Fragmented Knowledge in Collaborative Manufacturing Process Chains

Benjamin Knoke, Thorsten Wuest, Klaus-Dieter Thoben
BIBA – Bremer Institut für Produktion und Logistik GmbH
Hochschulring 20
28359 Bremen, Germany
[kno, wue, tho]@biba.uni-bremen.de

Abstract—Knowledge is a key element of today’s manufacturing companies in running, maintaining and continuously improving their processes. Centralized management approaches face the challenge of accessing and utilizing existing knowledge, as it is generated in numerous places throughout the manufacturing process chain. As this problem already exists within single organizations, it aggravates in networked production. To provide a structured analysis of knowledge fragmentation in a collaborative manufacturing environment, this paper presents an approach based on transforming the Johari Window for inter-organizational use. It sheds light on the state-of-the-art from a new perspective and presents future research challenges.

Keywords—Knowledge Management; knowledge fragmentation; Johari Window; suggestion system; manufacturing process chain; collaborative manufacturing

I. INTRODUCTION

While production is commonly defined as the transformation of production factors into tangible goods or intangible services [1], manufacturing focuses on tangible goods [2]. This transformation follows a chain of multiple processes that impact the physical state of the product. On an abstract level, manufacturing can be reduced to a product transformation process aiming at the fulfillment of customer requirements. The efficiency of this transformation process is a key success factor for most manufacturers and is highly influenced by the availability of knowledge on customer requirements and possible causes for manufacturing errors or improvement potential. In reality, difficulties of accessing this knowledge increase when product complexity and process dynamics rise, making both requirement engineering and Knowledge Management mandatory areas in organizational theory.

Collaboration adds another challenging dimension to manufacturing processes, where enterprises strive to successfully exchange knowledge. The significance of successful knowledge transfer and efficient communication can be estimated according to a study conducted by Marsh (2005). Marsh calculated costs of $611bn per year that were caused by poorly targeted mailings and staff overheads in the US, and also stated that organizations typically overestimate the quality of their data and underestimate the cost of errors [3]. Against this background, possible approaches to exchange process-relevant knowledge in collaborative manufacturing process chains are depicted, starting with a structured analysis of the problem.

II. PROBLEM ANALYSIS OF FRAGMENTED KNOWLEDGE IN COLLABORATIVE MANUFACTURING PROCESS CHAINS

Knowledge Management is the systematic and explicit control of knowledge based activities, programs and governance within the enterprise with the goal to make effective and profitable use of the intellectual capital [4]. The Knowledge Management research field is a very broad one and there are various research areas involved, from social science to psychology and business to engineering [5]. [6] emphasize that Knowledge Management does not only imply successful utilization of knowledge but also the creation, allocation and sharing of it. Knowledge is a key resource for enterprises [7] [8] and sharing knowledge is crucial for every modern manufacturing company, especially when working in a collaborative environment [9]. Sharing knowledge is always a challenge as it contains a context dimension in comparison to information [10]. Knowledge can be available in implicit (e.g. in the head of employees) or in explicit form (e.g. documentation) [10]. Some scholars argue that even explicit knowledge is partly implicit, as every person acquiring knowledge automatically interprets it in a personal way [11]. The pioneers in the field of Knowledge Management, [12] created the well-known model of the “knowledge spiral”, an illustration of the knowledge creating process that focuses on transforming implicit to explicit knowledge.

As some of the process relevant knowledge is implicit and created from hands-on experience, it can be difficult to externalize. Industrial manufacturing processes are not planned on operational level. Their planning is usually based on basic engineering and theoretical scientific knowledge, but hands-on knowledge is usually not available. [13] and [14] state that creative potential and process efficiency are significantly impacted by the combination of hands-on and theoretical knowledge. In order to be considered for process design or improvement, experience-based knowledge needs to cross the intra-organizational barrier from employees to an organization’s management. The transmissibility of this barrier strongly depends on various factors, as those described in Fig.4.
A similar barrier, inter- instead of intra-organizational, can be identified in the following cooperative manufacturing process chain: when employees within an organization gain knowledge that would be beneficial for another organization within the same process chain. If these employees don’t overcome this inter-organizational barrier to communicate with the partner’s management, the knowledge will remain fragmented.

