A Complexity Theory Approach to Knowledge Management – Towards a Better Understanding of Communication and Knowledge Flows in Software Development

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Abstract: This paper offers a view of communication networks in which professionals are connected via knowledge flows and communication processes. The discussion focuses on a case study of software business processes in two small-size Finnish software companies. The paper has two objectives. First, it assesses the knowledge flow model as a tool that can be used for developing knowledge-intensive services. Second, it offers a new way of seeing a software project from a communication and knowledge flow perspective.

Keywords: Knowledge flows, communication, software development, complexity thinking.

1. Introduction

This paper concentrates on knowledge flows and communication. Knowledge flows are essential when information is to be transferred to a person or an organization that needs it. Knowledge transfer occurs at various levels: between individuals, from individuals to explicit sources, from individuals to groups, between groups, across groups, and from the group to the whole organization (Alavi and Leidner 2001). Communication processes and information flows together build up knowledge flows, which are used to transfer knowledge from one place or format to another. The complex network of knowledge flows and communication should be controlled and managed. Together they form the basis for complexity-based knowledge management.

For this study we interviewed two managing directors of two small-size Finnish software companies about their opinions on agile software projects and how knowledge is transferred within and between different projects. In the early phase of our model construction we wished to analyze case companies that were easy to understand and in which our point of view could be clearly presented, but which still could give us a general picture of the complex operational environment in which knowledge-intensive organizations operate. On that basis, we selected two small software companies as cases. Since they serve as 'pilots' for a further research project, it should be noted that the number of their simultaneous projects is relatively limited.

From the process perspective, knowledge management concentrates on routing knowledge flows and on encouraging knowledge creating and sharing activities. Elements preventing information flows between communities of knowledge may be due to linguistic, expertise, motivational or hierarchical boundaries (Fong 2003, Koivuaho 2005). We identified several boundary roles to which employees conform during the software development process: project manager, chief architect, software engineer, graphical designer and roles that require, for example, technology-related specialties. The role that a person holds has a great effect on his or her role as a knowledge source. Senior roles have more outflow of knowledge, while junior roles typically concentrate on learning, i.e. inflows of knowledge.

Since knowledge-intensive work focuses on team effort and iterative working methods, it is of critical importance to develop the sharing, distribution, and dissemination of knowledge. We offer a dynamic knowledge flow model using the concept of a knowledge flow cube as a tool for understanding and improving multidimensional knowledge processes in software development. It is a three-dimensional conceptual model that can be used to analyze the input, internal, and output knowledge flows of an organization.

2. Framework for analysis

Software businesses offering tailored solutions are involved in selling expert knowledge and problem-solving capabilities. The project-based nature of development efforts and the dynamic composition of developer teams challenge traditional reductionist models of management that are based on the rigorous design and splitting of tasks. It can be argued that management, which follows the traditional waterfall model of software development, does not consider to a sufficient extent the dynamic nature of communication and activities. Iterative development methods offer a more functional approach, but also raise some challenges. How should communication and knowledge proc-

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esses be organized to support iterative working when continuous feedback processes create complexity?

Software projects are normally carried out in phases. One of the most well-known and until recent years also the most popular software methodology has been the so-called "waterfall" model. It is based on the assumption that a methodical approach to software development results in fewer defects and ultimately provides a shorter delivery time, better quality, and better value. In this approach, all projects can be managed better when they are segmented into a hierarchy of phases, stages, activities, tasks, and steps. There exist different variations of the model, but in the majority of cases the specification, design, and implementation phases can be identified.

Iterative software development is based on the idea that a software system should be developed incrementally. Developers can take advantage of what has been learned during the development of earlier versions of the system. Iteration means that modifications can be made to the earlier design and that also some additional features may be implemented. Iterations are analyzed continuously on the basis of user feedback, which requires active interaction between the development team and actual users. Feedback can be received on a substantially more frequent basis than in the waterfall model. Rational Unified Process (RUP) is an example of the iterative software design method. It is not so much a process guide as it is a framework for accommodating a wide variety of processes. RUP describes how to effectively deploy software using commercially proven techniques. Due to its process framework perspective, RUP can be used in a traditional waterfall style or in a more flexible manner (Fowler 2003).

