Chapter 5
Understanding Collaboration in Knowledge Processes in Indian Industry

Gokula Vijaykumar A.V. and Amaresh Chakrabarti

Abstract Collaborative design supports quality innovation in reduced cost and time to market; this is critical to sustain organizations within the current competitive product development landscape. Understanding the knowledge processes that occur through collaboration among stakeholders in designing should help industry assess the quality of its collaboration and knowledge processes. Existing models for understanding knowledge processes during collaboration are inadequate in describing significant details of these processes; importantly, they do not stress the centrality of interactions in processing knowledge. A collaborative model called Knowledge-Requirements-Interactions-Tasks, or "KRIT," is proposed to help understand how collaborative knowledge processing takes place through interaction among stakeholders in product development. Also, an Influence model has been proposed to assess the levels of satisfaction of the four elements in the KRIT model. Indicators for satisfaction of knowledge, requirements, interactions, and tasks of a solution are proposed using industrial data collected on collaboration. These models should inform development of support to assist knowledge processing to improve work performance of stakeholders and consequent quality of outcomes.

1 Introduction

Quality innovation in reduced cost and time to market is critical for survival of organizations within the global, competitive product development (PD) context. Collaborative design has the potential in enabling organizations to achieve this. A design process is termed collaborative when a product is designed through the

Gokula Vijaykumar A.V. • A. Chakrabarti (✉)
Innovation, Design Study and Sustainability Laboratory (Ideas Lab), Centre for Product Design and Manufacturing, Indian Institute of Science, Bangalore 560012, India
e-mail: g.v.annamalaivasantha@cranfield.ac.uk; ac123@cpdm.iisc.ernet.in

S.P. MacGregor and T. Carleton (eds.), *Sustaining Innovation: Collaboration Models for a Complex World*, Innovation, Technology, and Knowledge Management,
DOI 10.1007/978-1-4614-2077-4_5,

collective effort of many designers, including tools (Wang et al. 2002). Collaborative design is particularly relevant since designers currently expend a substantial proportion of their time to satisfy their knowledge needs. MacGregor et al. (2001) point out that engineers perceive 34% of their time is taken in sourcing and locating relevant information, and the mode of communication is 53% asynchronous with the rest synchronous, which demonstrates the importance of collaboration in knowledge processes.

Understanding collaboration among stakeholders (such as designers, manufacturers, managers, and consultants), the tools used, and the knowledge processes for designing should help organizations assess the quality of its collaboration and knowledge processes. This understanding, in turn, should help develop support to assist knowledge processes, so as to improve the work performance of stakeholders and consequent quality. Existing models for understanding knowledge processes through collaborative activities are inadequate in describing significant details of these processes; importantly, they do not stress the centrality of interactions in processing knowledge.

A collaborative model called Knowledge–Requirements–Interactions–Tasks, or "KRIT," which emphasizes interactions among designers, other stakeholders, and tools in processing knowledge during PD, has been developed. This model is used to understand how collaboration takes place among stakeholders in PD, from the point of view of knowledge processing. In the KRIT model, interaction plays the central role in identifying knowledge, requirements, and tasks with which requirements are addressed. The interactions cascade together to form a map of interactions, providing a view of all collaborations, and informing their quality from a knowledge-processing viewpoint.

In this chapter, the objective is to understand how knowledge, requirements, interactions, and tasks are satisfied during PD. A model of how satisfaction of requirements, tasks, interactions, and knowledge of solutions influence one another is also proposed, and discussed using data collected from two observational studies conducted in two organizations in India. The two organizations are chosen to highlight how a small, private enterprise and a medium, public enterprise contrast with each other in terms of their knowledge processing profiles. We detail the understanding obtained through these industrial case studies on the elements modeled in the two proposed models: the KRIT model and the Influence model. This understanding emphasizes the importance of collaboration and how the proposed models could be used to help sustain innovation through collaboration.

2 Innovation and Collaborative Design

The argument that collaboration and supporting knowledge processes enrich designers' creativity to produce innovative outcomes is highlighted widely in the literature. Larsson et al. (2003) observed that one-on-one conversations, held in parallel to a main discussion, were common in colocated teamwork and were a natural part of creative teamwork. Frankenberger and Badke-Schaub (1999) argued that availability of information is central to the success of design. They observed that designers spend more time individually than in teams, but critical situations occur during collaborations. Moritz and Schregenberger (1997) argued that prerequisites for producing creative solutions through cooperation are openness toward new ideas and viewpoints, application of efficient and effective state of the art methods, eventual objectives, and accumulation and distribution of information. Leonard-Barton and Sensiper (1998) posited that creative cooperation for merging knowledge from diverse disciplinary and personal skills-based perspectives is crucial to creating innovative, complex systems and products. Similarly, Sonnenwald (1996) found that design teams increasingly included participants from different domains to explore and integrate their specialized knowledge to create innovative and competitive artifacts and reduce development costs. Haymaker et al. (2000) considered approaches to collaborative design for new means of generating coherence and innovation by reformulating construction and flow of information. Lahti et al. (2004) pointed that computer supported collaborative environments for knowledge building provide a promising innovation to facilitate teamwork among designers, while Petre (2004) noted that innovative engineers are "hungry" for input, and work actively to maintain and update their knowledge base.

