COMMUNICATION IN ENGINEERING TEAMS: PERSONAL INTERACTIONS AND ROLE ASSIGNMENT

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Preface

The area of engineering communication has received little dedicated research investigation. In addressing this issue, I have taken the approach of exploring how engineers – in this case mostly engineering students, but also engineers in consulting practices – interact when in meetings. What I discovered by the end of this journey was a set of role descriptions that characterise the types of interactions, and a circumplex arrangement of these roles.

I wish to thank my primary supervisor, Dr Dirk Pons. My second supervisor, Dr Sid Becker, although not involved in the day-to-day running of the project, was in the background providing support and willing to be involved as a backup.

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Abstract

NEED – Communication is understood to be a key professional soft skill for engineers, but the components of communication are defined poorly. The literature on engineering communication is devoted primarily to formal information flows, the medium of communication, and technical documentation. There is comparatively little attention on the process, cognitive and organisational aspects.

PURPOSE – The overall objective of this thesis was to develop a model of casual role assignment in the engineering context. Specifically, to identify how participants of engineering project meetings choose and acquire communication behavioural patterns.

APPROACH – The research approach used mixed methods – a quantitative exploratory study followed by inductive qualitative analysis. The research consisted of four phases. First, a survey (questionnaire) was used to explore levels of satisfaction in communication of engineering team members (phase 1). Next, a new observational study method was developed to capture behavioural interactions within project meetings (phase 2). This is called the interaction diagram methodology. This methodology was then applied together with a structured interview, questionnaire, and Big Five personality test, to observational studies on student engineers (phase 3), and engineers in consulting firms (phase 4).

FINDINGS – This thesis made several original contributions. *First*, a novel observational method was developed that provides a graphical representation of the interaction flow during meetings and a procedure to quickly analyse communication situations, identify group roles, and compare group activity at different meetings. *Second*, a new set of 12 team roles was identified for participants at project meetings. These were based on the literature, and further modified by our observations. We proposed that *Social sensitivity* and *Personal satisfaction* from communication interact, resulting in four broad levels of team outcome. The best is *Team coherence*, and the lesser outcomes are identified as *Reluctant cohesiveness, Parallel compensation*, and *Behavioural divergence*. *Third*, observations of team behaviour lead to a new insight into the process of team role assignment, and the creation of a new theoretical construct. This is the Team role circumplex. While circumplexes exist elsewhere in psychology and human development, there is no prior work in the area of engineering team roles. Key features of the new circumplex are the identification of two axes against which all the roles may be placed: Personal Agency/ Communion and Social engagement/ Social Disengagement. *Fourth*, communication at project meetings at university and in commercial engineering firms was compared and several distinctions in communication patterns were identified. For example, official positions consist mostly of predefined communications in industrial organisations, whereas at university participants have more freedom to choose their communication style. Furthermore, factors influencing project team communication (temporal and permanent) were determined and analysed. These factors included the communication setting of the meeting, team size, location inside meeting places, styles of supervision, and personality and demographic factors (gender differences in communication preferences of engineers). It was observed that participants of engineering project meetings adjusted their communication style to the behaviour of other people or to different communication settings. We supposed that this happens at three different levels: micro-level (grounding processes in conversation), mezzo-level (emotional and rational regulation) and macro-level (over an extended period of time).

Publications

Published:

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3. Nestsiarovich, K., Pons, D., Becker, S. Communication Adjustment in Engineering Professional and Student Project Meetings. *Behavioral Sciences*, 2020, 10(7), p. 111.

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This paper was adapted in Chapter 10.

Terminology

Artefact (boundary object): An abstract or concrete item of information (such as an engineering drawing, project plan, specification, contract for works, design file, and resource consent documents) used by people within a work community.

Circumplex: A circular order of components describing and organising interpersonal behaviour.

Communication adjustment: the process of changing a communication behaviour.

Communication grounding: reaction to the miscommunication event.

Communication interaction: a change of turn-taking among participants or change of conversation addresser.

Communion: A tendency to prioritise interpersonal relationships. Adapted from [1].

Density of communication event: Quantity of communication interactions per time unit.

Formal communication: A flow of information through channels of organisation, generally containing official messages to one or more people.

Implicit communication (non-verbal): The use of body signals (facial expressions, gestures, or voice tone) for better understanding of messages.

Informal communication: Not official communication, generally unscheduled, more interactive and with using of informal language.

Interaction diagram (ID): A paper diagram with note-taking that provides a representation of communication between team members.

Materiality: The physical medium used to store and convey information such as engineering drawings, project plans, specifications, or design files.

Miscommunication: A lack of clear and adequate information.

Personal agency: The ability of a person to put efforts to make things happen. Adapted from [2].

Slide: A part of an interaction diagram that illustrates team communication in a time interval.

Social sensitivity: An aspect of empathy that helps a person to understand feelings of others in a group. Adapted from [3].

Team role: A behavioural pattern that represents how individuals behave in a team or as a way in which people interact with one another while performing a task. Adapted from [4].

Team role adoption: A personal conscious choice of communication behaviour.

Team role distribution: A joint allocation of roles based on what the team should accomplish (unconscious process).

Technical communication: Engineering work with paper or electronic documentation.

Contents

Chapter 1. Introduction

1.1. Background

Communication is a key competency for professional engineering practice [5, 6]. The importance of this competency is evident in accreditation requirements [7] and is supported by research [6]. Engineers who can convey ideas easily work more effectively and can achieve better results [8, 9]. In this context, engineering communication is understood to include: presentations; project discussions at meetings; written communication between engineers or engineering departments, such as feedback and emails; vertical communication, such as that between superiors and subordinates, and informal communication at the workplace; and non-verbal communication [7]. Engineering communication occurs in the context of people engaged in engineering activities such as design and project management.

The importance of communication is especially high in project management when employees exchange the necessary information about the development of a project and plans for its realisation. Here, misunderstandings can result in serious failures in plans of project execution, its delay, and, as a result, financial losses for organisation. We can say that company's formal and informal communication systems is of great importance for engineering organisation and needs constant improvement.

Despite the importance of communication for the profession, there is a scarcity of studies that have examined how these interactions occur in this area. There is a wide general literature on communication theories, but this has seldom been validated or applied to engineering.

1.2. Professional expectation for communication skills in engineering

There are professional expectations for communication skills in the specific case of the engineering profession. Therefore, it is interesting to examine the meaning of 'communication in engineering organisations', and which components are the most important for future and practicing professionals. This includes the ability of team members to avoid conflicts, not engage in fierce debate during professional discussions, express themselves clearly, and not let personal biases and emotions affect the objectivity of judgment. Any observer should also consider whether it is equally important for engineers, who work directly with the equipment and the 'office' engineers, to use a variety of communication strategies. The same applies to other professionals, such as project managers, consultants, and software engineers. Each group will have its own concept of communication and its key points.

It is common in the educational process of training of engineering specialists to place a strong emphasis on the development of accepted mathematical and logical skills that will be needed in the future. However, one of the main conditions for successful work of engineers and technicians in the enterprises is that they have enough sufficient communication skills to feel confident with finding solutions in different engineering problems, expressing their ideas and participating in teamwork. For example, according to the survey [10], the richest settings in the engineering professions for communication is the area of project management, followed by law and contracts, and then environment. It was identified that whenever the project activities are involved, there is a high probability that communication will be needed as well.

The following analysis was identified from the previous work of [10]:

'Communication emerges as the single most important topic. It encompasses many media (written, spoken), and the survey did not identify its specific subtopics…We identified two main contexts [from the survey data]:

Primary association: Communication is applied primarily in the context of project management (rules 57, 58, 62, 69, 66, 68, 67, 72, 70). Statistically, this context dominates for confidence, and has the most rules in support.

Secondary association: The second tier contexts for communication emerge as law and contract (rules 59, 61, 68, 67, 71), ethics (rules 65, 70), environment (rule 60), team development (rule 56), health and safety (rule 64), and risk management (rule 63).

That research also identified several strands of further research, including [10]:

'What do professional engineers understand as important within 'Communication', and how can that be included into curriculum?'

'Conduct a longitudinal study to determine whether the need for engineering management changes with career, when, and why. Explore how engineers' ranking of the importance of management topics changes over the span of their careers'.

The requirements for professional training of engineers were expressed in such international agreements as the Washington Accord and the Sydney and Dublin Accords in the form of the International Engineering Alliance [11]. The Washington Accord of 1989 [12] recognised equivalence in the accreditation of qualification in professional engineering. The Sydney Accord of 2001 recognised equivalence in the accreditation of qualifications in engineering technology, and the Dublin Accord in 2002 outlined qualifications in technician engineering.

Graduate attributes (student level)

For students at the point of graduation, the international expectation of competency in the area of communication is: *'Communication: Level of communication according to type of activities performed. WA10: Communicate effectively on complex engineering activities with the engineering community and with society at large, such as being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions'* [11].

In New Zealand the Institution of Professional Engineers of New Zealand (IPENZ) is the professional body that implements local accreditation process, and largely follows the Washington Accord [13]. Therefore, most of the engineering universities in New Zealand align their education standards to the Washington Accord attributes, considering WA as high-level reference standard.

In particular, according to the Washington Accord all graduates must '*Communicate effectively on complex engineering activities with the engineering community and with society at large, such as being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instruction'* [11].

However, it should be noticed that Accords are worded to offer only general guidelines. They say nothing about areas of communication such as team development, environment, project management, risk management, as well as nothing is said about the importance of these areas, the results of misunderstanding, wrong perception of information and its influence on the performance of engineering enterprise.

Professional competencies (practitioner level)

At the professional level – that is, after graduation and admission to chartered professional engineer status – competency is expressed thus at the international level:

> ***'10 Communicate clearly with other engineers and others that he or she is likely to deal with in the course of his or her professional engineering activities.***
> *Uses oral and written communication to meet the needs and expectations of his/her audience; Communicates using a range of media suitable to the audience and context; Treats people with respect; Develops empathy and uses active listening skills when communicating with others; Operates effectively as a team member* [14].

Below are the competencies that the expected of professional engineers.

'Uses oral and written communication to meet the needs and expectations of his/her audience'

The ability of oral communication is the most-valued skill for employers. Good oral and written abilities precipitate personal growth and professional development. This is especially important for engineers as well as for students: '*write effective reports, write design documentation, make effective presentations, give and receive clear instruction'* [11]. However, it is still unclear which communication skill is the most important for them.

'Communicates using a range of media suitable to the audience and context'

Engineers should design a product that works well and therefore think more about functions and forms. Drawings, plans, and other material objects help to illustrate how the machine would look at each point of completion. Every engineering discipline may prefer their own medium of communication and it could be difficult for engineers with different background to understand each other. This interdisciplinary boundary communication plays a vital role in the life of engineering organisation as it defines duration and quality of knowledge exchange, job satisfaction and the quality of the organisation's final output.

'Treats people with respect, develops empathy and uses active listening skills when communicating with others'

Communication in a modern way of understanding is not only the flow of information or information exchange. It is also the question of quality of received knowledge (knowledge sharing) and how does this information being perceived and interpreted. Even if engineers possess some well-developed communication abilities, their speech or text can be misinterpreted and understood in very different ways. Therefore, engineers need empathy and active listening skills to not miss important information, possess adequate self-estimation, treat others with respect, and build effective rapport. Different social position, age group, personal preferences creates distance between interlocutors and make communication more complex. We should not forget that engineers are not just professionals, but also human beings with unique perceptions of those around them.

