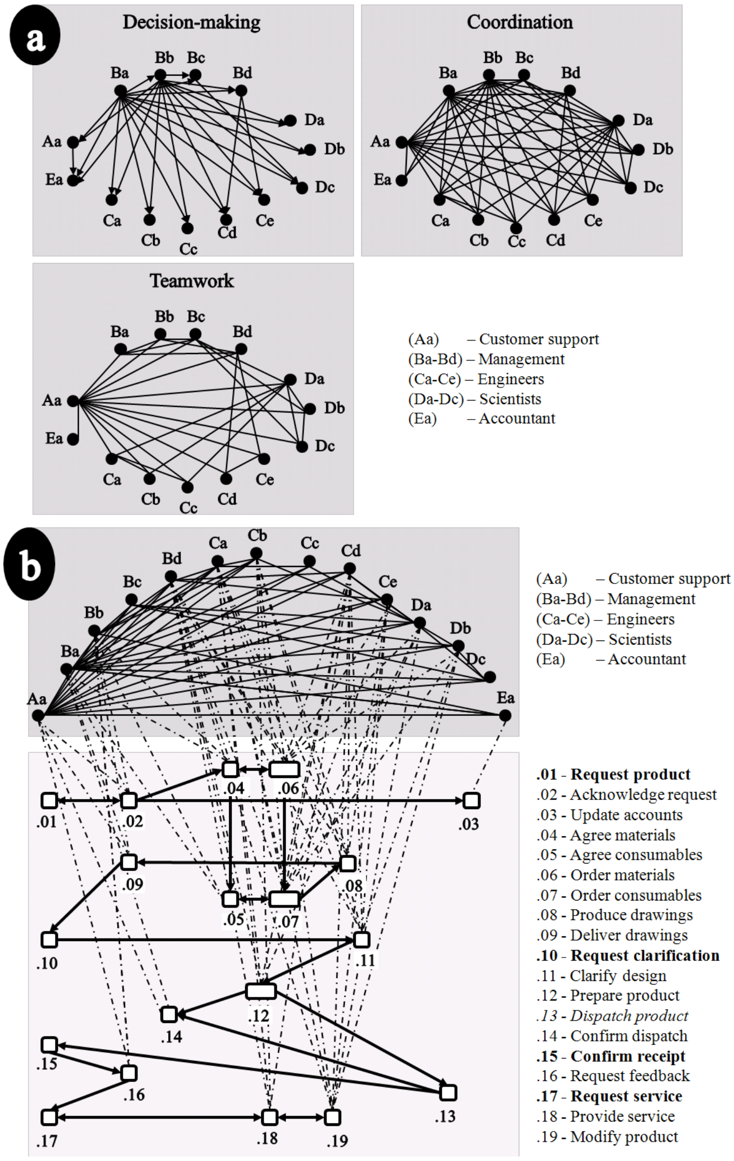

Fig. 2 (a) Social networks for decision-making, coordination and teamwork in Company B, and (b) Information structure for Company B

Teamwork for the social network for Company B is an undirected graph with clusters formed among groups of social vertices for V_s whereas coordination within Company B is also an undirected graph involving the entire network.

An aggregation of the social networks in Fig. 2a and the 19 (.01-.19) processes described by the CSM (that was validated by the participants of the face-to-face interviews) resulted in the information structure for Company B, as shown in Fig. 2b.

Activity vertices .01 (request product), .10 (request clarification), .15 (confirm receipt) and .17 (request service) are carried out by the customer whereas .13 (dispatch product) is the responsibility of the courier provider. For collaboration within Company A, the 14 available staff i.e. the social vertices Aa-Ea, are connected to the remaining 14 processes through 57 internal interface edges.

Management processes, associated with vertices Aa and Ba-Bd, form a subset of V_p consisting of activity vertices .02 (acknowledge request), .09 (deliver drawings), .14 (confirm dispatch) and .16 (request feedback). Similarly, engineering and science processes, associated with social vertices Ca-Ce and Da-Dc, form a subset of V_p involving activity vertices .04 (agree materials), .05 (agree consumables), .06 (order materials), .07 (order consumables), .08 (produce drawings), .11 (clarify design), .12 (prepare product), .18 (provide service) and .19 (modify product). The accounting process associated with Ea is activity vertex .03 (update account).