An example of this knowledge would be a collaborative manufacturing process, where one manufacturer applies metal sheets, which have been cut and drilled by a supplier. If the final product’s design is changed, and some drillings are no longer required, the focal manufacturer can transfer this knowledge to the supplier and decrease the overall manufacturing costs of the collaboration.

For a structured analysis of the identified barriers, the Johari Window can be applied. Its original structure and the adaptation to the inter- and intra-organizational levels are described in this chapter.

A. The Johari Window

The Johari Window is a concept that was originally developed by social psychologists Joseph Luft and Harrington Ingham in 1955. Originally, the Johari Window is a model that describes attributes that are known or not known among individuals in group situations, and analyzes the way people give and receive feedback [15], [16]. As shown in Fig. 1, the window consists of four panels that contain personal attributes. These personal attributes are sorted by their awareness to the referred person and group, resulting in four categorizing areas:

- The **Arena**, contains overall attributes that are known to the person, as well as to the group
- The **Blind Spot**, is comprised of knowledge that is available to the group, but not to the person
- The **Façade**, which holds attributes that are only known to the person they describe and unknown to the group
- The **Unknown**, which contains attributes not known to anyone

Despite its age, the Johari Window is still used as a popular tool to study feedback and exposure processes [17], [18], [19], [20]. Its success is based on its simplicity and extensibility. By adjusting the size of its panels according to their content, the Johari Window can be used to simulate and visualize dynamic feedback [21], [22]. The following subsection aims at an adoption of the Johari Window in order to analyze inter-organizational knowledge fragmentation in manufacturing process chains.

B. The Johari-Window in Collaborative Manufacturing Process Chains

When transferred to the inter-organizational level, the Johari Window can be utilized to differentiate areas of knowledge, which are relevant to the improvement of a specific organization’s manufacturing processes, while acting within a collaborative environment. As such knowledge is either available or not available to the focal organization and other organizations., the Johari Window for inter-organizational Knowledge Management can be created as in Fig. 2. The knowledge necessary to improve an organization’s manufacturing can be located in one of the four resulting areas:

- **Arena**: Contains knowledge available to the focal as well as related organizations. Realizing such improvements is usually demanded by network partners and should be priority for implementation.
- **Façade**: Knowledge that is only available to the focal organization. Derived improvements are unexpected, but beneficial for the organization and its collaborations.
- **Blind Spot**: Knowledge only available to other organizations. This area should be investigated with highest priority, to benefit from insights among partners and to maintain reputation and competitiveness in the network.
- **Unknown**: Knowledge about opportunities for improvement that is not available to anyone. Its identification leads to the Façade sector.

![Fig. 1. The Johari Window [15]](image1)

![Fig. 2. The Johari-Window for inter-organizational Knowledge Management](image2)
From an analytical perspective, the inter-organizational Johari Window represents a 2x2-matrix be defined as $A_{inter}$:

$$A_{inter} = \begin{pmatrix} K_f & K_o \\ K_o & 1 \end{pmatrix}$$  (1)

Where knowledge is fragmented between two elements:

$K_f =$ Knowledge available to the focal organization

$K_o =$ Knowledge available to other organizations.

For better alignment of this model to the characteristics of manufacturing processes, another dimension is added: While relevant information might be available within an organization, it must not necessarily be available to its management as well. Depending on the autonomy level of an organization’s manufacturing, and extension of any derived measures, such information needs to reach the management level prior to their implementation. This results in another intra-organizational Johari Window that can be defined as $A_{intra}$:

$$A_{intra} = \begin{pmatrix} K_f & K_e \\ K_e & 1 \end{pmatrix}$$  (2)

Where knowledge is fragmented between two elements:

$K_e =$ Knowledge available to the management of an organization

$K_e =$ Knowledge available to the employees of an organization.