'Operates effectively as a team member'

The main purpose of communication is to coordinate the collective activities of multiple people. The behaviour of team members in organisations is crucial to its performance. Every engineer plays some role in professional society as part of a team. This role depends greatly on his or her social position, age, gender, and belongings to different groups, and authority among colleagues, including professional skills, and personal characteristics. Operating effectively as a team member means doing one's own tasks and performing in team roles in a way that pushes the team forward in its development, helping the organisation to achieve its goals as a result.

Sometimes, misunderstandings, technical disagreements, and even conflicts can arise between team members. However, in the context of effective team performance, these issues are not necessarily problematic. Some conflicts can be positive and contribute to the team development, as opposed to others that are destructive and distract from work. We should try to find a way to understand witch type of conflict it is and handle it in a right way. Another question – can high communication skills, especially listening skill decrease the quantity of disagreements or is the reason of conflicts belong to the area of personal relationship and professional activities?

In addition, project reviews and feedback between members of the engineering team are part of every engineer's everyday work life and a part of routine communication. Hence, it defines the level of communication success extensively. The skill to write a good review and to accept critical remarks positively can help engineers to communicate with each other better, decreasing levels of strain and misunderstanding between members of the team. Roles that involve more complex problems have information that is more ambiguous, and thus more opportunities for misunderstanding.

Chapter 2. Literature review

2.1. Overview

Topics that are associated with communication will be examined alongside the practical results.

Journal articles, conference papers, and chapters in monographs

An initial overview of journal articles and papers in the database 'Engineering village', sorted by controlled vocabulary, yielded the following results. In the most of documents communication was associated with:

- Computers – 34594 items
- Engineering education – 25517
- Internet (networks) – 12172
- Communication systems – 14460
- Software engineering – 8748
- Mathematical models (modelling, algorithms for knowledge-based systems) – 8172
- Optical fibre (optical communication) – 7070
- Design (of communication systems) – 4168
- Technology (of communication) – 3927
- Other kinds of engineering – about 2000-3000 for each one

In addition, there were articles about other topics, including learning systems, embedded systems, signal processing, and e-learning.

There are several ways of categorising and describing communication. They are called 'lenses, with different lenses of communication described in the following sections of this literature review. We shall start with communication channels and models presenting the process of communication interactions in different ways. The section 'Cognitive aspects of communication' will provide information of how people percept oral and written information, and 'Organisational aspects' will describe different forms of organising communication. The chapter defines the main features of communication processes in organisations, such as elements, skills, barriers, miscommunication problems, and professional boundaries. Cultural and demographical factors such as gender also need to be studied. Finally, there are special areas that should not be avoided as well: conflicts among team members, the lifecycle of groups' development, and specific features of engineering communication such as engineering style.

2.2. Channels and methods of communication

Channels of communication

There are many meaning of communication channels in literature. In psychology, for example, channels of communication are divided into several groups: visual, auditory, proprioceptive, kinaesthetic, relationship, and world channels. The visual channel includes information received visually, such as colour and sight. The auditory channel refers to information received auditorily. For example, sound, music, language, and tone of voice. The visual and auditory channels are subdivided into verbal (language) and nonverbal channels [15].

The proprioceptive communication channel provides information through tactile means, including pain, pressure, tension, and temperature [15]. The kinaesthetic channel provides information from body movement or lack of movement, such as gestures and facial expressions

[15]. The other two channels are combinations of the basic four: the relationship channel, including gender roles and broader social influences, and the world channel, which includes information from the outside world, such as job, family, and broader social trends (Mindell, 1985). Regarding communication in engineering, we could define verbal communication as including meetings, conversations with colleagues, phone calls, text messages, electronic communication such as video conferencing, emails, and charts, and paper documents such as job instruction, letters, and messages.

Communication channels can also be divided into written channels or recorded and verbal (interpersonal) channels. Recorded channels include formal publications, dissertations, standards, proposals, letters, and computer programs and so on. Verbal channels include informal discussions, meetings, conference presentations, reports. Some information can be obtained through several channels, such as personal contact, journal, or telephone calls. There are sources of information that engineers can use within each channel of communication [16]. Indeed, engineers can choose the communication channel. Some factors influence this choice [16]:

1. *Personal factors*: education, profession, experience, status and stage of career, demographics, working style.

2. *Situational factors*: current project, work settings, sponsor characteristics, peer communities and other similar factors.

When considering the diverse array of communication channels in organisations, we may consider how people communicate with managers and supervisors, and the channels preferred in the workplace.

Another study [17] analysed 261 employees' ratings of supervisors. The analysis showed that employees prefer face-to-face communication with leaders to the telephone or email communication. Face-to-face communication was perceived as the most effective. A study in the construction industry [18] showed that emails, meetings, and phone calls are still the main channels of communication. However, these tools were found to be not very efficient methods of communication because they may cause delays in information delivery and limitations of storage.

2.3. Models of communication

Transmission model of communication

The communication is understood as '*the process of intentionally stimulating meaning in the mind of another'* [19]. In a typical 'sender-receiver' model of communication, the information is first encoded, then transmitted and decoded. After this, the receiver should signal receipt of the message, supplying feedback if necessary. The sender is responsible for the correct and clear information, while the receiver is responsible for correct understanding. The mode of communication is also important, as it can create noises that might compromise the delivery of the message [20].

This model came from the mathematical theory of information presented by Shannon and Weaver where the receiver changes transmitted information back into the messages [21]. There is always some 'noise' during the process of sending information, meaning that the received message contains certain distortions, errors, that could lead to increased uncertainty.

Another model [22] presented communication as a social interaction where interacting agents share some set of semiotic rules; syntactic, pragmatic, and semantic. This narrow perspective emphasises the quality of information and loss of information as the reason for misunderstanding. It tends to focus on the reciprocal exchange of information quanta, such as verbal messages, emails, and text messages. Later in 1970, a transactional model of communication was developed by Barnlund [23]. The basic idea of this model was that individuals are engaged in communication process simultaneously, sending and receiving information at the same time.

Among recent ideas is the concept that information flows in organisations can be understood as a communication network between stakeholders as senders and receivers of information. The quality of such communication between primary and secondary stakeholders in the construction industry was studied by [24], and [25]. These authors defined the six most effective communication indicators that shows the quality of information flow transmission between internal stakeholders, such as owners, designers, contractors, and engineers. Important factors include the number of contractor organisations, the number of decisions made, and delays in delivery of equipment. However, the transmission model of communication has more recently been greatly criticised. It is considered by many researchers to be a very oversimplified representation of real communications [26-28].

The interpretation of communication as information exchange was very popular in the 20th century, and it provided many interesting quantitative models that proved useful in engineering and technical aspects of communication. However, it did not show why problematic situations happen, how people feel communicating at workplace, and how to organise their communication effectively. Recently, many researchers study organisational and cognitive problems of human interactions to answer these questions, although there are gaps in knowledge.

Constitutive model of communication

In recent studies, communication is presented not only as a flow of information from sender to receiver, but also as some kind of 'social reality' that is constituted by people [29]. Such a constitutive approach to communication process focuses on how people interpret messages during communication time and integrate it into their system of knowledge. In other words, communication results in the creation of shared meaning between people. It involves simultaneous personal interactions, and is more than merely the information content [30]. However, constitutive models of communication are sometimes criticised for being too broad and vague, without strict definition what is communication [31].

Communication in organisation: communicative communication in organisation approach

The main idea of communicative communication in organisation (CCO) is that 'organisation is the result of communication' and not vice versa [32]. In other words, CCO presents communication 'as the main force that creates, generates, and constitutes to what we consider to be organization' [33].

This approach argues that elements of communication are not fixed in advance, but constituted within the communication itself [34]. There are three schools of thought in constitute communication: McPhee's Four Flows, The Montreal School and Luhmann's Social Systems approach [35].

McPhee's Four Flows

McPhee and Zaug [32] identified four constitutive flows of communication that generate social structure:

- *Organisational self-structuring* – organisations coordinate some work automatically or because of pre-existing social patterns. This can include hierarchical relationships and processes that may design the organisation and its subsystems.
- *Membership negotiation* – negotiation between members of organisations.
- *Institutional positioning* – describes communication at the macrolevel, including communications with suppliers and customers. An organisation must maintain two-way communication channels with the environment outside.
- *Activity coordination* is the process of adjusting the work process and solving immediate practical problems.

John A. A. Sillince [36] pointed out that McPhee and Zaug [32] cannot distinguish organising from marketing and networking. Instead, a theory of communication must concentrate more on how organisations are formed and maintained.

These sociological theories can help to provide a method of understanding and analysing human interactions and communication, presenting organisation as consisting of four communication flows [32]: activity coordination, self-structuring, membership negotiation, and institutional positioning. In particular, activity coordination implies communication for adjusting the work process and solving problems between members or part of organisation.

Model of Henry Mintzberg

Examples of coordination are well developed in the theory of Mintzberg [37] that describes six configurations of organisational activities:

1. Simple structure. A large unit with one or several top managers.

2. Machine bureaucracy. This happens when the work is very specialised. It requires large organisational structures to design and maintain the system of standardisation; this structure tends to be centralised vertically.

3. Professional bureaucracy. This type of coordination relies on trained professionals and is found in professional organisations such as hospitals and universities. There is a need for small and highly decentralised horizontal techno-structures.

4. Divisionalised form. Consist of several units (divisions).

5. Adhocracy. A structure that relies for mutual adjustments among experts.

According to [37], these successive states of configuration and transformation create life cycles of organisations. Therefore, the main goal of management is to maintain stability, but sometimes recognises the need for transformation. Managers need to coordinate these processes in organisations.

There are five types of coordination activities (describe how organisations coordinate their work) [38]:

1. Mutual adjustment. Simple process of informal communication – people communicate with each other to coordinate their work.

2. Direct supervision. Happens when one person coordinates work by giving orders to others.

3. Standardisation of work processes. To coordinate the work, the organisation specifies procedures.

4. Standardisation of outputs. To coordinate the work, the organisation specificies outputs.

5. Standardisation of skills. Coordination achieved by learning and achieving particular skills outside the organisation. In this way, managers know what to expect from people.

6. *Standardisation of norms.* Organisational norms are controlled, leading to a widely shared set of beliefs.

The Montreal School

The Montreal representatives see communication as a dialectic between the conversation and the text. The conversation is the place for organising a process. A text, meanwhile, is an interpretive framework. The organisation therefore is the intersection of conversation as actions and text as a structure [39].

This approach also suggests that what constitutes an organisation is a hybrid of human and nonhuman contributions; a text. Texts can talk, reminding employees what needs to be done and makes them more accountable. The best way to approach discourse is to analyse the active contribution of texts to organisation al performance [40].

Luhmann's Social Systems

The central idea of this school is that society is composed of communication between individuals and social systems, and the last one creates a boundary between itself and environment [41]. Luhmann argued that social systems are autopoietic; that is, they keep themselves going.

Communication is not only the exchange of information. For Luhmann [41], it is a particular form of observation and it consists of three components: information, utterance, and understanding. *Information* refers to 'what to communicate?' *Utterance* — to 'how to communicate?', the mean of communication (words, tone) and the 'why to communicate?'. Finally, we need *understanding* to distinguish information from utterances ([41], in [32]).

According to Luhmann [42], communication occurs as a synthesis of two selections: the selection of a specific piece of information, and the selection of a particular way of understanding. There is a zone of reduced complexity inside system. Reduction of complexity happens because communication within a system selects only a limited amount of all information available outside [41]. However, other authors [43] criticised Luhman's approach because it neglects the role of material agency in organisational communication.