While the maximum number of edges in a fully connected social network (G_s) of 14 social vertices can be computed as $G_s(G_s - 1)/2$ i.e. 91, the maximum number of interface edges to the 14 activity vertices within G_p (.02-.09, .11, .12, .14, .16, .18 and .19) on which collaboration is based, can be calculated as $G_s \times G_p$ i.e. 196.

As shown in Fig 2b, vertex Aa connects to 13 social vertices and 4 activity vertices. Consequently the values of Dc_i for vertex Aa within the G_s and G can be computed from eqn. (1) as 13/(14 – 1) = 1.000 and (13+4)/(14+(14 – 1)) = 0.630. Since, the social vertices directly connected to Aa form 54 edges with each other and 57 interface edges with directly connected activity vertices, the value of Cc_i for Aa within the social G_s and G can be calculated from eqn. (2) as 54/91 = 0.593 and (54+57)/(91+196) = 0.387 respectively. Similarly, the values of c_{ij} within G_s and G can be determined from eqn. (3) as 1/(13×1) = 0.077 and 1/((13×1)+((4×1) +((19 – 4)×2))) = 0.021. Values of Dc_i, Cc_i and c_{ij} for the social vertices in Company B have been computed using a similar approach and are shown in Table 1.

Table 1. Social network measures for social vertices within the social network (G_s) and entire network (G) of Company B (degree centrality - Dc_i, clustering coefficient - Cc_i, closeness - c_{ij}).

Social vertices	Within G_s			Within G		
	Dc_i	Cc_i	c_{ij}	Dc_i	Cc_i	c_{ij}
Aa	1.000	0.593	0.077	0.630	0.387	0.021
Ba	1.000	0.593	0.077	0.667	0.387	0.022
Bb	1.000	0.593	0.077	0.667	0.387	0.022
Bc	0.462	0.231	0.050	0.222	0.150	0.017
Bd	0.538	0.286	0.053	0.593	0.220	0.020
Ca	0.538	0.275	0.053	0.519	0.226	0.020
Cb	0.385	0.165	0.048	0.407	0.160	0.019
Cc	0.385	0.165	0.048	0.185	0.139	0.017
Cd	0.462	0.231	0.050	0.481	0.185	0.019
Ce	0.462	0.231	0.050	0.407	0.209	0.019
Da	0.923	0.582	0.071	0.593	0.380	0.020
Db	0.462	0.231	0.050	0.370	0.150	0.017
Dc	0.462	0.231	0.050	0.222	0.150	0.017
Ea	0.231	0.033	0.043	0.148	0.073	0.015
Overall average	**0.593**	**0.317**	**0.057**	**0.437**	**0.229**	**0.019**

With an overall average Dc_i value of 0.593 (59.3%) and 0.437 (43.7%) for G_s and G from Table 1, this study suggests a significant level of interconnectedness within

Company B. Similarly, the values of c_{ij} (0.057 and 0.019 for G_s and G) suggest high activity of personnel within Company B. This is because if all Company B's personnel were fully active, i.e. each vertex can connect directly to other vertices, then the average values of c_{ij} for Company B would be 0.080 and 0.037 for G_s and G respectively. In Company B's current state, this represents 74.1% and 51.3% of potential activity within G_s and G respectively. However, low values of Cc_i (0.317 and 0.229 for G_s and G) indicate possible weak individual connections for relationships across the organisation. Nonetheless, the average value of Cc_i is higher when analysed for social vertices within working groups (such as activity vertices Da-Dc), indicating stronger connections for teams as opposed to the entire organisation. This finding correlates with existing studies in which it is suggested that small and medium enterprises (SMEs) within high-tech firms, such as Company B, are effective at working together for innovation [11].

5.3 Implications for sustainable operations

Two important lessons for sustainable operations were learnt from the case study involving considerations for dichotomies based on small-scale R&D (research and development) vs. large-scale manufacturing, and hierarchical vs. flat structures.

Firstly, although Company B applies a small-volume-large-variety production business model, on-going efforts to expand operations for large scale production poses major challenges for coordination, decision-making and teamwork. Further analysis following discussions with the company director of Company B revealed that this challenge is a major cause for disagreements and conflicts that has currently severed ties and friendships within the company, impacting on collaboration levels.