The intra-organizational fragmentation of knowledge can occur in both instances of (1), thus resulting in a fragmentation between four elements. Two resulting matrices can be identified, for the focal and for other organizations:

$$A_f = \begin{pmatrix} K_{fm} & K_{fe} \\ K_{fe} & 1 \end{pmatrix}; A_o = \begin{pmatrix} K_{om} & K_{oe} \\ K_{oe} & 1 \end{pmatrix}$$  (3)

The Kronecker product of (3) shows all possible combinations of knowledge fragmentation, and the complexity of the problem:

$$A_f \otimes A_o = \begin{pmatrix} K_{fm}K_{om} & K_{fm}K_{oe} & K_{fe}K_{om} & K_{fe}K_{oe} \\ K_{fm}K_{om} & K_{fm}K_{oe} & K_{fe}K_{om} & K_{fe}K_{oe} \\ K_{fm}K_{om} & K_{fm}K_{oe} & K_{fe}K_{om} & K_{fe}K_{oe} \\ K_{fm}K_{om} & K_{fm}K_{oe} & K_{fe}K_{om} & K_{fe}K_{oe} \end{pmatrix}$$  (4)

Assuming that an organization’s management is the only actor who changes its manufacturing processes, the knowledge ($K_{fe}, K_{om}, K_{oe}$) of the other three elements of (1) and (2) must cross the barriers to be beneficial. The following chapter aims to analyze the state-of-the-art in regards to this challenge.

III. APPROACHES TO ACCESS FRAGMENTED KNOWLEDGE IN COLLABORATIVE MANUFACTURING PROCESSES

According to the previously constructed model, several combinations of fragmentations can occur within knowledge that is valuable to the management of organizations, while participating in collaborative manufacturing processes. Although some of the possible combinations shown in (4) might bear socio-analytical potential, they are not within the scope of this paper.

Fig. 3. Barriers and Access Priorities for Intra- and Inter-Organizational Knowledge Exchange

If the same knowledge is available to more than one of the entities identified in Fig. 3, knowledge should be collected by the focal organization’s management accessing those entities with the highest access priority. These access priorities (A-C) follow the general accessibility process, as contacting employees within the same organization might be the easiest solution, and contacting employees of other organizations the most difficult. Possible approaches are described in the following sub-sections in the same order (from A-C). As knowledge transfers can differ in various aspects, in this context distinguishable characteristics are:

- Formal or informal (anticipated or spontaneous)
- Documented or undocumented
- Implicit or explicit
- Reactive or proactive (Transfer either triggered by the organization’s management or others)

Within the focused scope of this paper, only approaches to establish formal and informal knowledge transfers between a focal organization’s management and other entities (A-C) are described.

A. Transfer of Knowledge available to the Organization’s Employees

Establishing knowledge transfer between employees and management of an organization is a classic area of research. While informal exchange strongly depends on individual leadership style, initial approaches for formal knowledge exchange were made by Alfred Krupp in 1872 [23]. Since then, employee suggestion systems have been elaborated and
have spread, especially during the Second World War [24]. They became popular again with the rise of Kaizen and the Toyota Production System in the late 90s [25], [26]. Intense research and application made the concept of Continuous Improvement (CI) the core instrument of incremental organizational change [27]. Such suggestion systems are usually initiated by the organization’s top management. They rely on certain success factors, which have been the subject of numerous studies, such as [28].

Business models and Knowledge Management Systems (KMS) for formal knowledge exchange between organizations on managerial level are currently the object of research in various sectors. However, only few collaborative KMS have been successfully implemented into industrial practice. Initial positive examples can be found in aerospace enterprises that focus around a centric OEM [34]. These initiatives focus on improvement by encompassing upstream supplier networks and downstream customer-focused activities. Because these suppliers and customers aim for highly specialized products, and strongly depend on each other’s relationship towards the OEM, they are less likely to compete with each other.

![Fig. 4. Success factors to overcome the intra-organizational barrier](Image 37x539 to 295x683)

As in Fig. 4, these factors are based on encouragement, organizational support, and committed resources. These success factors will later be transferred for inter-organizational use.

It can be concluded that, since the latest advancement of suggestion systems and Continuous Improvement, many manufacturers already access the knowledge of their employees [29]. While formal knowledge exchange is mostly realized through suggestion systems, some companies, such as IBM, apply more innovative approaches, e.g. employee blogging (a blog based topic suggestion system [30]).

B. Transfer of Knowledge Available to the Management of Other Organizations

The inter-organizational barrier for knowledge exchange aiming at the collaborative improvement of operations is hindered by the competition between organizations [31]. The competitive advantage is defined by [32] as a value creating strategy, simultaneously not being implemented by any current or potential competitors. Against this background, it can be difficult for such competitors to exchange crucial knowledge. Organizations can lower this barrier, if they operate in different sectors (e.g. aerospace and automotive); have established a long lasting relationship, which is based on a high level of trust; or are connected through a strong dependency (e.g. a OEM and highly specialized suppliers).