2.4. Cognitive and philosophical aspects of communication

According to Miller's hypothesis [44], the human short-term memory does not exceed seven to nine symbols (span of intermediate memory $\sigma_m \leq 8$). That means that we can comprehend, remember and repeat only seven things at one time. There is also an Ingve theory [45] about the relationship between the number of assimilated symbols and depth of the derivation tree, which is strictly proved in a mathematical linguistics: $\gamma + 1 \leq \sigma_m$. Comparing the Ingve theory with the hypothesis of Miller, the inequality $\gamma \leq 7$ can be obtained. It shows the relationship between the observed linguistic fact, the psychological hypothesis, and mathematical theorem [46].

Yngve [45] analysed different grammatical structures in the English language and established a 'model of sentence production'. Based on the model, he proposed a hypothesis of the depth limitation of languages. The sentences actually used in the spoken language have a depth that

does not exceed a certain number; around seven. Moreover, the grammars of all languages have rules that restrict using complicated construction in which sentences can exceed this depth. Whenever speakers make sentences with higher depth, they become trapped and have to stop and start over.

In [30], the cognitive-affective model of organisational communication was developed. According to this model, our mutual understanding depends on the 'communication complexity' (cognitive, dynamic and affective). Cognitive complexity is the function of [30]:

1) The intensity of information exchange between communicators. This can increase the probability of misunderstanding.
2) The multiplicity of view held by communicators (message can be understood in different way).
3) The incompatibility between representation and use of information (information should be translated before use).

According to the author [30], communication is a process of building relationship between sender and receiver. However, high levels of communication complexity can fail. Message form, size, distribution (the number of destinations) and the degree of message organisation (extent to which the information is ordered) influence mutual understanding greatly. Therefore, messages should be good organised to be clear, preferably with low levels of formality. A low quantity of distributed messages is more effective. Poorly organised, lengthy messages written in stressful situations also increase cognitive complexity. Senders adapt messages by increasing attention focus [30].

From a cognitive perspective [30], greater differences between sender and receiver (age, social groups, values, and languages) always increase the complexity of communication and decrease level of mutual understanding. High cognitive distance also gives high level of uncertainty about what the receiver knows. There is a correlation between personal strategy and individual attributes of message. When personal interactivity is high, messages are generally short. If the channel capacity of the sender is low, messages become formal. High task variety (complicated questions) increases the frequency of requesting information. Distance reduces quantities of communication, but can improved by the availability of computer-mediated communication [30].

Passing and parsing of information

According to some studies [47], the content of information is transmitted through the language: takes a verbal form. At the same time, it is necessary to form the idea in words in 'inner speech', then move from inner to external speech – that is, to tell. A distortion happens at each stage of information transmission: planned (100%) – expressed (80%) – heard (70%) – understood (60%) – remained in the memory (24%). Thus, the perceptual information losses in monological speech can reach 50% and even 80% [47].

Therefore, while transmitting a message verbally from one person to another, information losses increase. If the information was purely a text message, the perception losses of 70% leads to a message become impossible to decipher. This happens because 70–80% is a level of redundancy in most European languages. According to Piotrovski [47], the redundancy of the developed modern English language is 71.9-84.5%. In comparison, redundancy for Russian is 72.1-83.6%, and French is 70.6-83.4%. It should also be noted that levels of redundancy of business-style language is usually much higher; business English has a rate of 82.9-92.1%. To compare, according to the Weaver [21] the level of redundancy of English was 50% in 1948.

Perceptions of written text

According to Shreider [46], the distortion of information also occurs while reading the written text. Depending on the recipient's, message can contain different information. The information in the message also depends on the sender's intentions. Sometimes sender diverges from the traditional use of meaning to express ideas. For a sign system, there can be many models that allow to interpret the texts and many possible models of text comprehension by a recipient

Electronic texts on the internet have their own specific features. Online readers can choose information they need, decide which pieces of text to view and in what order. As a result, readers can find many reading materials from all over the world [48] created a model according to which the online reading comprehension is divided into two groups – offline (inferred) and online (observed) reading processes. In addition, the online reading processes in its turn are divided into three groups: input, process, and output.

[48] also found that reader comprehension depends on various factors. These factors include reading skills, vision skills, web skills, reading styles, and knowledge. Upon reading, people activate the Reading procedure: integrate words, phrases and sentences while at the same time they are checking their local reading coherence [48].

A 'Prism Model' was proposed to demonstrate the dissemination of information that has gone through a human during the reading process of online media information [49]. According to this model, readers' perceptions of information can be neutral, positive or negative and it is considered as subjective rather than fixed. First, it needs to be evaluated whether there is a change when comparing the incoming (input) and disseminating (output) information. Later, a change in the information requires one more evaluation to decide whether this change was positive or negative.

Another author [49] developed a 'self-perception measurement model'. When a reader receives online information (input phase), they goes through several steps back and forth between reception and perception procedures to understand, compare, ignore and absorb information (called process phase). This allows person to blend the new receiving information with their personal knowledge and believes (result in output phase).

The studies above presented communication as a simple transition of information, from a 'sender-receiver' perspective, without considering how this information may be interpreted and understood.

Personality development trait theory

The earlier developments by Cattel (Cattell, 1962, 1982) resulted in a 16-factor personality inventory. Subsequent developments reduced these to five key traits using factor analysis [50-52]. This became known as the Five Factors, or the Big Five model of personality. It is a trait theory, as opposed to the psychodynamic theory of Freud [53].

The Five factors are *Openness to experience* (high imagination, curiosity), *Conscientiousness* (tendency to display self-discipline), *Extraversion* (energy creation from external means), *Agreeableness* (readiness to compromise own interests with others) and *Neuroticism/ Emotional stability*) [50, 54]. They are assessed by a variety of personality inventory tests, e.g. the NEO-EPI [55]

There are many theories of communication that clarify different aspects of information or cognitive processes. However, most of them are about communication in general and not in engineering. There is still need in clear representation of how interpersonal communication

happens in engineering organisation, how engineers perceive written instructions, and how different groups of engineers communicate with each other.

2.5. Organisational aspects of communication

Formal and informal communication

Communication in organisations can be formal or informal. While formal communication is characterised by paper documents, instructions, meeting, and official emails, informal communication is generally mediated by physical proximity.

An experiment by [56] showed that 52% of all conversations were between people located within the same corridor, and 87% of them took place among people from the same floor in a building. In other words, the more spontaneous the conversation, the greater the likelihood that participants' workplaces are in close proximity.

Formal communication is the flow of information that goes through channels of organisation and generally contains some official message to one, several or many people. It delivers necessary substances to organisational units. However, according to [56], informal communication seems to be a dominant activity in organisations. People go to the meeting but stop on the way to discuss a problem with colleague. They generally ask a person on the next desk to find more information about production procedure rather than consult an appropriate manual. Informal communication is an important part of everyday company activities. It helps members to learn about each other and their work, supports both production work and the social relations that underlie it [56].

According to [56], features of formal communication includes scheduling in advance; arranged participants; one-way communication; use of formal language; and impoverished content. Features of informal communication are unscheduled; random participants; interactive; using of informal language; rich content.

In addition, the authors of the work of [56] found that distribution of 117 conversations in organisation were analysed. Of these conversations, 12% were scheduled, 36% were intended, 21% were opportunistic, and 31% were spontaneous. If to assume that only scheduled meetings are formal, then by tis definition 88% of the conversations were informal. Furthermore, about 50% of the conversations were unplanned, that means that participants did not know they were going to speak to each other until they physically met.

Another work reviewed the evidence from seven studies of managerial communication [57]. The conclusions were that around 50% of verbal information is unscheduled face-to-face meetings, and 12% is telephone calls. Therefore, 50% of manager’s time is used by unscheduled communication [57], reviewed by [56].

The mechanism of informal communication [58]:

- First, when a person sees the colleague, simple associations remind the person of the original need for conversation.
- Second, the colleague's presence decreases the cost of communication. The decision maker can see whether the colleague is available and has a clear channel through which the conversation can start; every conversation has its own value.

Among recent work in the area of informal communication we could mention study of Barmeyer C. [59] and Polat V. [60]. The last work presented a model of potential relationships

among team factors, such as trust, team autonomy, experience, formal and informal communication. This was done for New Product Development teams. The first study [59] was about spontaneous meetings of employees that contribute to the 'natural' information circulation in organisations. The authors used a qualitative methodology with case studies. The results showed that informal meetings can be useful for workflow planning and structuring of the day (the workday is divided into several sections between 'coffee breaks'). Also, these coffee breaks may support relationship between people and help to develop social networks. The main limitation of this work — the focus was on the positive sides of informal meetings whereas there may be also negative aspects of such communication that are not useful for organisation.

Processes of self-organisation in management systems

The great importance for management theory was the development of cybernetics as well as the theory of information in 1948 by the efforts of Claude Shannon [61] and Walt Weaver together with Norbert Wiener [62]. This theory considers only information that reduce the uncertainty for recipient. The uncertainty exists because of incomplete information, and there is a necessity of choice of one from two or more options.

The amount of information can be determined using the information entropy of Shannon [63]:

$$H = -\sum_{i=1}^{n} q_i \log p_i , \tag{2.1}$$

where N — number of elements; q_i — probability of system element; p_i — the probability of element's impact on achieving the goal.

Therefore, the information is a negative entropy (negentropy) and can be considered as a contribution to the system ordering. The 'minus' in the formula of Shannon points out that the information processes are opposite to the natural thermodynamic processes. In this way, entropy can be a measure of information that is necessary for company management and is used in situations characterised by uncertainty [63].

In the work of Prangishvili [64], the entropy was used for assessment of quantity of managerial efforts required to choose right decision. The smaller the entropy or uncertainty in the project, the less effort is needed for a manager to make a decision. The aggregate of possible states, which can get a system, is determined by the total entropy. It shows how much information is required for making decision.

In general, systems can be divided into two classes: open and closed. Ludwig von Bertalanfy [65] introduced the concept of an open management system. The open systems can exchange mass, energy and information with the environment. The closed systems are isolated from the environment. The concept of open systems, entropy and complexity are closely related to the concept of self-organisation. Any system must produce the information in order to resist entropy. On the one hand, the complexity of the system leads to an increase in entropy. On the other hands, however, a system with additional interaction links must reduce the entropy. The more complex the subject – that is, the higher its complexity – the more information is necessary to describe and manage it. Therefore, division into two subsystems occur in an open system with a complex internal structure: the dynamic (force) and information (control). In this case, the system becomes sensible to the slightest changes [65].

Pystogov [66] suggested the graph-analytical model and method of optimisation of informal information flows for industrial enterprise. A scheme of official communication processes

('communicative matrix') was built, which allowed authors to define 'generators of information power' – specialists and managers that provide growth in information resources. The work described industrial management structure as self-organisational system that is not isolated from the environment. There is an exchange of energy-information between inside world (incoming information) of company and outside (outcoming information). Furthermore, there should be a balance between these two information flows, which in turn can be calculated by using quantitative methods of research. The work [66] also provided quantitative model of information processes inside company. However, qualitative research methods were not used there; questionnaires or interviews with employees were not conducted. In this way opinions of people who work in company, there thoughts and perception of information were not considered.