In the high-tech sector, knowledge is considered to be the only meaningful economic resource (Buchanan and Gibb 1998). MacMorrow (2001) argued that potential benefits of managing knowledge range from improving productivity, decision making, customer service, and innovation. Newell et al. (2002) argued that knowledge is used to support innovation within both teams and companies, and Cheung et al. (2008) demonstrated that knowledge reuse resulting from a repository type of knowledge management system actually inhibits creative performance of individuals, especially on the qualitative dimension. They argued that knowledge reuse for innovation focuses on knowledge integration through which others' knowledge is integrated into one's existing knowledge stock to accomplish an innovative task. These results emphasize the importance of collaboration and the associated knowledge processes.

3 Knowledge Processes Models

One common limitation in current literature in this area is that the concepts used are rarely defined in a systematic manner. The following definitions are used in this chapter to understand knowledge processes.

- *A knowledge element is defined as an entity (building block) processed in the PD process.* For example, function, behavior, and structure are some of the high-level knowledge elements for a product description.
- *A knowledge process is defined as the process through which knowledge elements evolve in their life cycle.* For example, search, retrieve, generate, capture, store, share, and (re) use are some of the commonly observed knowledge processes.
- *An agent is defined as a perceptible object through which designing occurs.* For example, designer, customer, computer, and documents are some of the agents.
- *An interaction is defined as a mutual or reciprocal action or influence of agents.* For example, "designer working with computer," "two designers working with a computer," and "many designers interacting with each other" are some of the interactions.

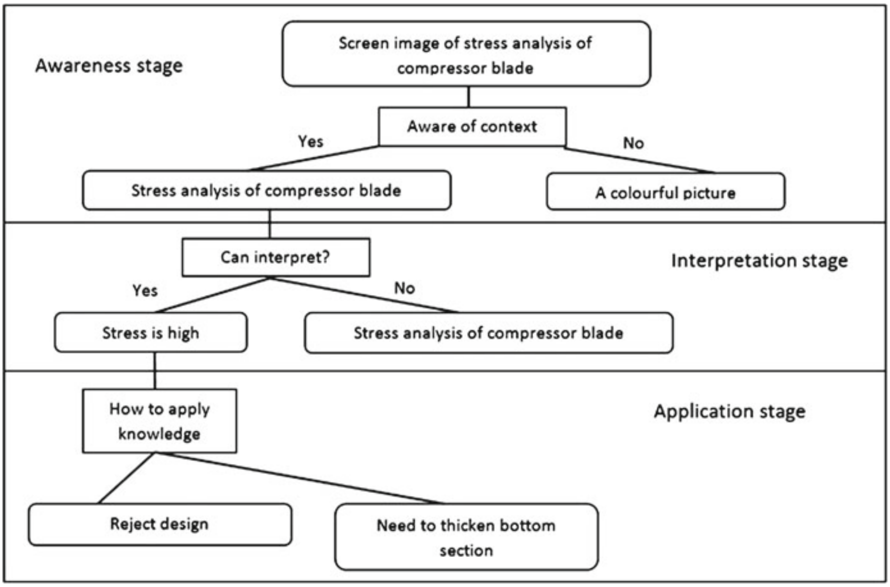

Fig. 5.1 Definition of data, information, and knowledge through stress analysis example (Ahmed et al. 1999)

The definitions of data, information, and knowledge are used from Ahmed et al. (1999). Data are taken as symbols or facts without context and are thus neither directly nor immediately meaningful. Information is data placed within some context. Knowledge is taken as a meaningful interpretation of information. We choose these definitions as they take into account scenarios in which a source and a user are involved in reciprocal actions. In our research, such scenarios are termed “interaction.” Figure 5.1 explains these definitions through an example given by Ahmed et al. (1999).