3. Complexity approach

The main emphasis in software business is on solving customers' complex problems in a complex world. From a production perspective the problems may concern optimizing different processes. However, complexity sets some conditions for the design process. For example, the traditional view of subsystem optimization may face some difficulties when the number of interaction and feedback loops starts to increase dramatically. Subsystems have an effect on the functioning of the system as a whole and vice versa. The negative effect of a decision made in some part of the design process may spread in gradually aggravated form in the production network all the way to the subcontractors, and finally a seemingly trivial change may make it necessary to change the total production chain.

The approach to complexity-based knowledge management in this paper builds on Seth Lloyd's hypothesis that "Everything that is worth understanding about complex systems can be understood in terms of how it processes information". In considering the actions that people take as individuals, as part of a group, and collectively in an organization, it is worthwhile to examine how they interact, what kinds of patterns of action may emerge, and what kinds of knowledge flows are created. The patterns that arise are a result of the structure of the organization and the rules used in the interactions between individuals. The way to manage these interactions can benefit from complexity thinking. A good example is Ashby's law of requisite variety (1956), which basically suggests that the fundamental issue in developing an organization and making it successful is to correctly match the system's complexity to its environment. Another way of describing the phenomenon of requisite variety is presented in Figure 1.

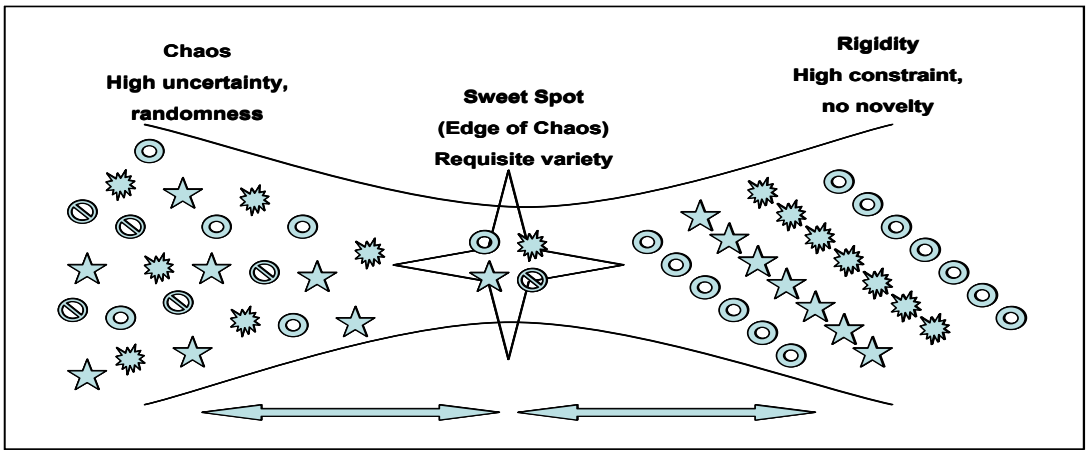

Figure 1: "Sweet Spot" between excessive disorder and excessive order (Clippinger 1999: 9)

Clippinger calls this optimum point of variety the sweet spot. In complexity thinking, this point is also generally known as the edge of chaos. This place between excessive disorder and excessive order is the place where an organization is maximally responsive to the variety in its environment, but sufficiently structured so that it can act and maintain itself (Clippinger, 1999: 8-9).

From the knowledge flow and communication point of view, the concept "edge of chaos" or "sweet spot" could be interpreted to mean that predetermined structures and reporting relationships are needed, but on the other hand, ad hoc knowledge flows should also be allowed and encouraged so that the right knowledge finds the right people. In other words, organizations should not build obstacles to knowledge flows and to communication; instead, they should create circumstances in which people can communicate and find the required information and knowledge. It is a question of dismantling excessive control and strict hierarchical organizations. However, the concept also emphasizes that too much freedom and a total lack of control do not lead to the optimum, at least not in all situations. A more robust solution lies somewhere between these two extremes – in the sweet spot.