Informal knowledge exchange between the management of collaborating organizations is usually established on the occasion of mutual site inspections. Such opportunities are extremely important for smaller or low-tech manufacturers to improve themselves, as they do not house R&D departments or incorporate the relevant competencies themselves [33]. This type of exchange can be enabled by occasional meetings, but not be enforced.

![Fig. 5. Success factors to overcome the inter-organizational barrier](Image 307x463 to 559x622)

Success factors to overcome the inter-organizational barrier (Fig. 5) can be identified similarly to those within single organizations. Additional factors are the competitive relationship, trust, mutuality of the knowledge exchange, and financial benefit for the supporting organization.

C. Transfer of Knowledge Available to the Employees of Other Organizations

The formal knowledge exchange between employees across inter-organizational barriers is in its infancy. Normally, accessing an organization’s human resources from the outside is not accepted, because this is usually related to evolving costs and headhunting. This requires the commitment of the other companies’ management, works council, and the employees themselves. Regardless of these factors, the exchange can provide access to highly valuable knowledge.

Informal knowledge exchange may be established during mutual site inspections, or commonly organized events of the cooperating organizations. However, such informal occasions usually only allow exchange that is time-limited, and should be established with caution depending on the mindset and level of trust within the collaboration.

Formal knowledge exchange between an organization’s management and the employees of other organizations require specialized infrastructure and a collaboration that focuses on mutual improvement of operations. While such approaches are
not to be found in current industrial practice, scientific progress is being made in projects such as BIVEE (Business Innovation and Virtual Enterprise Environment). BIVEE is an ICT-project founded by the European Commission (grant agreement no. 285746) that focuses on the elaboration of Virtual Enterprise Environments (VEEs). These VEEs are defined as highly dynamic, temporary alliances, where different organizations add their core competencies and act as a single Virtual Enterprise [35]. Within their environment, these VEEs create a Value Production Space containing a shared production that is accessed by a central Mission Control Room for monitoring and improvement of operations. Organizations participating in this endeavor have the opportunity to make use of this tight collaboration and shared production space to incorporate knowledge from other organization’s employees.

Knowledge from the employees of other organizations needs to cross the inter-organizational barrier to reach the management of a focal organization. Thus, the success factors to overcome the intra-organizational barrier (Fig. 4) can be applied. If the other organization’s management is included into the exchange, the intra-organizational barrier also needs to be crossed within the other organization. This is enabled by the success factors to overcome the inter-organizational barrier (Fig. 5).

IV. CAUSES FOR FRAGMENTED KNOWLEDGE IN COLLABORATIVE MANUFACTURING

Apart from access methodologies, this paper briefly faces the question about the reasons for knowledge fragmentation. Generally, knowledge fragmentation appears whenever:

- entities with differing qualifications face the same situation, or
- entities with the same qualifications face a different situation, and
- changes or gained knowledge are not immediately communicated among the entities.

While people from different sectors usually see problems from different angles, even slight differing situations may determine if an opportunity for improvement is observed or not. In reality, the manufacturing of an organization is a highly dynamic socio-technical system. While people and processes within this system constantly change, and new knowledge is created, only parts of this knowledge are process relevant. Because some of this knowledge cannot be externalized, or a lack of communication exists, the knowledge within the collaboration becomes more fragmented.

V. CONCLUSION AND OUTLOOK

Knowledge is a highly valuable resource for manufacturers aiming to improve their operations. This knowledge is not only created within these organizations, but also in their collaborative environment. To become accessible to the manufacturer’s management, this knowledge has to cross intra- and inter-organizational barriers. These barriers have been analyzed with the application of the Johari Window and an analytical approach. The success factors to overcome these barriers, formal and informal approaches for knowledge exchange within a collaborative manufacturing chain, have been discussed. While intra-organizational knowledge exchange is commonly implemented through suggestion systems and Knowledge Management Systems (KMS), only initial attempts exist for inter-organizational knowledge exchange.

Opportunities for future research in this area can be identified in analyzing the following: additional entities other than the organization’s management and employees; dynamics resulting from combinations of the knowledge fragmentation among these entities; intra- and inter-organizational knowledge exchange characteristics; new approaches to tackle the intra- and inter-organizational barriers; and the impact of different degrees of openness, up to open Innovation approaches.

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