It was suggested that organisations could be described as live interpretation systems [67]. Information the about external world could be obtained, filtered and processed into 'central nervous system'. Organisation is an open system that exchange information with environment, which contains some level of uncertainty. Therefore, it should seek information and develop mechanism of information processing. All kind of interpretation processes are carries by individuals.

However, other researchers [68] pointed that organisation is more than just a group of people; it has its own cognitive system and memory. Organisation is a learning system and may keep knowledge, norms, and values over time [67].

Among recent works in the area of self-organisation in social systems, we can mention a study [69] with a focus on communities: how collaborative communities manage to distribute workload between its members.

While organisational aspects of communication are well studied, only a few studies were conducted in engineering organisations. They did not provide clear answers to the questions: 'How should we organise people in engineering they understand each other better?' and 'What are the specific features of communication in engineering?' (see 2.10). Furthermore, most research works are devoted to the formal information flows. The area of informal or casual communication is still not well defined.

2.6. Features of communication processes in organisation

Elements of communication

The main unit of verbal communication is a *communication interaction*. This consists of instances of communication when participants are required to share some piece of information [70]. Each interaction has a set of participants and a restriction mode. Interaction can be *multidirectional*, when all participants interact with each other. In case of *unidirectional* or *bidirectional* interactions, people are divided into two sets: participants in one set interact only with those in the other set [70].

Coding of discussion time

It was defined five types of discussion that took place in the observed inspection meeting [71]:

- *Defect time* – recording and discussing the actual defects;
- *Global discussion* – discussion of other general topics;
- *Unresolved* time refers to issues that cannot be resolved during this discussion;
- *Administrative time* – time spent for the discussion of administrative procedure;

- *Miscellaneous time* – miscellaneous discussions of a technical nature.

For each discussion types that took place during the inspection meeting, the observer recorded its length, participants, topics, and the overall tone of discussion. Then a value was calculated for the discussion time variables [71]. It should be noted that in this study the audio recording was not available, so the researcher had problems with the accuracy of information. The researcher asked a second observer to present and to check information. For example, the division of the discussion into different types was rather subjective and obviously needed to be confirmed by a second person.

The work of Seaman an Basil [70] has some limitations: the finding were limited with only one project and authors did not continue research in different organisations, the relationship between communication efforts and the quality of communication (effectiveness) was not studied at all, as well as between the frequency of miscommunication and: a) length of every discussion part, b) number of interactions inside every type of discussion, c) other factors such as team role, social position. The work used mostly methods of quantitative analysis. It could be interesting to conduct similar research by combining both qualitative and quantitative methods of data possessing and compare results in different engineering organisations.

Communication skills and barriers

The ability to communicate effectively is the most important skill that helps people in personal, interpersonal and professional development. Basic communication skills are essential in most jobs and occupations. According to the National Association of Colleges and Employers of USA, oral communication is the most-valued employee skill for employers. Good communication skills precipitate personal growth and professional development.

A study [72] showed that many industry managers found communication skills of engineering graduates to be poor and thought they should be developed.

Communications skills are very important for engineering students because prepare them for competitive job market. According to another study [73], senior and mature students have more positive attitudes towards developing communication skills that young undergraduate students.

We could mention the following types of communication skills:

- listening ability
- resolving conflicts
- persuading a person
- negotiating to achieve agreements
- summarising
- questioning
- technical communication

Identified specific sub-sets of communication include the following. These are all items that were identified as important for engineers:

- Collaboration [74]
- Conflict resolution [75]
- Cross-cultural skills [76] [77]
- Documentation
- Verbal presentations

- Writing effective reports [11]
- Writing design documentation [11]
- Making effective presentations [11]
- Giving and receiving clear instruction [11]
- Non-verbal communication
- Staff management
- Ethics
- Electronic data exchange (technical communication).

Poor communication skills have several negative consequences. Researchers [78] estimated that communication barriers arise in around 90% of the time during problem solving. According to Riemer [78], the most common communication problems are:

- lack of knowledge and experience
- poorly defined ideas
- messily written communication
- one-sided or inappropriate communication
- differences in values
- poor listening

To these problems, we can add:

- misunderstanding due to the personal characteristics, such as age and gender.
- misunderstanding due to different education background or experience
- delay in message delivery
- lack of information
- excess of unnecessary information
- low language skills of some colleague
- technical problems with transmitting of information (Internet, computers)
- ethics and low communication culture
- information is presented ambiguously and can be interpreted in different ways

Miscommunication and grounding processes

Approaches to miscommunication

Miscommunication can be defined as lack of clear and adequate information. It was addressed in many disciplines, including ethnography, communication science, conversation analysis, and social psychology. There is also a long tradition of research of organisational communication where miscommunication was viewed as result of conflicts, desires, and values. Most of these works emphasise 'effective communication' and suggested dialogue as the best way to solve the differences. Other works studied miscommunication in different social contexts, such as gender or cultural differences in conversational styles, or person-machine communication or in clinical and organisational contexts, which relate to how humans communicate with one another [79].

Conversational analysis studies microanalysis of communication patterns, including transcripts of conversations, communication style, grounding and repair processing).

Types of miscommunication

Miscommunication is divided into misunderstanding and non-understanding [80]. Skanze [81] also added partially understanding, or understanding some part of the full intention.

Non-understanding occurs when person fails to interpret a message at all (not having any hypothesis) and is aware that it has happened. In misunderstanding, by contrast, a participant believes that his or her interpretation is correct, but not the one that the other speaker intended to obtain [80]. Misunderstanding should not be confused with misconception – errors in prior knowledge [82]. Generally non-understanding is recognised immediately while misunderstanding may not be identified until the end of conversation (or never identified) [81].

It was suggested to divide misunderstanding into self-misunderstandings, made and detected by the same person, and other-misunderstandings, made by one person but detected by another [80]. In the second case, a participant in the discourse may attempt to change other's interpretation by utterances (signs), changing previous messages, or directly telling the interlocutor that they have misunderstood or the point, in order to avoid awkwardness.

The grounding processes

Communication can be defined as a process that make common knowledge and beliefs (create common ground) [79].

As Clark [83] points out, a speaker cannot simply deliver a message and hope that listeners will understand it. Instead, the speaker must receive signals about the comprehension of information constantly. This process is called **grounding** ([83] reviewed by [79]). In order to ground information, people give evidence of understanding or non-understanding. For example, listeners can ask questions or ask the speaker to repeat the whole sentence ('Sorry, I did not understand. What did you say?'. 'Could you repeat, please').

According to Clark [83], there are at least three important factors ('grounding criteria') that define the choice of what evidence to give: the level of uncertainty, the cost of misunderstanding and task failure. The more evidence is given the less risk that misunderstanding occurs. Evidence can be positive or negative. However, there are some situations where we do not need positive evidence (lecturer does not need continuous positive evidence from all students). Negative evidence may be given in case of some sort of miscommunication, by asking questions such as 'what did you say?') [83] reviewed by [79].

In the work of [80], an utterance that tries to resolve misunderstanding is called *repair*. There are different 'turns' of repair process. The 'first-turn' is the same thing as self-correction. The 'second-turn' repair occurs when hearer makes utterance showing misunderstanding immediately after that happened. If the speaker then recognises misunderstanding and try to correct it, it is a 'third-term repair'. To show understanding, a listener may reply in a way that is consistent with the expectation of the speaker [80].

Nowadays, most of work about grounding processes in communication are devoted to human-robot [84] or human-computer interactions [85]. Interpersonal interactions are rarely mentioned.

Professional boundaries in organisational communication

Interdisciplinary communication

Interdisciplinary communication is a communication between people from two or more academic disciplines working together with the aim of generating a common understanding [86].

While there are many different perspectives of interdisciplinary communication, they mostly fall under three different notions [87], articulated by Kuhn-MacIntyre, Bataille-Lyotard, and Habermas-Klein.

Thus, according to *Kuhn-MacIntyre* [88-90], different disciplines are like different worlds; they are incommensurable, and therefore interdisciplinary communication can only happen if one learns the language of another discipline (adopt different point of view). Members of organisations may need interdisciplinary communication when they cannot solve the problem using only knowledge and ability of own discipline [87].

Bataille [91] opposed two types of communication:

- Weak communication happens through the profane use of language (reasons, identities, things) and is used to gain clear understanding.
- Strong communication arises when we cannot find the words, it appears at the moment when the weak communication breaks down.

Interdisciplinary communication may have many such 'break-downs'. After that, members should create a new style of discourse that combine previous styles from other disciplines ([91] reviewed by [87]).

Habermas [92] and Klein [86] believe that interdisciplinary communication involves the integration of two or more disciplinary languages for generating a common understanding. They think that difference is normal and may need to construct an integrated framework with shared language ([93] reviewed by [87]).

Professional boundaries

Interdisciplinary communication in organisation always involve two types of boundary-crossing ('boundary paradox'), where team members are able to exchange their knowledge ([94] reviewed by [95]). There are boundaries between team members of different disciplines and boundaries between clients, consultants, and contractors.

According to Fong [95], the *expertise* boundary can be crossed not only through knowledge redundancy but also through boundary objects (e.g. drawings, personal conversations), whereas the *hierarchical* boundary is crossed when team members value knowledge and experience of others. In the work, it was also developed a model of knowledge creation within multidisciplinary project environment. The main focus was done on the processes rather than the outcomes.

The work of Bucher [96] described boundary between professionals in healthcare field. Authors found that there are two main parameters that define boundary communication: discipline status and discipline centrality. *Professional status* is the authority (capacity) with which engineers within one discipline control the work of professionals in other disciplines [97, 98]. The authority and status increase with the exclusiveness of professional's experience and knowledge. ([99] reviewed by [96]). There is also vertical differentiation of the professional work.

Boundaries demarcate professions and sub-professions with different status and centrality. However, boundaries are not fixed and professions negotiate about them by engaging in boundary work [96].

Boundary objects and materiality in organisations

A boundary object is an '*analytic concept of those scientific objects which both inhabit several intersecting social worlds and satisfy the informational requirement of each other*' [100]. These objects can be abstract or concrete. They have different meanings in different social worlds, but also possess some common structure so people from both worlds can easily recognise them [100].

In other words, a *boundary object* is a piece of information used in different ways by different groups of people (for example, by engineers with different backgrounds). Material objects

(*materiality*) can become a boundary object if it helps people from different groups to understand each other (create meaningful information) [101]. Typical materials used as boundary object in engineering organisations include engineering drawings, project plan, specification, contracts for works, and design files.

The work of [101] explored boundary objects in design engineering. The author pointed that objects play vital role in team communication: engineering sketches and drawings act as 'social glue' between individuals and engineering team, facilitate the understanding of the alternative meanings among members of group. In contrast with other specialists, engineers rely more on visual representation. Drawing and sketches can create for them a link between visual information and nonverbal tacit knowledge, socially organise the work process. Sketches are the most important carriers of visual knowledge because engineers need them to think and to construct new design. Sketches assist in communication (shared cognition) and help engineers to understand the parameters of engineering project. Pictures or writing can be a carrier of some concept [101].

In the work of Beth A. Becky [102] the workplace interactions and using of organisational artefacts (engineering drawings, machines) were examined in problem solving across boundaries between engineers, technicians and assemblers. The research method used in this work was observation of participants during the same time period (a year), together with formal interviews for clarifying details. It was found out that in this engineering organisation, artefacts were widely used for problem solving between occupational communities. The drawings were used as boundary objects between engineers and technicians because both communities had some experience and felt comfortable with them. The machines were used for communication between technicians and assemblers. However, when engineers and assemblers needed to communicate and find common decision, they used machine more often than drawings, because the language of drawings were too abstract and unfamiliar for assemblers. The author concluded that boundary objects work more effectively when they are tangible and concrete. However, there can be situations in which tangible objects are not sufficient for creating mutual understanding or common ground [102, 103].