4. Construction of knowledge flow framework

A knowledge flow model is a three-dimensional conceptual model that can be used to analyze the input, internal, and output knowledge flows of an organization. Input flows are the knowledge that a project receives from outside of its boundaries. Output flows are the knowledge that a project shares with the rest of the organization. Internal flows are the communication within the project. In the model, the knowledge flow –based framework created by Gupta and Govindarajan (1991) is connected to a communication flow model that distinguishes between *bureaucratic*, *communal*, *professional,* and *adhocratic* communication.

4.1 Knowledge flows –based framework

Gupta and Govindarajan (1991) have studied knowledge sharing within multinational organizations and they argue that knowledge transfer and knowledge flows between a subsidiary and the rest of the corporation vary substantially. The same certainly applies also if we scale down to the group level. Different groups are in this case the parallel of subsidiaries.

In their study, Gupta and Govindarajan define intracorporate knowledge flow as the transfer of either expertise or external market data of strategic value. The type of expertise Gupta and Govindarajan (1991: 773) refer to is transferred by purchasing skills, by product, process, and packaging designs, or by sharing marketing know-how. Gupta and Govindarajan have outlined administrative information in their study. This kind of framework could also be used for modeling knowledge-intensive organizations, which are mainly interested in the information that could be used for creating new business opportunities.

Using their framework, Gupta and Govindarajan (1991: 773-775) place subsidiaries in four categories according to their role in the network of knowledge flows:

- Global innovator. In this role a subsidiary serves as the fountainhead of knowledge for other units. This kind of organization has very few inflows of knowledge; it acts as an innovator for other organizations.
- Integrated player. This role implies responsibility for creating knowledge that can be utilized by other subsidiaries. The integrated player subsidiary is not self-sufficient in the production of its own knowledge flows.
- Implementer role. An implementer produces little knowledge of its own and relies heavily on knowledge inflows from either the parent or peer subsidiaries.
- Local innovator. The local innovator role implies that the subsidiary has almost complete local responsibility for the creation of relevant know-how in all key functional areas. However, this knowledge is seen as too idiosyncratic to be of much competitive use outside of the country in which the local innovator is located.

This fourfold framework is described in Figure 2. The framework provides a good presentation of the outflows and inflows of an organization, and the roles that Gupta and Govindarajan have determined describe the actual situation very well.

In today's highly connected and rapidly changing environment this framework is not sufficient. We argue that especially in the context of knowledge-intensive service organizations a third dimension is needed to be able to understand and explain the dynamics of a modern organization. Internal knowledge flows should also be considered, not only outflows and inflows. In the following chapter we present a model that has been used for conceptualizing the internal knowledge flows from the communication perspective. Further, these two models will be used for constructing a framework for studying knowledge-intensive service organizations.

Outflow of knowledge from the local subsidiary to the rest of the corporation			
	High	Global Innovator	Integrated Player
	Low	Local Innovator	Implementer
		Low	High

Inflow of knowledge from the rest of the corporation to the local subsidiary

Figure 2: A knowledge flows –based framework (Gupta and Govindarajan 1994: 774)

4.2 Communication flow model

Organizations have different practices for facilitating knowledge creation, sharing, and distribution. In the communication flow model developed by Koivuaho (2005), organizations are divided into four classes, based on the fundamental types of interaction, namely the bureaucratic, communal, professional, and adhocratic (Lindkvist and Llewellyn 2003). The types of interaction influence management style as the boundaries between information-sharing parties are different and the degree of boundary-crossing information and peer communication is distinct in every type considered (Figure 3).