To understand the knowledge processes involved in designing, many models have been proposed: these variously focus on the design process (French 1985; Pugh 1991), argumentation process (Kunz and Rittel 1970; MacLean et al. 1991), artifacts being designed (Chandrasekaran et al. 1993; Chakrabarti et al 2005), and activities of designers (Blessing 1994; Nidamarthi 1999). All these models provide rich descriptions in their own segments. However, for understanding the day-to-day knowledge processes of designers, we felt that the following points, missing in the current models, need to be incorporated.

- Interactions must be centered on the knowledge processes.
- Types of knowledge processes (e.g., knowledge capture, reuse) must be explicitly mentioned.
- Interlinks among knowledge elements (i.e., product and process aspects) must be highlighted and represented.

McDermott (1999) noted that approaches and tools developed to assist designers are inadequately adopted in industries due to an inadequate understanding of the knowledge processes of designers and industries. Analyses of relevant literature and observational data from industry indicate that the following points must be taken into account in any model to be used to understand the knowledge processes of designers:

- Each major knowledge element should be possible to be shown explicitly, with links to other knowledge elements.
- The interactions responsible in processing knowledge should be made explicit, and linked to associated knowledge elements.
- The model should provide a simple, easy-to-use, and meaningful representation for day-to-day knowledge processes.
- All major knowledge processes should be possible to be shown explicitly.

Given the points above, developing a new model is necessary. It should help organizations and designers to understand the dynamics involved in knowledge processing during PD. This, we argue, should help understand the associated knowledge processes, i.e., what knowledge is generated, captured and reused, and how (well) these are (currently) carried out. Besides being useful in aiding generation, capture and reuse of knowledge, this model should help provide insight to the process of knowledge transfer in an organization, which can be quite complex, requiring much time and effort to understand and assess. In this work, our aim is to support practice to better understand its collaborative knowledge processes.

4 Focus and Approach

The main foci of this chapter are to understand how knowledge is processed during collaborative PD in industry, and how efficient these processes are. We developed two models: the KRIT model, and based on this, an Influence model, to address these.

The KRIT model helps understand the knowledge processes during collaborative PD. Its distinguishing feature is the central role played by interactions in knowledge processing, something not explicitly taken into account in earlier models. Interaction of designers with other people and tools, we argue, is the vehicle through which knowledge processing occurs during PD. Our primary hypothesis in this model is the mutual influence of interactions and knowledge processes on one another. To understand how efficient these knowledge processes are, an Influence model has been developed with the KRIT model as the basis. These two models are detailed in Sects. 5 and 6.

To realize the benefits of these proposed models, two ethnographic observational industrial studies were undertaken: one in a small, private enterprise (providing innovative solutions and services in consumer products) termed SmallCADCo; and the other in a medium R&D organization (developing special purpose aircraft) termed MediumAeroCo. SmallCADCo is a joint (50:50) venture between a reputed academic institution and an IT company. The organization is 12 years old and consists of 15 employees. A substantial number of interactions for the personnel in this organization occur in consulting domain experts from the academic institution. MediumAeroCo collaborates with various public and private sector companies and

Table 5.1 Characteristics of companies involved

Characteristics	SmallCADCo	MediumAeroCo
Joint ventures	Partnership between private and academic institution	Public organization (funded by Government of India)
Number of employees and groups	Less and no specific groups	Medium and more groups
Complexity of products	Less and Medium	Highly complex and integrated
Place of work	Colocated	Distributed around India

academic institutions to design and develop special purpose aircraft. The groups in the organization are structured as: Systems Directorate, Propulsion Systems, General Systems, Air Frame, Flight Test, Integrated Flight Control System, Quality Assurance and System Effectiveness Group, Independent Validation and Verification, Project Management, Aerodynamics Research and Development, Protovehicle and Productionisation, Advanced Projects and Technologies, Information Systems, and other administrative departments. A total of around 240 employees are distributed across these groups. Both the organizations observed primarily serve Indian markets. The specific characteristics of these organizations that might influence collaboration and networking are summarized in Table 5.1.

In SmallCADCo, three designers involved in different projects were observed serially for 3–7 days each. The designers observed were novices with 1–3 years of work experience. All projects observed were carried out for the first time by these designers. The average duration observed per day for the subjects were 5.4, 3.0, and 2.8 h. In MediumAeroCo, seven designers were observed with 1–40 years of work experience. All except one designer were at senior levels in the organization. The observed number of days varied from 9 to 27. The average duration observed per day for each designer was 4.6, 2.7, 3.5, 1.8, 1.3, 2.3, and 3.3 h. Different projects involved in different stages of PD were chosen to evaluate the general applicability of the models proposed.