In addition, boundary objects can represent the authority of some group. For example, in a previous case, using drawings by engineers helped the group to maintain their status as experts. Technicians regularly participated in the drawing processes too; however, their suggestions should be approved by engineers. Hence, the authority of technicians was lower than engineers' but higher than assemblers who cannot make changes to the drawing project. On the other side, control of the machines gives opportunity to technicians to challenge engineers and maintain authority over this area. Therefore, artefacts serve both as the means to reinforce and maintain authority. Finally, material objects have jurisdictional function and represent the legitimacy, valuing the work. Every drawing had label with engineer's name and so engineers' performance was evaluated on the basis of them [102, 103].

The work of [104] explored the role of boundary objects in new product development. Boundary objects were described as a means of representing, learning, and transforming knowledge to solve existing problems at a boundary. The author observed in practice how people with different roles (sales worker, design engineer, production technician, and manufacturing engineer) used materiality and how knowledge was created and structured through this. As a result, there was made a list of 'objects and ends' used in different areas of engineering practice. 'Objects' refer to the collection of artefacts that individuals create or manipulate. 'Ends' are the consequence of this manipulating (sales contracts, assembly process certification, etc.). In design engineering, the main objects are technology, drawings and parts (materials) [104].

The role of full-scale mock-ups as boundary objects in innovative construction were studied in [105]. This work showed that concurrent location of teams and objects and focus of team members on experimentation rather than on task completion helps them to solve a problem quickly and to work effectively.

An innovative approach towards concept of boundary objects was represented in the work of [106]. The author investigated the use of visual artefacts in organisations to represent time. These timelines – for example, Gantt chats – can work as temporary boundary objects because they allow different groups of people (at boundary) to negotiate and coordinate their work.

Zeiss and Groenewegen [107] made a preliminary exploration of the articles and journals with the concept of boundary objects for the period 1989 until 2008. They found 442 works. That shows that this concept was very popular everywhere and was used in many different fields; it is still popular today. However, this approach was transformed so far from its original formulation by Star and Griesemer [100] that its utility is under the question now [107].

As mentioned by [108], the concept of boundary objects is frequently misunderstood. Boundary objects can be used not only for interdisciplinary communication: they reside between two different groups (communities) where they are bad structured; these groups maintain object's identity as a common object and make them more specific and therefore useful for NOT interdisciplinary work [108].

Initially boundary object is an action (movement) between two forms and not a thing: *'When the movement between the two forms either scales up or becomes standardized, then boundary objects begin to move and change into infrastructure, into standards and things'* [108]. The role of boundary objects in interdisciplinary communication was studied in many other works [86, 87, 100, 104, 109-111]. Meanwhile, [110] observed 23 scientists in several research institutions involved in project collaboration and engaged in cross-disciplinary communication in biomedical engineering. Semi-structured interviews were also conducted with all 23 members of the research community.

In cross-disciplinary collaboration, boundary objects work as translation and transformation devices between different worlds and ways of thinking. Professional boundaries are potentially problematic for understanding, but must be understood if they are to be overcome [110]. The work of [111] examined the cross-boundary communication and using of boundary objects in product development. According to the authors, engineers discussed their projects to understand each other's activities, coordinate their actions, and make decisions, and that frequently involved using of boundary objects. They generally create objects using their perception of other specialties' values and the level of resistance (possible conflicts) that they expect to face in this communication. There are two different strategies for creation of boundary objects: *a strategy of ambiguity* – production of ambiguous objects meaningful to everybody, and *a strategy of clarity* – production of clear boundary objects forcing competing specialties to accept a specific outcome [111].

A strategy of ambiguity includes different *motives* [111]:

- *Establishing future design directions* (discussion of future models). This kind of boundary object is always ambiguous and therefore can be understood in different way by different specialists.
- *Promoting compromise.* Engineers create boundary objects to promote compromises: let other colleagues to make changes to initial models.
- Avoiding potential conflicts.

According to [111], there are two types of *design activities* used to achieve ambiguity: *simplifying data* and *eliminating* of *unnecessary data*. They are needed to support multiple meanings of objects while making them easy for understanding for different specialists. Engineers use the *strategy of clearance* when they expect resistance from their peer, therefore create an object that is clear enough to force others to follow their ideas.

The role of boundary objects in creating a common knowledge across cultural boundaries was explored in the work of Di Marco and others [112]. To examine this, authors observed and analysed design review interactions between engineers from the United States and India. An interaction was defined as a situation when one participant refers to another participant or to a boundary object. The focus was on how engineers of different nation use boundary objects for communication. It was discovered that objects play a central role in negotiating and may decrease quantity of misunderstanding and conflicts [112].

Among recent work in the area of boundary objects in organisations, we could mention the book 'Discursivity, relationality and materiality in the life of the organisation: Communication perspectives' [113]. The authors introduced a 'communicative approach to sociomateriality (information technology)' when boundary objects are seen as an expression of important matters in conversation. The work had focus on how social (digital) and material objects work together in organisational communication.

Communication and project success

Projects and project management are at the centre of engineering organisations' objectives. The communication among team members are vitally important for project success. That is why the correlation between different factors and project success has always been popular area of research. Project success and individual communication was studies in the work of [114]. The authors found that the frequency of communication among participants, the project centrality in communication network, and the interproject cohesiveness are positively correlated with project success. Moreover, the frequency of communication has the greatest impact on it than both project centrality and diversity of communication [114].

Another author [115] explored communication patterns among members of engineering project team (new product development). The authors used observation method, and as a result created a link scheme of communication processes. They used circles and different width of line to measure intrafunctional and interfunctional levels, and the loading of every communication channel in project discussion. These schemes were then used to compare communication patterns of several teams with different organisational functions [115].

Prescott and Pinto [116] identified ten factors related to the project success: project mission, top management support, project schedule plan, client consultation, personnel, technical tasks, client acceptance, monitoring and feedback, communication, and trouble-shooting. Authors tried to measure the impact of every factor on the project success at every level of its lifecycle (conceptual stage, planning, execution and termination of a project). The factor *Client consultation* (communication, listening and feedbacks) was found to be critical during the conceptual, execution and termination stages. On the other side, *Client acceptance* was critical during the planning stage. The authors made conclusion that project team should first listen and then ask questions to develop communication skills, then sell ideas and then listen and listen again [116].

Summary

Previous works provided rather clear explanations of different objects, activities and strategies that engineers use at the boundary. However, the questions of choices of this objects and strategies were not discussed sufficiently. What influences the engineers' choice? What is the role of discipline status and power in the boundary communication and boundary objects' production? How does complexity of discussion influence the cross-disciplinary communication processes and change the perception of proposed information?

It can be argued that frequent use of drawings, plans and presentations can help engineers to understand each other better. Engineers understanding of processes is a schematic rather than as a process-based understanding. They are most concerned with form, fit and function because they should design a product that works well. Engineers' knowledge is centred on creating drawings that illustrate how the machine or construction would look at each point of completion [103]. However, engineers from different disciplines and with different positions and team roles may use different materiality to illustrate what they would like to say. Electrical engineers, for example, are used to electrical schemes and presentation of processes made in mechanical way may lead to increasing of misunderstanding rather than helping in sharing common knowledge. Therefore, the question is 'which material object is the best suitable to be a boundary object for communication between engineering team?'

There are also many works devoted to the conversational analysis and grounding (adjustment) processes in communication. However, most of them study theoretical issues of these questions. It could be interesting to see how these processes work in engineering conversational practice. Other unsolved questions are: 'What is the influence of team role and background on the communication processes during engineering meetings?'

2.7. Gender aspects of communication

From a cognitive perspective, differences between people, such as age, gender, values, and languages, always increase the cognitive complexity of communication and decrease the level of mutual understanding [30]. Of these social variables, the most extensively researched is gender. These are mainly from biological and sociological perspectives [117-120].

Communication style and skills

It has been shown that men are more likely to communicate for control (instrumentally), while women communicate more for pleasure and relaxation, expressively, with a higher level of affection [121]. Men need to gain more compliance from colleagues, as they are more competitive and put greater emphasis on the efficiency of work and personal achievements, whereas women are more relational oriented [122]. In addition, [123] proposed that males communicate concerning coordination and establishing their position in society, trying to follow some rules of conversation.

Women in general have higher ratings in communication. This means that they have shown a greater capacity to talk and keep people informed. They rate higher for empathy and feedback, preferring to give and to receive detailed information, than male counterparts. In addition, they have more critical minds and always try to set high standards in production [124]. In other words, males tend to be talkers whereas females are more inclined to listen. However, there are gender norms that dictate that men must emphasise their achievements in conversation, whereas women are supposed to be modest [125].

Other works also showed that men talk more in a public context – at meetings, for example – and tend to determine the agenda of conversation, whereas females talk less in professional situations [126, 127]. Feminine speech styles are softer, and engage more in informal and private talking, building relationships, avoiding conflicts, and often seeking approval [119, 128].

Females rate higher on people-oriented skills (listening and talking, free-flowing interactions and collaboration) and males on business-oriented leadership [124, 129]. Females use overlaps and minimal responses to support the conversation [130]. However, some researchers disagree about females' talkativeness. In the study in reference [131], an experiment with students was conducted that showed that women and men both use approximately 16,000 words per day. In addition, men and women use the same number of words in electronic communication [132].

Nonetheless, gender differences in communication at the workplace still exist [133]. Due to biologically different brain functions, men prefer to discuss one topic at a time, whereas women can focus on many. In addition, males have a greater concentration on tasks and therefore use neutral or negative tones in conversations, whereas females worry more than males about relationships and generally prefer warm and polite tones [122].

Language

There are language differences between gender groups. A data analysis revealed that females used more tag questions than males [125, 128]. In addition, women demonstrate more disclaimers than men and prefer a direct way to express their opinion in writing [134]. Females like to talk in high-pitched voices for physiological reasons, whereas males generally use falling intonation to show their confidence and even power [128].

Another researcher [135] analysed five meetings at a university and found that men take longer turns than women. It was also noted that men use more jokes in conversation, slang and swear words than women [125, 136]. There are also other language differences: for example, women are good at using colour words and adjectives [128].

Written communication

It was asserted [133] that women use 50% more words than males in written communication. Women's resumes are generally longer but shorter on details: 91% of males describe their high job achievements, but only 36% of women do this [133, 137]. However, [138], tested this idea and did not find any statistically significant differences between males and females in the number of words and sentences in the written text. It was only found that females use a more positive tone in written communication than males.

Self-promotion and self-confidence

As for linguistic style in corporate life, Peters [139] proposed, based on focus groups, that women are less likely than men to self-promote and are therefore less likely to be recognised. In addition, females generally prefer to request rather than issue orders, and that can be perceived as a sign of a lack of self-confidence for many people; therefore, in management, women are forced to change their linguistic style to a more command-oriented form [130, 139]. To solve this problem, organisations should develop a shared conversational management style.

Vertical communication

In the matter of conversational turn-taking between a supervisor and subordinates, it has been shown that male subordinates generally had more turns, more often interrupted each other and

talked longer than the female supervisor [130, 140]. Women prefer to speak in a way that minimises the status difference with subordinates, whereas men try to maintain these distinctions [141]. According to a recent study [138], males use a more negative tone in written communication with subordinates than do females.