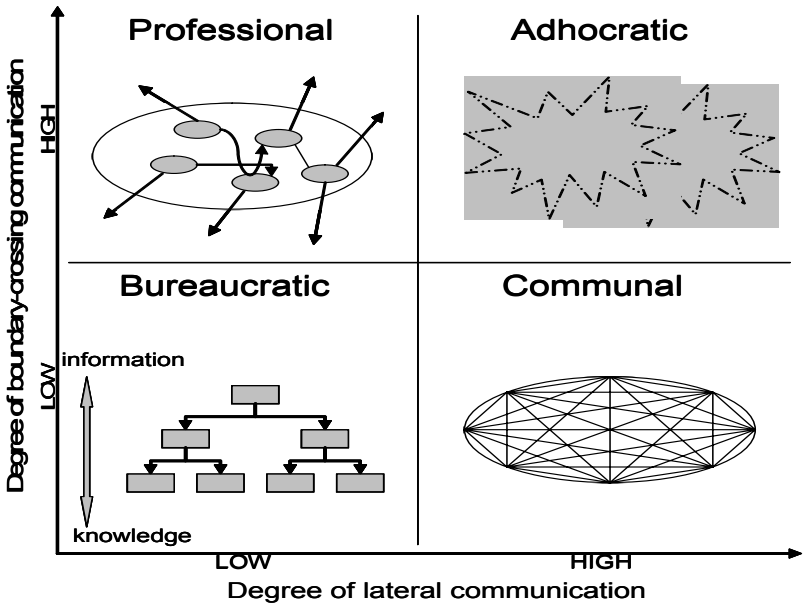

Figure 3: Communication flows in four organization types (Koivuaho 2005)

The above-mentioned organization types have been illustrated in a two-axis schematic (Figure 3). The degree of lateral communication is shown on the horizontal axis. It concerns communication between peers. The vertical axis shows the degree of boundary-crossing communication. Boundaries are considered to be crossed, for example, when a customer and an employee are communicating with each other and the communication is done over the formal organizational limits. In addition to its organizational boundary-crossing character, it can be understood also more broadly as communication that takes place between different linguistic groups. Therefore, it could also refer to the communication performed outside the limits of a shared work unit or an organization. It seems that the communication taking place becomes more context-dependent according as it moves away from the lower-left-hand corner of the schematic. As peer communication increases within organizational boundaries, parlances and metaphors in use start to converge to distinct meanings. Such internal lexicon may be useful in deepening the knowledge domain. Weber's bureaucratic model is based on a view of communication as the linear exchange of messages. In it the communication process is seen as distributing explicit knowledge in message packages. The bureaucratic model may be illustrated as a hierarchical network structure in which the

knowledge management's task is to design the interaction relationships according to organizational functionalities. Communication flows are designed to move unprocessed information upwards and refined information downwards. Vertical flows are favored because decision-making is centrally controlled. This structure is satisfactory in static environments where the solution domain is predetermined. However, problems arise when knowledge is to be acquired from an unconventional route.

A more dynamic and holistic view seems to be rewarding when the environment and the internal organizational structure is in continuous change. Many scholars (e.g. Boland and Tenkasi 1995) describe work done in knowledge-intensive companies as communal activity. A communal organization is based on common interests and values. The division between work and leisure is not clear. What makes the communal organization efficient in knowledge creation is the depth of its knowledge domain, as the knowledge that the members have originates in the same field. It also makes communication easier, because linguistic forms are shared.

Even though communal organization offers an opportunity for the creation of highly specialized knowledge, there are risks of narrowing the perspective and building too rigid boundaries to the outer environment. In bureaucratic and communal organizations, communication processes deal with intra-organizational dynamism since linguistic forms are commonly shared. In communal organizations the knowledge domain may be deeper, since the members do not have functional roles. Instead, they are all striving to achieve a common goal. The lack of boundary-crossing communication helps to create a general lexicon, thereby contributing to the diffusion and creation of knowledge.

The professional organization type is basically totally decentralized. It is a loose structure where communication between experts may be rare. Often the internal interaction in professional organizations consists mainly of sharing the same office and workers carrying out the routine work (medical practices, legal offices, etc.). The lack of lateral communication hinders the creation of organizational knowledge. However, communication flows in a professional organization are not restricted by organizational boundaries. Professionals may have their own networks of reference.