Data was collected using questionnaires, data sheets, voice recordings, and unstructured interviews, on the following topics: purpose of the tasks, interactions, place and duration of interactions, whether interactions were satisfying or not, project details, and subjects involved in the observations. All subjects observed informed that the observations had not disturbed or influenced their activities. Though we focused only on a total of ten designers in the two organizations, the data collected also included all other designers who interacted with these core ten designers during the observational period.

5 The KRIT Model

We propose the Knowledge–Requirements–Interactions–Tasks (KRIT) model, in which interactions of designers with people and tools are central to processing knowledge during PD. We argue that interactions lead to various knowledge elements, and

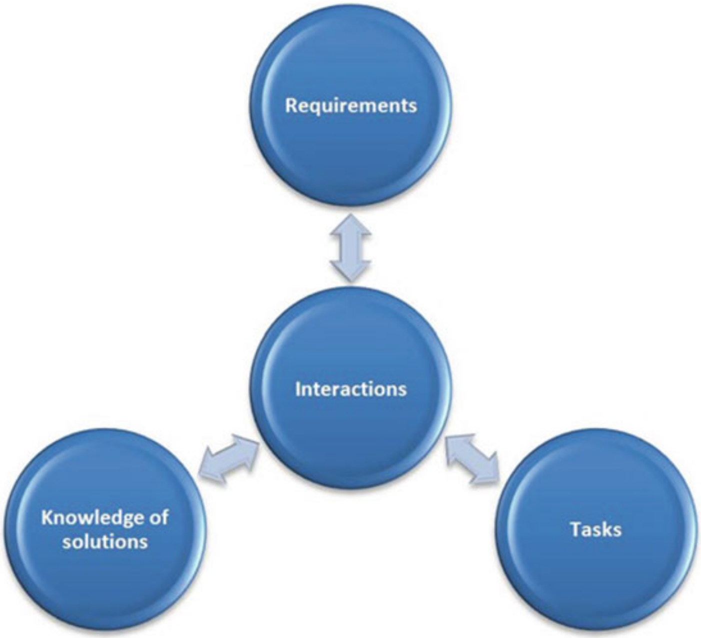

Fig. 5.2 Links between knowledge elements and interactions (the KRIT model)

these knowledge elements lead to various, new interactions. Nonaka et al. (2000) have a similar hypothesis for knowledge creation. They state that organizations create knowledge through interactions between explicit and tacit knowledge.

In order to encompass knowledge elements from both product and process points of view, "requirements" (representing product knowledge) and "knowledge of solutions" (representing product and process knowledge) and "tasks" (representing process knowledge) are included in the model. Their definitions are as follows:

- *Requirements*: Intended aspects of the product considered by designers during PD. For instance: "What is the working hours mentioned for filter head?"
- *Knowledge of Solutions*: The outcomes, i.e., artifact being designed, produced by designers to satisfy requirements. For example: "Extra steel plate should be added here because there is a gap of 1 cm."
- *Tasks*: A piece of work to be done to satisfy requirements. Two examples are: "to modify existing mold design," and "to measure dimensions from physical model."

In order to provide insight into the knowledge processes, links among requirements, tasks, interactions, and knowledge of solutions are explicitly represented. Using interactions as the core enabler, links are established among the knowledge elements, see Fig. 5.2.

6 Observations in Industry

Analyses of information collected from the ten subjects show that all three knowledge elements (requirements, tasks, and knowledge of solutions) are present in the collaborations and are connected via explicit interactions. We now discuss the observations related to each element.

6.1 Knowledge of Solutions

Knowledge of solutions has been classified into "product-based" and "process-based" knowledge. Product-based design knowledge is concerned with the objects being designed; examples are "it blows air at a certain pressure" and "the function might be to reduce the noise." Process-based design knowledge is concerned with how to design; examples are "cut till the inside surface" and "now I will make it this way." In this work, both product-based and process-based knowledge are classified based on the purpose of the tasks carried out by the subjects. In both the studies, the amount of time spent on product-based knowledge is much higher than that on process-based knowledge. This indicates that irrespective of the complexity of products being designed, and size and number of groups within the organizations, the focus has primarily been on knowledge about the product.

6.2 Requirements

As classified by Nidamarthi (1999), two types of requirements: Solution-Neutral Requirements (SNRs) and Solution-Specific Requirements (SSRs) are observed in both the studies. SNR describe the generic requirements which designers address with their designs. Solution-Specific requirements are specific to certain solutions only. For example, in a project designing an injection mold for a given component, its manufacturability and strength are SNRs, whereas questions of "how to avoid liquid leakage due to this dwell?" and "how much length should be given such that the engravings should not be affected?" are SSRs. The amount of discussions around SNR and SSR is much higher in SmallCADCo than in MediumAeroCo, due to the longer design time involved in MediumAeroCo.