In addition, it was found that gender groups often choose a different way to give orders to subordinates: women tend to soften their demands, whereas men's speech is more direct [119, 142].

Visual-spatial and verbal abilities

Several studies were conducted in this area [143-145]. The general findings were that men have a higher visual-spatial ability and visual-spatial working memory, whereas women have higher verbal ones. Moreover, men's spatial visualisation is negatively correlated with their use of drawings and positively correlated with their use of visualisation; the reverse is true for females [146].

Gender based style preferences in engineering communication

While corporate communication is well studied, the literature is sparse regarding engineering communication specifically. Most works describe technical communication systems, as opposed to the differences in communication style and communication preferences. The literature that does exist relates primarily to gender differences regarding interactions with information and computer technology (ICT). For example, as recently as 2019 the comment was still being made that 'There is a dearth of nuanced understanding of women's ICT usage and their own perspectives and worldviews – mental models – on a possible intersection between gender and ICT in their communities' [147]. Engagement with ICT is a recurrent theme in other papers such as [148] (N= 2429 school children, females prefer messaging, males games), engagement with social media (N=216) [149], programming performance of school children (N=217) [150], website feature preferences (N=56) [151], multicultural differences in ICT communication media (but excluding gender) (N=184) [152], list server participation [153], and gender-ethnic cultural expectations (N=4 qualitative) [154]. A few earlier papers do exist on ICT preferences of students by gender, such as [155-157] but their finding may have been overtaken by the rapid changes in ICT media since those times.

Regarding engineering, the literature on differences in gender preferences (or styles) in communication is extremely cursory and can be summarised as follows. First, female engineers students are more negative about team experiences in design projects (N=200) [158], women students sometimes felt excluded in team interactions (N=2, qualitative method) [159]. Second, male student engineers are harsher than non-engineers in their judgement of female speech [160]. Also of interest, though somewhat peripheral to the current topic, is work done on exploring gender differences in motivation to student design projects (N=164): the differences were not marked [161], and this did not directly involve communication as a variable. Third, there is some recent work examining linguistic preferences in technical writing, which found female students used adverbs and passive verbs in different ways to male students (N=87) [162]. Note that all the above works examined students not practicing engineers. There appears to be no literature whatsoever that examines gender preferences for communication among practicing engineers.

Summary

Gender underpins similarities in some areas and differences in others. It also forms the basis for the development of common understanding and hence shared language. Colleagues and co-workers of both genders may have different communication styles and preferences that result in misunderstanding.

However, it should be noted that while corporate life is rather well studied, there is no available information about engineering communication in particular, as most of works in this area describes technical communication systems.

2.8. Cultural aspect of communication

How culture affects communication

Communication and culture influence each other reciprocally. Cross-cultural communication is often problematic due to the different value systems and communication style among people of different nations. Moreover, different reactions to misunderstandings may intensify the impact of this misunderstanding.

Communication style is a set of communication patterns that are understood to be typical for some nation. This is connected with cultural issues – certain social factors, such as the country's status, history, religion and traditions [163]. The culture in which people was socialised influenced on its communication style. These styles are [164]: direct/indirect, personal/contextual, elaborate/succinct, instrumental/ affective:

- A *direct* communication style means explicit verbal expression between interlocutors. In *indirect* communication, participants express their ideas implicitly, using hints and words like 'perhaps', and 'maybe'. The listener is expected to monitor the nonverbal communication.
- A *person-centred* (personal) communication style is informal and emphasises individual relationships. The *contextual* style is more formal, status and role oriented with information that is not explicitly expressed [164];
- An *elaborate* communication style implies the use of rich language, metaphors, and idioms. The main characteristics of the *succinct* style are frequent pauses, silence and 'low key' verbal expressions.
- An *Instrumental* communication style is goal-oriented and sender-focused. An *affective* communication style is process-oriented and listener-focused [164].

These styles are present in all cultures. However, one particular style may be considered more appropriate in a given situation.

There are two basic approaches to the study of communication and culture [165]: ***emic*** and ***etic***. In the first approach, the communication is studied from inside the specific culture – how does members understand own language and traditions. Most of works with ***emic*** approach belong to the ethnography of speaking. It focuses on the distinctive patterns of communication and rules that are used inside a particular speech community. The second approach focuses on understanding communication by comparison of two cultures (from outside). Most sociological and psychological studies are epic, whereas most anthropological research tends to be emic [165].

Generally, *emic* research examines one culture but sometimes it uses a comparative perspective. One of good example of this is Hall's distinction between low and high-context culture [166]. In

the work, the differences in communication style were explained through categorisation cultures into different groups: *high-context* and *low-context*.

Communication style in the *high-context culture* (HC) is determined by the closeness of human relationships, well-structured social hierarchy and strong behavioural norms. The information in this style is not explicit and hidden deep in the text so listener is expected to be able to read 'between the lines'. People generally speak one after another and the speaker is seldom interrupted [167].

According to [164], this kind of communication is indirect, ambiguous, harmonious, reserved and understated. Communication involves non-verbal aspects to a greater extent [166].

For example, communication styles in any regions of India follow a high-context culture discourse. In most Indian languages, such as Hindi and Marathi, people use respectful forms of words when speaking to elders. The purpose of communication for Indians is to maintain harmony and forge relationships, not to exchange exact information. However, Indians differ in communication style from East Asian countries like Japan, China or Korea by being more verbose and dialogue-oriented ([168] reviewed by [163]).

In a *low-context culture* (LC), meanings are stated through language explicitly. During communication, people expect explanations when something is unclear [163]. Also, in low-context culture it is thought to be normal to ask questions whereas in high-context ones it is too personal and even rude [169]. New Zealand, Britain and Australia occupy a middling position in this scale [170].

However, many immigrants in New Zealand work in different positions in engineering organisations. Misunderstanding can occur due to differences in culture and communication style among colleagues. For example, colleagues from many Asian cultures are softer with their colleagues, rarely trying to persuade and having more developed listening skills. In Western cultures, by contrast, engineers are more active in communication, seek more frequently to persuade and insist [171].

Etic approaches generally use *dimensions of cultural variability* to explain differences in communication styles. There are many dimensions used in different studies, for example, Kluckhohn values [172] with five basic orientations: human nature, man-nature, time, activity, and relational orientations.

However, the most popular is Hofstede's dimensions [173]. According to Hofstede, '*culture is collective programming of the mind witch distinguishes one group or category of people from another'* [173]. Hofstede presented a model in which worldwide differences in national cultures are categorised according to five independent categories or dimensions [173, 174]:

- *Power distance (PD)* – the degree of inequality among people. Relatively equal societies have small power distances, while among unequal societies the distance widens. Individuals from high PD cultures accept differences very easily as a part of society, whereas members of low PD culture feel stress.
- *Individualism-collectivism.* In individualistic cultures, the values and needs and goals of separate persons take precedence over the values, needs and goals of groups. In collectivistic cultures group values are more important. In collectivist societies children learn to respect the groups to which they belong; generally the family. When children grow up, they remain members of their groups, expecting the group to protect them. In individualist societies by contrast, a child learns early to think about his or herself as 'I',

not ‘we’. It is expected that one day they will stand independently, without protection from the group’.

According to [175], people in collectivistic cultures have only a few general in-groups, such as their work groups or families, that influence them strongly and apply different value standards. People in individualistic cultures, meanwhile, tend to be universalistic. They take part in many in-groups and apply the same value standard to all, using the same communication style for all interactions [165].

- *Masculinity-femininity*. A culture with high masculinity places a high value on maintaining power structures. Quality of life and maintaining warm personal relationships are less important. People from highly masculine cultures, such as Korea, Japan, Italy, Switzerland, and Mexico tend to have less contact with members of opposite sex during the period of growing up as they found significant differences in communication.

In cultures where femininity predominates, such as Chile, Denmark, Norway, and Sweden, people value fluid gender roles, quality of life, and service [165].

- *Uncertainty Avoidance (UA).* People in cultures with high UA, such as Korea, Japan, France, Spain, Portugal, and Greece, generally have low tolerance for ‘uncertainty and ambiguity’ and try to avoid it. They feel greater anxiety in uncertain situations, and a greater need for formal rules and absolute truth. They are also less tolerant for people with deviant behavior. Low-UA cultures, meanwhile, such as Canada, India, Denmark, and the United States, are more ‘easy going’. They are more accepting of uncertainty and are more tolerant of unusual behaviour of others. In addition, they tend not to show strong emotion when unusual behaviour arises ([174] reviewed in [165].
- *Long-term/short-term orientation.* In a long-term culture, people have values that are more oriented towards the future, such as savings and persistence. On the short-term side, people are more concerned about the past and present, such as respect for traditions and fulfilment of social obligations.

Other works with etic approaches

The study by [30] described the difference in communication styles between Western, individualistic culture, and Eastern collectivistic cultures. In Western culture, the individual goal is dominant, and ties between people are weak. This is associated with low-context communication, which is precise and direct. Collectivism in many non-Western cultures, by contrast, is associated with high-context (tacit) and more frequent communication [30].

Lewis [171] divided cultures into three groups: linear-active, reactive, and multi-active. Linear-active cultures are calmer and more decisive. They are task-oriented, highly organized, and prefer doing one thing at a time. They stick to facts and information that they got from reliable sources. This cultures prefer direct discussion, speaking and listening in equal proportions ([171] reviewed by [163]).

Typical multi-active traits are warmth, emotionality, and impulsiveness. They can do many things at the same time, such as speaking and listening, and feel uncomfortable with silence [171].

Reactives prefer compromises. They are good listeners, preferring to listen first in order to establish both their own and the other’s position. They often seem slow to react after a presentation or speech and they try to avoid confrontation ([171] in [163]).

The analysis of literature shows that people from different countries communicate in different ways and with different communication styles. That may influence all aspects of work in

engineering organisations, lead to misunderstandings at workplace and even conflicts. Therefore, cultural issues are of great importance for people, especially in such multinational countries as New Zealand. This area is a relatively new field for study, with almost no work about cultural problems in engineering communication.

2.9. Unique features of engineering communication compared to other professions

Professional bodies of knowledge

Engineering management

The Guide to the Engineering Management body of knowledge [176], gives some basic knowledge about communication in marketing and nothing much on its other areas.

Risk management and Project management include communication within their bodies of knowledge [20] [177].

Risk management

Risk management methods specifically include communication [177]. Another source of information about communication in engineering are standards: 'Communicating and consulting about risk' [178], 'Managing risk in project. Application guideline' [179]. 'Risk management. Principles and guidelines' [177] and others. They focus mainly on communication with stakeholders – that is, how important it is to possess correct information about risk because stakeholders make their judgment based on their perception. These perceptions vary according stakeholders' differences in need and values [177]. A stakeholder is identified as a person that is affected be a decision or perceive themselves affected [178].

The message itself is less important than how it is interpreted. There are many factors that influence success of communication: context, culture, knowledge, language, motivation, complexity of message, etc. People estimate the probability of an event by its similarity to another kind of event [178]. To summarise, these standards talk mostly about subjective risk perception and about general criteria for good risk communication.

Project management

Another source of information is '*A guide to the project management body of knowledge*' [20]. It is a recognised standard for project management and includes established methods, norms, key concepts and techniques used in managing project. A chapter on 'Project communication management' provides information about basic communication activities during the project conductance, tools and techniques.