In an adhocratic organization the organizational boundaries are not clear, as the composition is transforming continuously. Multidisciplinary teams are used to create more diversity in peer communication and thereby potential for new innovations. Lateral and boundary-crossing communication is needed to create a shared vision from an often largely divergent knowledge domain. When peer communication increases within organizational boundaries, linguistic forms start to converge. However, in the case of adhocracies, communication is frequent also cross-organizationally. The balance between sufficient diversity of knowledge domain and the need to find a common lexicon between interpreters remains the crucial question.

4.3 Knowledge flow model

We argue that the two above-mentioned models are not able to depict the complexity of the network of knowledge flows and communication in knowledge-intensive organizations. It seems that the knowledge flow model ignores the role of internal interaction in organizations, whereas the communication flow model lacks the perspective of input flows, which are essential for the collection of new business information from the environment. By combining these models, we are able to include the lacking perspectives and to synthesize the models for the needs of complexity-based knowledge management.

The knowledge flow model is a three-dimensional construct (Figure 4). The dimensions represent the knowledge flows of an organization as output flows, input flows, and internal flows. The knowledge flow model forms the face of the cube and the communication flow model adds the depth dimension. The model can be applied as a tool for analyzing interaction and communication processes on an organizational level, but from the viewpoint of this paper it is applied as a tool to analyze phenomena that arise from group dynamics.

In the context of group dynamics and small-scale organizations we refer to output flows as being communication and knowledge sharing over the boundaries of the group. As an illustration, consultancy work aiming to produce a piece of advice for a customer could be seen as an output flow. The internal flows, on the other hand, are used to depict the interactions taking place within the organizational boundaries. However, in the case of small-size organizations the distinction between boundaries, e.g. in the case of a customer's contact person, is not clear. Input flows refer to the learning processes taking place in an organization. They refer to assimilation of knowledge done by individuals, groups, or organizations. Higher input flows might occur for example when the project is in the early phase of a learning curve.