6.3 Interactions

Interactions are a primary constituent for knowledge processing in an organization. In SmallCADCo and MediumAeroCo, respectively, 19 and 17 different types of interaction were found to be present. These types are classified based on the variety and the number of agents participating in a single interaction. The variety and number of agents involved in these interactions demonstrate the complexity of collaboration within these organizations. In both studies, the agents involved in these interactions, apart from humans, were: computer, measuring device, prototype model, document, notebook, paper, calculator, and whiteboard. The designations of the humans involved were: designer, engineer, design student, academic, external consultant, manager, supplier, customer, manufacturer, and scientist. In both studies, the interactions that occurred most frequently are: “one designer working with a computer,” “two designers working with a computer,” and “two designers interacting with each other.” In MediumAeroCo, two designers spent almost all their time individually interacting with a computer only. Tools for supporting knowledge capture and reuse must support these interactions, to ensure that capture and reuse can be built-in in a natural way into a designer’s work patterns.

6.4 Tasks

We classified tasks into six categories, based on knowledge exchanges performed by the subjects:

1. Generating knowledge alone (by the subject)
2. Generating knowledge (by the subject) with others
3. Giving knowledge (by the subject) to others
4. Taking knowledge (by the subject) from others
5. Searching for knowledge (by the subject)in documents or computer
6. Capturing knowledge (by the subject) in documents or computer

The first two categories represent knowledge generation; the next three represent knowledge reuse, while the last one represents explicit knowledge capture; note that all six categories of tasks might involve implicit knowledge capture. The amount of time spent in each task varied substantially between novice and expert designers. The variations were greatest in *generating knowledge with others* and *giving knowledge to others*. Novice designers, understandably, spent more time in *generating knowledge with others* and less in *giving knowledge to others,* whereas expert designers spent most of their time in *generating knowledge alone*. The amount of time spent on tasks to capture knowledge was very low, in both the studies. Knowledge capture happened only as part of the other five knowledge exchanges. The reasons for this could be due to the time pressure of the projects, low awareness of the importance of knowledge reuse, and since most of the projects are perceived to be unique in nature, low incentives to capture knowledge due to the perception that chances of reuse is low. We argue that increasing awareness and possibility of knowledge transfer from one project to another would substantially improve the proportion of knowledge captured, and reduce the amount of time spent on giving and taking knowledge, both impacting on the amount of time of designers involved in these tasks. The average time spent on these knowledge exchanges in both the organizations are summarized in Table 5.2.

Table 5.2 Average time spent on knowledge exchanges in SmallCADCo and MediumAeroCo

Types of knowledge exchanges	SmallCADCo (%)	MediumAeroCo (%)
Generating knowledge alone	29.8	42.9
Generating knowledge with others	44.2	22.1
Taking knowledge from others	13.4	3.3
Giving knowledge to others	5	4.5
Searching for knowledge in documents or computer	5.9	7.8
Capturing knowledge	1.7	19.4

In MediumAeroCo, the only novice designer involved found it difficult to search the documents available. He spent less time in searching and taking knowledge from others. This designer had to repeat some tasks several times. More attention needs to be provided to understand resources, including experts, from which knowledge can be gained.

Informal capture in private notebooks was predominant in MediumAeroCo, with the drawback that no one else could access this knowledge. To overcome this, a method to share informal knowledge capture might be necessary. Expert designers were largely preoccupied with their own tasks, and rarely interacted with others to share knowledge. This isolation must be avoided in a meaningful manner to facilitate efficient transfer of expertise. Experts spent more time in searching for knowledge in documents, indicating that they found the documents more useful, and that experience played a vital role in identifying appropriate knowledge resources. It would be interesting to investigate what knowledge was used to identify the documents and search them.

By studying the variations in time spent across tasks by each designer, we found that designers stick to their preferred modes of working. Capturing knowledge in MediumAeroCo was forced through adoption of standards, only as required for standards accreditation before the inspection period. However, this was not part of the normal routine of the designers involved. This scenario needs to be changed to incorporate a practice of capture as part of the daily routine of designers. Relevance of the captured documents is assessed by comparing their content with the questions asked by designers during PD. This revealed that only 18.7% of the answers to the questions asked were captured in, and therefore possible to be answered using, the documents; this leaves substantial scope for improving knowledge capture.