Project managers spent much time communicating with external stakeholders, such as customers, other projects, organisations, and the public, and internal stakeholders within the project. Bad communication leads to delayed message delivery, insufficient communication with stakeholders, and misunderstanding of the message. The project manager should consider the number of potential communication channels [20].

There is a general overview of common communication types and methods in project management, however, deep analysis of the communication processes has not been done. Different types of managers' and engineers' areas of work were not considered.

Engineering style of communication and main communication problems

The lifecycle of engineering communication and time distribution

The communication cycle of engineers were depicted by [16]. The main ideas were: that the work performed by engineers is the middle of cycle; that information input is defined by the effort or time that engineers need for information assimilation; and that information output is measured by the amount of presentations and the time that engineer need to prepare them [16]. Authors agreed with Pinelli et al ([180], who argued that engineers spent focussed more on their 'output' of information than on 'input' at different stages of project.

Many studies claim that engineers spent most of their time communicating. Thus, estimates range from 40 to 66% of their work time in [181]. Other authors, such as [182] pointed out that as much as 75% of time is devoted to communication; this time is increasing. A study of members of IEEE [16] found that electrical engineers communicated 58% of time with other employees working on the same project; less time – with other inside employees (2%) and with people outside the company (22%).

Moreover, according to Vest, Long and Anderson [183] about 62% of communication in organisations happens with work peers – 24% with supervisors an only 14% with subordinates. Forty per cent of communication occurs on a face-to-face basis, with the remaining time devoted to writing emails, telephone, and so on. Over a half of external communication happens by telephone ([183] reviewed by [16]).

Comparison between communication styles of engineers and those of other professions

According Tenopir and King [16], there is a difference between engineering communication style and styles of other professions. Engineers tend to use more interpersonal and informal communication channels. The reason for this may be the nature of engineering work, personalities, and different learning styles, such as listening and discussing rather than observing and reading. Engineers also tend to be self-sufficient and use a direct approach in their work.

Indicators of good engineering communication [16]:

- Engineer productivity and amount of communication are correlated.
- Engineers' with work that was recognised or awarded tend to communicate more.
- Developed communication skills lead to better career opportunities.
- High communication level results in higher quality work and better performance.

According to the authors, science information doubles every 15–20 years [16]. That means that engineers should always learn, and communication is necessary component of this learning processes. Also noteworthy is that engineering communication is very complex due to the many tasks performed by engineers (research, design, development, production and so on). Every of these activities need information and communication as a resource. And the result is often an information that should be communicated to others.

The book [16] also gave suggestions for improving engineer's communication:

1. Increase the education levels of future engineers. They should be trained how to communicate effectively.
2. Engineering organisations should promote better communication, improving information channels, sources and services to train engineers in communication.
3. Engineering societies and Web-based services should be adjusted to accommodate engineering needs.
4. Designing of flexible communication systems inside organisations.

Main communication problems in engineering organisations

It was offered a list of main communication problems (breakdowns) in engineering companies [184]:

1. Not understanding the whole picture

- Lack of awareness of tasks that need to be done and information history.
- Lack of awareness of how information is applied and changes to process.

2. Missing information provision (engineers are not told what they need to know)

- No feedback of information provided.
- No status information. People do not understand whether this information is important or not.
- Power structure excludes viewpoints.
- Information is consciously withheld.

3. Information distortion

Sometimes information is passed via many people in big organisations, until the information finally reaches the recipients. The generator of information may not know the final recipients, their needs, or their backgrounds [184].

- Information is oversimplified. Different team members may have different criteria for what information is relevant.
- 'Chinese Whispers'. If information passed on orally the details or emphases are likely to be changed.
- Hierarchical communication paths. In many companies, information is passed on along hierarchical levels. Each person selects information from original message, so that little information reaches its final intended destination.
- Expertise of intermediary. The people who pass on the information may not have enough knowledge or background to interpret it in right way.

4. Interpretation of representation

- Interpretation of ambiguous information is based on context. People interpret information based on their own experiences.
- Recipients are unable to extract the required information from representation. Many kind of information can be displayed in different ways [184].

Communication is understood to be a key soft skill for engineers, but the components of communication need to be defined more clearly. The list of communication problems and the statistic of time distribution during communication at workplace in modern engineering organisation should be updated. The cycle of engineering communication is mostly unexplored.

Other engineering communication problems

The process of communication in the specific context of engineering teams was investigated from multiple directions:

- *Technical problems in communication.* Engineering communication has been mostly seen as a technical process that includes software problems [185], communication protocols [186], engineering communication networks [187], and developing electronic communication skills [188].

- *Miscommunication.* Main communication problems of engineers was described in the work [184]. Also, communication problems in automotive requirements engineering were identified in the work [189].
- *Engineering communication skills.* The literature to date has devoted extensive attention to the problem of gaining communication skills for working in engineering industry [190, 191].
- *Artefacts (boundary object) in engineering communication* were studied in many works, such as [192, 193].

However, for the specific problem of *team roles in engineering,* the literature is sparse. The field is dominated by two studies, both from the perspective of business process re-engineering (BPR). This is a type of change-management application and it is unclear how this applies to other engineering situations [194, 195].

2.10. Key insights gained from the literature review

Our understanding of the literature suggests that the following relationships exist:

- Communication can be presented in two different ways: as information exchange and as cognitive process.
- Communication in engineering organisations may have some specific features.
- Material objects can be a suitable mean for clear communication.
- Background, team role and social position affect the discussion processes.
- Cultural aspects and personality affect communication styles.
- Gender roles are likely to be significant.

We shall return to these factors later as part of the theory-building process.

2.11. Research gaps (unsolved problems)

1. There are several research works devoted to the assessment and improvement of communication in organisations. However, in most cases, they are concerned primarily with information systems modelling and technical communication and not personal interactions between engineers.

2. The majority of studies in engineering communication today are devoted to the formal information flows and technical communication. The area of informal or casual communication is insufficiently explored. Informal flows are generally an object of research for psychologists, and models of the management offered by them have verbal character.

As this shows, the engineering perspective of communication is focussed primarily on the medium of communication. There is comparatively little attention on the process, cognitive, and organisational aspects:

- The unknown issue with *process* – there is not enough information about the nature of communication barriers and disagreements during communication processes, team roles emergence in small group of engineers.
- The unknown *cognitive questions* are how engineers perceive work information during interaction with those from other fields of practice and roles in organisations. Most of works in this area are devoted to managers in social companies.

- In *organisational issues:* there is a lack of clear instructions about what strategies engineers use to check others understand a situation in the same way they do. What triggers them to pause and check? Which organisational measures can be taken to provide better understanding among members of the engineering team?

3. There are many theories of communication that clarify some aspects of information or cognitive processes. However, most of them are about communication in general, rather than specifically in engineering. There is still a need for clear representation of how interpersonal communication happens in engineering organisation, how engineers perceive written instructions and how different groups of engineers communicate with each other.

4. Previous works gave rather clear explanation of different objects (artefacts), activities and strategies that engineers use at the boundary. The questions of choices of these objects by engineers of different roles and positions have not however been sufficiently discussed.

5. Cultural aspects of communication have received little attention – there is almost no work about cultural problems in engineering communication.

See Chapter 9 for research gaps in team role assignment.

Chapter 3. Approach

3.1. The general context to the research question

The primary goal of the research was to find a way of increasing the efficiency of communication between engineers at project meetings. To do this, we developed a theoretical model of communication management. This was a complex problem because it included many aspects of engineering interactions: communication skills, styles, phases, mediums of communication, and interdisciplinary problem-solving.

The goal was worth achieving because of the potential to help engineering practitioners be more effective personally, help organisations to create more pleasant work environments, respond to clients more quickly, and minimise errors; these advantages would improve overall performance. A better understanding of team roles also has the potential to inform teaching practices and hence prepare engineering students for future professional work in organisations.

We were interested in team communication practices where members of the team were students or engineers of various role, whether social roles, group communication roles and organisational positions, with different backgrounds and purposes.

3.2. Specific purpose of this research

The overall objective of this thesis was to develop a model of casual role assignment in the engineering context. Specifically, the objective was to identify how participants of engineering project meetings choose and acquire communication behavioural patterns.

Research questions

- How do organisational duties (rules) predefine communication at project meetings?
- How are team roles formed (over time) and distributed among members? What communication patterns may indicate or predefine the adoption of team role?
- What is the difference between communication styles at project discussion meetings in engineering organisations vs. a university setting?
- How do factors such as physical location in the room, and status within a group influence team communication?
- How do engineers use material objects for communication?
- How, if at all, do engineers change their communication behaviours over time?

The areas under examination were (a) student teams at university and (b) engineers in professional practice, where interactions occur between people as they work on complex projects. The latter group included representatives from consulting and manufacturing disciplines.

The communication events of interest were student final year project team meetings at university, and the project design meetings at the commercial organisations. The former involved student engineers of similar backgrounds and academic years of study, plus a supervisor, whereas the latter included engineers of diverse organisational positions.

3.3. Research methods and paradigms

We used *mixed methods research* – a quantitative exploratory study followed by inductive qualitative analysis, and therefore two different paradigms.

Qualitative methods were used in this study because the data to be collected was mostly of a qualitative nature, capturing the behaviour of people at the meetings and their team roles. We combined multiple data collection methods (observation, interviews, and questionnaires) that allowed the evaluation of engineering communication from different perspectives. This is similar to the approach taken by [195].

Quantitative and qualitative research approaches have roots in different philosophical traditions. Most qualitative research use the 'interpretivist' paradigm. The assumption therein is that reality cannot be separate from peoples' knowledge of it and the truth is negotiated through conversations between researchers and respondents. Interpretive approaches rely on naturalistic methods such as observations and interviews to observe and collect information about the event, and then interpret it, matching information with some abstract patterns.

In contrast, the positivist perspective of quantitative research assumes that there is an objective reality and objects are separate from human knowledge. Researchers here need to follow strict methodological protocols to achieve objectivity. Typically, quantitative experimental and manipulative methods are used [196].

However, relying on only one type of data is limiting. Both approaches have their strengths and weaknesses, hence mixed methods are commonly used to understand social processes. One method can be used to verify findings from the other method. As noted by Dzurec [197], meaning is not a function of the type of data collected. Rather it is a result of the interpretation of data represented by numbers or words [196].

In the specific area of communication, the *sender-receiver* literature tends to use quantitative methods almost exclusively [24, 47, 66]. In the *team roles* literature, plain qualitative [195] or quantitative [198] methods are used, and mixed methods are rare.

In the present study, we used a design characterised by an exploratory quantitative study, followed by a mixed method investigation. These are described below.

Phases of research

Phase 1. Exploratory quantitative study (selected questions on gender)

An initial scoping stage of research was conducted by using a quantitative exploratory study. The objective was to define the levels of dissatisfaction and satisfaction in internal interaction processes. The questions covered a wide area of communication and included details about internal meetings and people's feeling about this. We were interested in what engineers think about communication at workplace, from a wide perspective.

This part of the project used a *positivist* approach. We examined the literature on communication findings and theory in the area of engineering management. From this literature, we extracted several survey questions. At this early stage of the work we started with the deficit model of communication; that is, that a lack of information causes misunderstanding. The questions were therefore designed to explore the efficacy of information flow. We were seeking to understand how the deficit model applied to engineering management. The survey primarily collected quantitative data and was analysed using quantitative statistical methods such as ANOVA.

The sample size of N=34 meant this was an exploratory study. Several trends were identified for differences in communication preferences. Even with this small sample size the gender responds were marked.