Secondly, further discussions with personnel also revealed a split between management staff wanting fewer organisational layers to ease the flow of information and engineering personnel favouring hierarchies for structure in processes. However, non-management personnel (such as vertex Da) have been able establish links across the divide through negotiation and interpersonal contact. In contrast, some experienced management personnel (such as Bc and Bd) have not been able to effectively collaborate in Company B, a situation which according to the company director is due to the split between R&D and manufacturing, and poor interpersonal skills. These lessons reinforce the importance of trade-offs for MST firms [12] that offer avenues for maintaining collaboration as well as business driven and simplified information flow.

6 Conclusions

In this paper, a model of information flow for collaboration is proposed as a combination of *social networks* involving decision-making, coordination and teamwork of human entities and *activity networks* containing non-human entities such as production processes, technologies and systems. The model also applies measures of degree centrality, clustering coefficient and closeness from social network analysis (SNA) to assess the level of collaboration within organisations. Useful insights from a case study of delivery within a microsystem technology (MST) firm, based on the proposed model, suggested that high-tech small and medium enterprises can be effective at collaborating for delivery. For the case study, social vertices (i.e. participants in collaborations) were assessed using the SNA measures from: a sociological perspective for the social network and an organisational perspective for the entire (social and activity) network. Findings from the study also suggested that effective collaborative delivery requires trade-offs for strategising capabilities for operations and for managing organisational layers that enable expansion.

Acknowledgments. The authors would like to extend their sincere thanks to the Engineering and Physical Sciences Research Council (EPSRC), for its support via the Cranfield Innovative Manufacturing Research Centre (CIMRC), towards the work carried out in the preparation of this paper.

References

1. Boccaletti, S., Latora, V., Moreno, Y., Chavez, M., Hwang, D.-U.: Complex networks: Structure and dynamics. *Phys Rep*, 424 (4-5): 175--308 (2006)
2. Schultz-Jones, B.: Examining information behavior through social networks: An interdisciplinary review. *J Doc*, 65 (4): 592--631 (2009)
3. White, L.: Connecting organizations: Developing the idea of network learning in inter-organizational settings. *Syst Res Behav Sci*, 25 (6): 701--716 (2008)
4. Durugbo, C., Hutabarat, W., Tiwari, A., Alcock, J. R.: Modelling Collaboration using Complex Networks. *Submitted to Inform Sciences* (2011)
5. Durugbo, C., Tiwari, A., Alcock, J. R.: An Infodynamic Engine Approach to Improving the Efficiency of Information Flow in a Product-Service System. *CIRP IPS2 Conf.*, 107--112 (2009)
5. Hatala, J.-P., Lutta, J.G.: Managing information sharing within an organizational setting: A social network perspective. *Perform Imp Quart*, 21 (4): 5--33 (2009)
6. Valente, T.W., Coronges, K.A., Stevens, G.D., Cousineau, M.R.: Collaboration and competition in a children's health initiative coalition: A network analysis, *Eval Program Plann*, 31 (4): 392--402 (2008).
7. Barabasi, A.L., Oltvai, Z.N.: Network Biology: Understanding the Cell's Functional Organization. *Nat Rev Genet*, 5 (2): 101-113(2004).
8. Batallas, D.A., Yassine, A.A.: Information leaders in product development organizational networks: Social network analysis of the design structure matrix. *IEEE T Eng Manage*, 53 (4): 570--582 (2006)
9. Collins, S.T., Bradley, J.A., Yassine, A.A.: Analyzing Product Development Task Networks to Examine Organizational Change. *IEEE T Eng Manage*, 57 (3): 513--525 (2010)
10. Kumar, R.: Research methodology. Longman. London (1996)
11. Trumbach, C.C., Payne, D., Kongthon, A.: Technology mining for small firms: Knowledge prospecting for competitive advantage. *Technol Forecast Soc*, 73 (8): 937--949 (2006)
12. Durugbo, C., Tiwari, A., Alcock, J. R.: Survey of media forms and information flow models in microsystems companies. In: Camarinha-Matos, L. M., Pereira, P., Ribeiro, L., (eds.) *DOCEIS* 2010. IFIP, AICT 314, 62--69. Springer, Heidelberg (2010)