In SmallCADCo and MediumAeroCo, respectively, 18.4% and 7.8% of the time were spent in taking and giving knowledge to/from others, which is less than the 20–30% reported in literature (Court and Culley 1995; Marsh 1997; MacGregor et al. 2001). This decrease could be due to the post-social web revolution. The percentage is less in MediumAeroCo, possibly due to the greater experience of its designers observed. The variations between SmallCADCo and MediumAeroCo, and the fact that each designer stuck to his preferred working pattern, illustrate that knowledge processes should be supported in a more personalized manner, while utilizing organizational resources effectively. These observations emphasize the importance of collaboration among agents in the various knowledge exchanges and also highlight the importance of solo work within any framework of collaboration: collaboration always includes both individual work and team interactions put together to create a harmonious whole.

7 Influence Model and Assessment

Using the KRIT model, the PD process is explained as follows. Requirements are taken as the primary objectives to be fulfilled in PD. Each requirement requires some tasks with purposes and outcomes (knowledge of solutions) to be carried out, which are generated through various interactions. As a result of these interactions, knowledge is generated to satisfy the tasks and fulfill the requirement. Each task has a set of knowledge to be processed, which are processed through a complex variety of interactions. The knowledge generated to satisfy the tasks will be input for other tasks and requirements and will be carried out further down the PD process.

Figure 5.3 illustrates the Influence model developed from the KRIT model. Requirements satisfaction is the primary objective to be fulfilled. To satisfy each requirement, a set of tasks with purposes and outcomes should be satisfied. A set of knowledge of solutions have to be processed and satisfied to complete a task. Knowledge of solutions could be satisfied only if a set of interactions among designers (and tools) gets satisfied. The following subsections define the four satisfaction levels, and observations from SmallCADCo. We restricted the analyses to SmallCADCo due to the more detailed information collected in this study.

Fig. 5.3 Influence model by hierarchy tree of element satisfaction

7.1 Knowledge Satisfaction

We take knowledge to be satisfied, if right answers are obtained for the questions asked. In addition, knowledge satisfaction is high, if the process follows a Generate–Evaluate–Select cycle. This is based on the observation that designers were highly satisfied, when a proposed solution was accessed, justified and agreed commonly among the stakeholders involved. Knowledge satisfaction was the least when:

- The questions asked were not answered.
- The answers were refuted or solutions criticized.
- Differing points of view existed across stakeholders.
- Complexity of solutions was high.
- Answers were incomplete, missing or were unknown.
- Assumptions were made without proper verification.

Such instances should be prevented from happening to increase knowledge satisfaction in PD. A detailed study on the questions asked by the designers in SmallCADCo revealed that nearly 50% of the old queries were answered by colleagues (Vijaykumar and Chakrabarti 2008). This would significantly impact design time, as each such interaction consumes time of both the designers and the colleagues with whom they interact. This was either because the captured documents were inadequate or inaccessible, or because designers trusted their colleagues more than the documents. Increasing capture and retrieval efficiency would enhance knowledge satisfaction, decrease time consumed in discussions, and prevent unnecessary assumptions made due to poor retrieval.

7.2 Requirement Satisfaction

Requirements are taken to be satisfied if they are appropriately identified and solved. These processes were effective when customers were actively involved, life cycle phases were considered, and needs behind requirements were recognized. The instances with negative impacts on requirement satisfaction were the following:

- Uncertainty and ambiguity were noticed in the requirements chosen.
- Immature trade-off between requirements at early stages of PD was found.
- The requirements were found to be criticized during the later, more detailed stages.
- A wider scope was assumed for a requirement without justification.
- Due to time pressure, a compromised decision was taken to satisfy a requirement.

To improve requirement satisfaction, such instances should be prevented from happening.

7.3 Interaction Satisfaction

As defined before, interaction is the mutual or reciprocal action or influence of agents. Before defining interaction satisfaction, we clarify what is a single interaction Is. A period of observation is considered a single interaction if during that period the goal has not changed, the outcome is not achieved and the agents are not changed. By analyzing the interactions observed in SmallCADCo, the instances that negatively impacted the interactions are noted. Minneman (1991) enlists the various ways by which design outcomes emerge from interactions among individuals and groups as they establish, develop, and maintain a shared understanding. Negotiating understandings, conserving ambiguity, tailoring engineering communication for recipients, and manipulating mundane representations are identified as some of the crucial group activities. The following are identified as negative instances:

- Difficulty in visualizing articulations and features were noted.
- Misidentification of features was identified.
- Substantial time was spent in establishing common understanding. Misinterpretations were noted, time was spent in clarifying and in creating awareness to maintain a common understanding among subjects.
- Avoidance of communication was noted with some stakeholders due to fear of time consumption.
- No common software was used among all the stakeholders. Interoperability between software was an issue. It was difficult to use files across different software of the same type, e.g., CAD software.
- Identification of documents was time consuming. Tracing their locations was difficult.
- The size of the computer files made document sharing via e-mail difficult.
- Some of the required features were unavailable in some of the software used.
- Some of the required software was unavailable.
- Some of the interactions with stakeholders had been delayed or postponed due to unavailability of the stakeholders.
- The place of work was not tidy; documents were placed awkwardly and made discussion difficult.