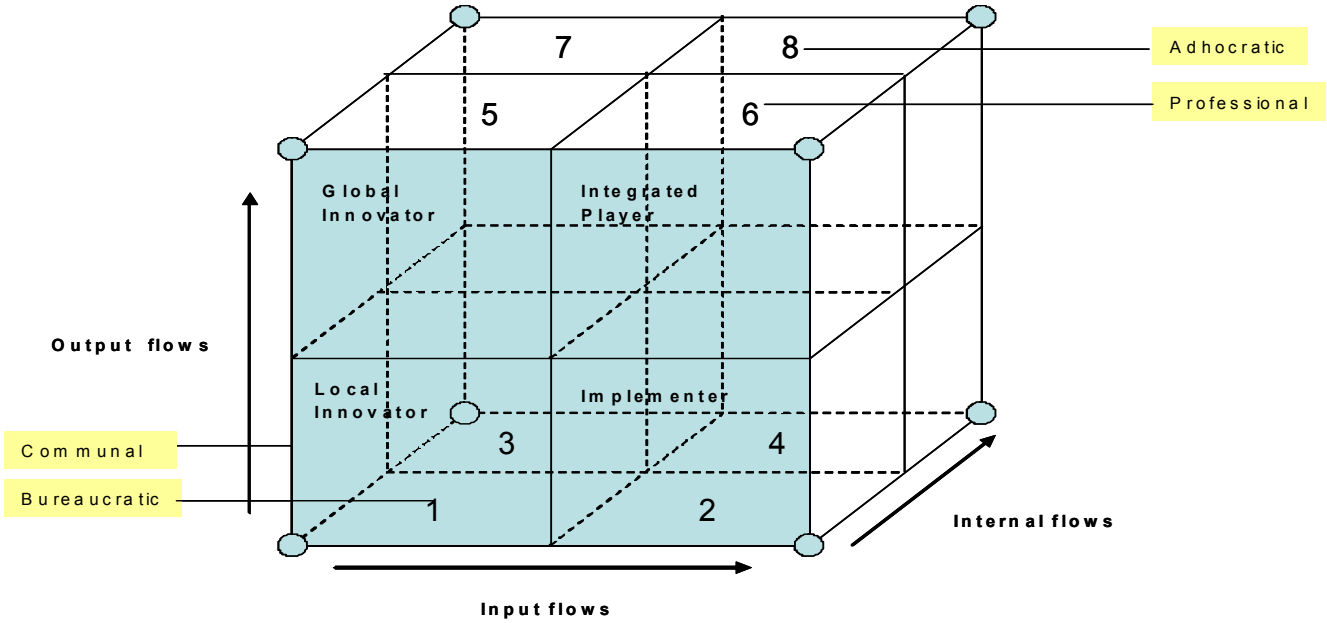

Figure 4: Knowledge flow cube

It is important to notice that the position of a certain group in the cube is dynamic. It changes during the evolution of the group and its members. Also the environment is in continuous change and this sets high requirements for communication and knowledge sharing, both internally and across different boundaries. In this study the management of this complex network of interaction is called complexity-based knowledge management. Next, the discussion moves on to the application of the knowledge flow model in small-size software companies.

5. Preliminary insights from the model in small-size software companies

Software development is a knowledge-intensive business and therefore it is an appropriate environment for a preliminary application of the conceptual model. In software business there are various kinds of specialists, who are all experts in their own field. The aim is to find out what kinds of thinking would enable them to communicate and share knowledge more efficiently and if there are possibilities for the management to conceptualize the ongoing process better.

5.1 Case companies

Gofore Ltd. is a small-size software consulting company established in 2001. It is specialized in Java/J2EE technologies and modern software engineering methodologies. Gofore identifies itself as a technology partner that can solve technical challenges and implement solutions to fulfill the requirements specified in cooperation between Gofore and its customers' representatives. Gofore was formed by four partners, each with many years of experience in IT projects in different professional roles. The managing director sees active knowledge sharing and communication as an essential part of successful business.

NetComp Ltd., established in 2002, is a small-size IT company that is specialized in network communications and the design and implementation of software solutions. NetComp Ltd. carries out software projects where they implement tailor-made solutions based on their own products. According to the managing director, communication and knowledge flows within the organization create possibilities for innovative solutions for customers' needs.

Both companies are in close interaction with their customers and are eager to improve their capabilities in this area of knowledge flows and communication. Both managing directors have long experience also of large-scale companies and in the interviews they were asked to reflect their previous experience in their answers. As an implication, some aspects presented in this paper are also an issue in a larger context, although we want to emphasize that the implications of this study do not necessarily hold true in other companies.

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5.2 Professional roles as routers of knowledge

The different professional roles that are usually identifiable in software projects will be mapped. As software production is in general project-based, the roles of individuals may vary from one project to another. Therefore, it is important to recognize the tasks that individuals in these roles are typically responsible for (Table 1).

Table 1: Perceived roles in IT projects based on interviews in case companies

Role	Description of the role
Project manager	Creates the business case and coordinates the project tasks. Makes go / no go decisions. Plans, tracks, and manages risks.
Chief architect	Decides on technologies for the whole solution and is responsible for the architecture design.
Process engineer	Owns the process for the project and creates guidelines for using a specific tool.
Software engineer	Codes a set of classes or a single set of class operations.
Graphical designer	Role subcontracted in both companies.

The roles that were identified based on the interviews match very well the roles that RUP presents. They also seem to be common in software projects more generally. Still, it is important to make a distinction between these roles from the communication and information flow perspective. Every role has very different responsibilities in this sense. From the knowledge flow perspective, some of them are more inflow- and some more outflow-oriented. These factors obviously depend on the personality of the individual, but there are also some role-related differences.

It is interesting to study how these roles could be placed in the knowledge flow cube. It could be argued that in knowledge-intensive work the roles are typically situated on the back wall of the cube, since the trend has been on shifting work practices towards team work, where people with different backgrounds work together and therefore the amount of internal knowledge flows is higher than in more traditional industries. The discussion with the managing directors confirmed this presumption in small-size software business. In the case companies the importance of team work and open knowledge sharing was stressed. As an interesting addition to the official roles in software projects, both companies emphasized the role of openness and transparency towards the customer as a prerequisite for effective communication and knowledge sharing, from the perspective of trust within the business relationship. This has implications especially for the functionality of input and output flows.