From these observed instances, we argue that interaction will be satisfied if intended actions and reactions take place through required composition and capabilities of people, tools, process, and information (Fig. 5.4). The current situations in the observed organizations should be improved substantially by considering these factors, to satisfy interactions.

7.4 Task Satisfaction

A task is taken to be satisfied if another task, dependent on this task, is found to be carried out subsequently in the PD process. Tasks chosen based on customer preferences led to positive structuring of tasks. Tasks were found to be executed in an ad

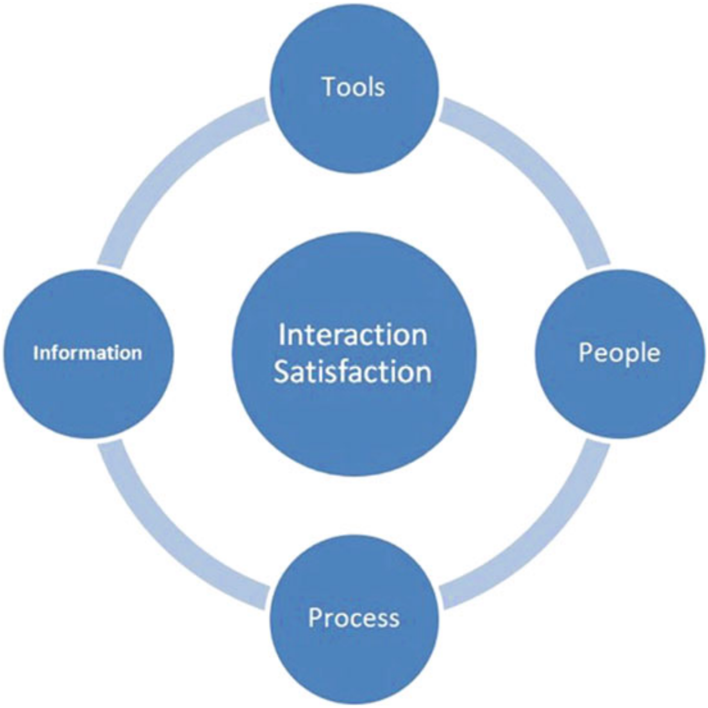

Fig. 5.4 Common merge of factors influencing Interaction Satisfaction

hoc manner, without following any formal structure. Tasks were carried out in an opportunistic, subjective fashion. Often, designers carried out new tasks without completing current tasks. This behavior led to task failure, task repetition, and iterations. The scope of tasks was sometimes reduced, and some tasks were removed due to the perceived effort and time involved in executing them. Difficulty to plan tasks and schedule timings was also observed. Assessment criteria should be modified to stress quality of the tasks' outcomes. Tasks should be executed in the right sequence to enable more effective task satisfaction, as repetitions could be avoided.

8 Discussion and Conclusions

The overall aim of this work is to support industry develop high-quality novel designs in reduced time through effective knowledge processes. Using the proposed KRIT model and Influence model, the understanding obtained on the knowledge processes involved in collaborative PD from two industrial studies is reported. This understanding should help improve collaborative capabilities of organizations, which is important for improved innovation in challenging business markets.

The KRIT model highlights the centrality of interactions in knowledge processing, something not adequately highlighted in earlier models. A major, potential benefit of this model is in representing knowledge processing in terms of interactions to develop requirements, tasks, and knowledge of solutions. These results should inform development of support to assist knowledge processes to improve work performance of stakeholders, and consequent quality. The model makes explicit and highlights the various stakeholders involved in these processes such as designers, engineers, and external consultants. The KRIT model is primarily developed to understand and support designers and industries. However, this model could also be used to study in detail the effectiveness of collaborations among quadruple helix actors (i.e., collaborations among firms, users, public organizations, and universities).

The Influence model proposed is intended to help assess the quality of collaborations and knowledge processes in PD. We argue that understanding the degree of satisfaction of interactions, knowledge, task, and requirement, collaborations should be possible to be assessed. A list of potential issues for each of these has been identified. Issues involved in data, information, and knowledge transformation are highlighted in interactions satisfaction through difficulties incurred due to lack of awareness and misinterpretation. The results indicate that substantial enhancement in knowledge processing is possible if the interactions carried out by designers during PD could be improved. Improvement in interactions and its impact on knowledge processing, however, need to be studied in detail, to provide a theoretical basis on which strategies for effective knowledge processing could be developed.

References

Ahmed S, Blessing L, and Wallace K (1999) The relationships between data, information and knowledge based on a preliminary study of engineering designers. ASME Design Theory and Methodology Conference, Las Vegas, Nevada.

Blessing L (1994) A process-based approach to computer-supported engineering design. Ph.D. Thesis, University of Twente, Netherlands.

Buchanan S, and Gibb F (1998) The Information audit: An integrated strategic approach. Int J Inf Manage 18: I, 29–47.

Chakrabarti A, Sarkar P, Leelavathamma B, and Nataraju B.S (2005) A Functional Representation for Aiding Biomimetic and Artificial Inspiration of New Ideas. Artif Intell Eng Des Anal Manuf 19:2 113–132.

Chandrasekaran B, Goel A, and Iwasaki Y (1993) Functional Representation as Design Rationale. IEEE Computer 26 48-56.

Cheung P. Chau P.Y.K. and Au A.K.K. (2008) Does knowledge reuse make a creative person more creative? Decision Support Systems 45: 219–227.

Court A.W. and Culley S.J (1995) A methodology for analyzing the information accessing methods of engineering designers. Proc. of Int. Conf. on Engineering Design 2: 523–528.

Frankenberger E, and Badke-Schaub P (1999) Information management in engineering design – empirical results from investigations in industry. Proc of Int Conf on Engineering Design 911–916.

French M. (1985) Conceptual Design for Engineers. Design Council – Springer Verlag, London, UK.

Gokula Vijaykumar A.V, and Chakrabarti A (2008), Understanding the Knowledge Needs of Designers During Design Process in Industry. J Comput Inf Sci Eng 8 011004-1–011004-9.

Haymaker J, Keel P, Ackermann E, and Porter W (2000) Filter mediated design: generating coherence in collaborative design. Design Studies 21: 205–220.

Kunz W, and Rittel W (1970) Issues as Elements of Information Systems. University of California Working Paper No. 131.

Lahti H, Seitamaa-Hakkarainen P, and Hakkarainen K (2004) Collaboration patterns in computer supported collaborative designing. Design Studies 25: 351–371.

Larsson A, Torlind P, Karlsson L, Mabogunje A, Leifer L, Larsson T, and Elfstrom B-O (2003) Distributed Team Innovation- A framework for distributed product development. Proc of Int Conf on Engineering Design.

Leonard-Barton D. and Sensiper S (1998) The role of tacit knowledge in group innovation. California Management Review 40:3.

MacGregor SP, Thomson AI, Juster NP, (2001) Information sharing within a distributed collaborative design process: A case study, Proceedings of DETC'01.

MacLean A, Young R, Belloti V, and Moran T (1991) Questions, Options, and Criteria: Elements of Design Space Analysis. Human-Computer Interaction 6:3–4 201–250.

MacMorrow N (2001) Knowledge management: an introduction. Annual Review of Information Science and Technology, Williams ME, Ed. 381-422. Medford, NJ: Information Today.

Marsh J R, (1997) The capture and utilisation of experience in engineering design. Ph.D. Thesis, St. John's College, Department of Engineering, University of Cambridge.

McDermott R, (1999) Why information technology inspired but cannot deliver knowledge management. California Management Review 41:4 103–117.

Minneman S L (1991) The social construction of a technical reality: Empirical studies of group engineering design practice. Ph.D. Thesis, Department of Mechanical Engineering, Stanford University.

Moritz E F, and Schregenberger J W (1997). How to achieve creative synergy – Contemplations, cases, and concepts in cooperative design, Proc of Int Conf on Engineering Design 2: 149–156.

Newell S, Robertson M, and Scarborough H (2002) Managing Knowledge Work. Palgrave, London.

Nidamarthi S (1999) Understanding and Supporting requirement satisfaction in the design process. Ph.D. Thesis, Gonville and Caius College, University of Cambridge.

Nonaka I, Toyama R, and Nagata A (2000) A Firm as a Knowledge-creating Entity: A New Perspective on the Theory of the Firm. Industrial and Corporate Change, 9:1.

Petre M (2004) How expert engineering teams use disciplines of innovation, Design Studies 25 477–493.

Pugh S (1991) Total Design : Integrated Methods for Successful Product Engineering, Addison Wesley, UK.

Sonnenwald D H (1996) Communication roles that support collaboration during the design process. Design Studies 17: 277–301.

Wang L, Shen W, Xie H, Neelamkavil J, and Pardasani A (2002) Collaborative conceptual design – state of the art and future trends, Computer-Aided Design 34: 981–996.