From the knowledge management point of view, it is also worth noticing that on the basis of the interviews even the small software businesses are trying to make their knowledge more explicit. They are actively building tools that utilize explicit knowledge and improve their communication and knowledge flows with the customer. Gofore Ltd. has launched an extranet that is used for exchanging project-related documents with the customer. The tool has also other features, such as a shared calendar that includes all the agreed meetings, deadlines, and other important dates, visible both to the employees and to the customer. Development conversations can be held on an electronic forum, where project members can discuss the problems and keep track of the task portfolio with an issue-tracking tool. Change requests are also prepared with this tool. Customers have been very interested in using this tool as an integral part of the communication process.

Since the implementation of the tool, Gofore Ltd. has noticed that the amount of email has been decreasing and project-related information is now stored in one place where everyone can find it when needed. Similar tools have been used in large-scale companies, but it is interesting to notice that knowledge flows and communication have been converted to electronic form also in smaller-size business. In NetComp Ltd., projects use a software system to coordinate project-related documentation internally and the tool is not used in communication with customers. According to the interview, this kind of communication might not fit the organization's way of working. In NetComp Ltd. most of the communication with the customer is directed through the project manager, who has an important role also as a filter of information.

Based on the analysis of the two small-size case companies, it could be concluded that most of the employees can be plotted to sub-cubes 5, 6, 7, and 8. Their employees were very experienced and they have had long careers in software business. Their expertise is widely utilized internally (*internal flows*) and they all have the required social skills to participate in meetings also with the customer (*input and output flows*). Larger companies may have more rigid communication structures in the form of reporting responsibilities and more defined responsibilities for the different IT project roles. For example, they might have so-called junior software engineers, who could be

plotted to somewhere near the implementer role in the knowledge flow model (sub- cube 2).

6. Conclusions

In this paper we constructed a conceptual framework for studying and managing knowledge flows in knowledge-intensive organizations. The framework connects two existing models, i.e. the knowledge flows –based framework and the communication flow model, and synthesizes these models for the needs of complexity-based knowledge management.

Theoretically, our knowledge flow model seems to explain the complexity of the communicational environment of knowledge-intensive organizations and adds a dimension to the two models that were used as a basis of the framework. The knowledge flow model ignores the role of internal interaction in organizations, whereas the communication flow model lacks the perspective of input flows that are essential for the collection of new business information from the environment.

The knowledge flow model is a scalable framework that could be used for understanding knowledge flows and communication behavior at different levels. It was designed to be used at the organizational level and we applied it as a pilot in small-size companies. In the future it could be developed further and tested in larger knowledge-intensive organizations. This study gave us an insight that could be utilized in further development of the framework. Context dependency is one of the issues that should be taken into account, because it is obvious that the position of the roles does not remain static in sub-cubes through time. Another interesting issue might be to define measures that could be used to position different organizations in the framework.

On the basis of the discussion in case organizations it seems that the knowledge flow model could also be used as a managerial tool. Managers can use it to position their own organization or group in the model from the knowledge flow and communication perspective. After they have acknowledged their position, they could define a strategy and the required actions for reaching the desired position by developing and managing knowledge flows.

The knowledge flow model might be useful in recognizing the nature of the process related to the service offering, i.e. an organization producing standardized products might find the knowledge flows based on a bureaucratic model applicable, whereas the production of customized products will require more interaction with the customer and a combination of other ways of organizing, e.g. professional and adhocratic, would be a way to pass through the elements hindering knowledge flows.

The conceptual approach of the knowledge flow model has practical relevance in situations where the number of individuals and work groups is high or increasing. In such a situation it is hard for the manager to piece together the knowledge flows taking place. Recognizing the situation through the three different flows discussed in the model and situating the organization or a part of it accordingly offers a way to develop new procedures and control methods that are more suitable for the challenges of the operational environment. Changing the organization and making it co-evolve with the environment might require more communicational openness, which from the perspective of the model means an increase in the inflows and outflows. These have an impact also on the internal structures and procedures.

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