See Chapter 4 for the detailed methodology, survey questions, and results of this work.

Phase 2: Development of a method to observe interactions (interaction diagrams)

In this phase, an exploratory study was conducted using only the observational study method. We observed five student engineering teams who were doing final year projects. Meetings took place once a week or once per two weeks, with between five and seven meetings in total. These meetings are referred to below as the 'first stage of observation'. Students were from the University of Canterbury in Christchurch, New Zealand. This phase was used to refine the observational method and to identify a preliminary set of team roles. Chapter 5 explains the detailed approach, and the new methodology of interaction diagrams that arose from this work.

Phase 3: Study of engineering students at work meetings

In the third phase, we added a structured interview, questionnaire and Big Five personality test to the regular observations to collect more data from participants.

We again investigated communication in teams of engineering students who were doing a final year project. These were different students to the previous phase. These observations lasted for the whole academic year ('second stage of observation'). A total of five teams participated, each comprising nominally four students and one academic supervisor. The number of teams was determined by what was feasible for the researcher to follow since the teams tended to all meet on the same day. Students were from the University of Canterbury, New Zealand. All students were in the final year of a four-year Washington Accord engineering degree. Chapter 7 presents this approach in detail, with subsequent chapters presenting the results including the proposed new circumplex of team roles.

Phase 4: Study of engineers at industrial organisations

In the fourth phase of study, we observed communication at project meetings in two industrial organisations (case studies). The design of the observation was identical to that of Phase 3 and was conducted concurrently. We applied the same method of research there (observations, interview, questionnaire and Big Five personality test), so the data from both university and organisation would be comparable. Interview questions were the same as for university participants except for several questions that were not relevant to people in professional practice.

Selection criteria for inclusion of project teams in the study were:

- The group consists of between three and eight members.
- The group meets on a regular basis.
- The group includes at least one participant from a different engineering discipline (official position or education) than other team members or
- The group includes at least one person with higher official position than other members.
- Project discussion is in the initial stage of development – that is, the first five meetings.
- All members agreed to participate.

Data collection for phases 2–4

Data were collected via an initial questionnaire, observational study, and structured interview, as follows:

Initial questionnaire and Big Five test. We gave a small questionnaire to participants (seven questions for industrial organisation members and four questions for students) to identify their education background, age, gender and social links between members of the group. We also used the '50-item IPIP version of the Big Five Markers' test created by [199] and taken from [200]. We selected this test and online resource because of the limited numbers of questions – participants needed only 10-15 minutes to answer – and because the data from this test can be processed online.

Observational study. Participants had regular internal meetings where they discussed project problems and future plans for project development, reported results to supervisor (manager) or client, and/or asked questions to them. The researcher observed team meetings on a regular basis. Meetings typically occurred weekly for students during the whole academic year, and every day for participants in organisations. The researcher did not participate in discussions, but sat alongside participants while taking notes. There was no audio or video recording, only written notes using the previously developed interaction diagram (ID) method [201]. Participant identity was recorded using a code. This helped to track the longitudinal observation across multiple team meetings.

Structured interview. At the end of the observation period a structured interview took place with each participant to clarify communication situations and team behaviour.

Ethics approval was obtained from the University of Canterbury Human Ethics Committee (HEC 2017/70/LR-PS), and consent was obtained from all participants.

Data analysis

The data were analysed using qualitative and quantitative methods. The observational method provided a type of coding scheme (using symbols) and the both the context in which these interactions occur and the time sequence. We analysed the associations within these data using NVIVO software. Also, we quantified the frequencies of the various types of interactions and then used this data as additional information. This provided a mixed method for the collection and analysis of data and extraction of findings.

Chapter 4. Quantitative exploratory study

4.1. Introduction

We started our investigation in engineering communication with a quantitative survey. The situation under examination was New Zealand engineers in consulting and industrial organisations. Initially the survey questionnaire was designed to explore the level of satisfaction in communication of engineering team members (see Appendix A). However, we received only 34 usable answers. Therefore, to receive meaningful results, we decided to extract information only about the biggest groups – gender ones.

This study can be called exploratory because of introduction level of research (small sample size).

4.2. Approach

Research questions

The main research question was: *Do female and male engineers differ in their communication preferences while working on a project?* A second question was: *where do the barriers arise*? In approaching this, we have not taken the hypothesis route, nor with any particular belief about which factors might be important or how they might be related. Instead we sought to determine the extent to which the various findings from the literature might be applicable to this situation. We did not commence with a theoretical perspective, nor did we seek to test any of the many pre-existing communication theories with their different lenses. Rather we ascertained the key factors found in other studies and sought to include elements thereof. We used a questionnaire to test for these various factors, and then analysed all the responses by gender.

Survey methodology

A quantitative survey was designed and distributed using an online survey tool. People were recruited by emails, social networks (groups of professionals on LinkedIn), and in person. Invitations for participation were distributed via email to networks of contacts. It is estimated that about 300 such invitations were issued, but it was difficult to determine the reach exactly. The inclusion criteria were for participants to be in an engineering-related role or have an engineering qualification. Ethical approval was received from the University of Canterbury (reference HEC 2015/47/LR-PS). The survey ran for three months in an online format. Anonymity and confidentiality of responses arose from the online nature of the survey – no personal details were collected. There were 34 usable responses.

Design of survey

Questions were arranged into four sections (see Appendix A):

- **Demographic questions.** These were demographic questions about gender, location, years of experience, and practice field. The latter were taken from the Institution of Professional Engineers New Zealand's (IPENZ) practice college fields with minor variation.
- **Personal communication at work including personal attitudes toward communication problems.**
- **Communication in the organisation including barriers and flow of information.**
- **Communication between engineering departments and effect on performance.**

The questions were designed to cover the various communication factors identified in the literature, with a particular focus on engineers. The intent was to determine the relative importance of these factors and whether there were gender specific responses. The survey included multiple broad categories of question, within which were sub questions. The broad categories were:

- *Factors contributing to personal misunderstanding in the workplace*.
- *Preferable communication means with superiors and subordinates*.
- *Engineers' first communication contact in case of a lack of information or misunderstandings*.
- *Common communication skills* that are the most useful for work.
- *Proportion of information*. This is arguably the most problematic communication domain in the organisation. Proportion of information is generated by a) others that one actually understands and b) by someone in a way they think others can actually understand.
- *Impact of project reviews* and *communication structures* (protocols, rules) on performance.
- *Frequency of rework* because of lack of prior information regarding the capabilities of other interdependent teams.

Between them these questions and sub-questions (which are reported in the results) covered a large number of factors that were identified in the literature.

Statistical analysis

One-way ANOVA tests were performed with gender as the categorical variable.

1. The primary test criterion was $\alpha = 0.05$ for determining statistical significance.
2. The support criteria were:

- Support of less than 45% was considered dislike of the parameter.
- Results in the support band of 45% –55% are evenly balanced.
- Support of greater than 55% was considered preference for that parameter.

A third set of criteria was applied to look for possible trends and research questions:

3. An ANOVA parameter estimator d (which represents the direction of the effect) that exceeded 0.1 in absolute value, and $p < = 25\%$.

4.3. Results

The initial number of responses received was N=113. The response rate was disappointing. Partly this was because we were only seeking responses from engineers in industry, but a potentially large pool of students was not available. This was partly because we did not have access to the names of specific engineers in industry. We primarily had to rely on posting invitations at online groups at LinkedIn which might be frequented by engineers, or our own contacts on that

platform. We admit to being disappointed in the results of this strategy. It occurred to us that the difficulty of getting good data seemed to be related to the nature of the topic, that perhaps engineers were really not very interested in communication theory. These data difficulties were significant in our decision to redirect the subsequent phases of the project elsewhere. Our subsequent observational studies in engineering organisations (not reported here) were also marked by a reluctance on the part of engineering firms to host such studies, to the extent that we devised a less intrusive measuring instrument to make it easier for them to host our study.

On examination it was found that the responses were clustered into two main groups: engineers working (mostly in the consulting industry) in New Zealand, and engineers working in India (many in computer engineering), with a smattering of other responses. We decided that the different national contexts were a significant confounding factor, and communication styles may be affected by ethnicity. Consequently, we only took the New Zealand responses forward for analysis.

The admission criteria for analysis were that candidates hold engineering roles and be working in New Zealand. The number of responses that met these criteria was 34, comprising 21 males and 13 females. Most of these engineers were full-time salaried with bachelor's degree in different job positions and roles. The overwhelming majority of respondents were from organisations in the private sector with more than 100 employees.

We draw attention to the small sample size and point out the limitations that arise from a statistical perspective. The nature of the questionnaire does not permit a qualitative analysis to be performed.

ANOVA revealed no statistically significant differences in terms of either gender by field of practice distribution, organisation type or gender by education level and years of experience.

Given the large number of questions asked, we provide visual ANOVAs to assist with interpretation, followed by a brief discussion at the end of each question bank.

Question 1. Factors contributing to personal misunderstanding in the workplace

Causes of misunderstanding are given in Table 4.1, and the ANOVA decompositions in Figure 4.1. Highlighted items were statistically significant (criterion I above). The tabular data are ranked by level of support (criterion II).

Table 4.1. Reason for misunderstanding performed as individual ANOVAs

How important are the following factors in causing personal misunderstanding?	Support across both genders, %	Pearson coefficient of correlation, r	F	p	Direction parameter, d (male) [1]	Gender preferences
Problems in work organisation	73.5	0.1379	0.6214	0.4364	0.0000	Both genders agree that this is important.
False information	71.7	0.2313	1.8211	0.1879	0.2083	Males tend to be more positive[2].
No trust inside team	68.5	0.3683	5.0716	0.0320	0.3333	Males tend to be more positive.
Lack of information	67.7	0.0990	0.3180	0.5771	0.2500	Males tend to be more positive.
Delay in message delivery	66.9	0.0965	0.3020	0.5868	-0.1666	Females tend to be more positive.

Personal characteristics	66.4	0.2365	1.9021	0.1780	-0.2500	Females tend to be more positive.
Low job motivation	66.4	0.1532	0.7709	0.3869	0.1250	Males tend to be more positive.
Communication skills	65.6	0.0336	0.0364	0.8499	-0.4166	Females tend to be more positive.
Technical problems	65.6	0.2205	1.6406	0.2100	-0.3750	Females tend to be more positive.
Too many people	64.2	0.1297	0.5498	0.4645	0.1250	Males tend to be more positive.
Language barriers	63.7	0.3504	4.5199	0.0421	0.2500	Males tend to be more positive.
Physical separation	63.7	0.1540	0.7800	0.3843	-0.6250	Females tend to be more positive.
Education	63.3	0.0358	0.0412	0.8405	-0.2083	Females tend to be more positive.
Excess of information	61.3	0.1361	0.6057	0.4427	0.0416	Both genders agree that this is important.
Wrong distribution of duties	60.5	0.1080	0.3788	0.5430	0.000	Both genders agree that this is important.
Ambiguous information	56.8	0.0344	0.0380	0.8466	-0.1250	Females tend to be more positive.
Cultural diversity	53.2	0.2144	1.5487	0.2232	0.3750	Males tend to be more positive.
Age	51.6	0.0715	0.1650	0.6875	-0.4166	Females tend to be more positive.
Different gender	47.7	0.0066	0.0013	0.9704	-0.4166	Females tend to be more positive.

[1] Positive indicates that males tend to be more positive, negative indicates that females tend to be more positive
[2] Positive means agreed that the item causes problem

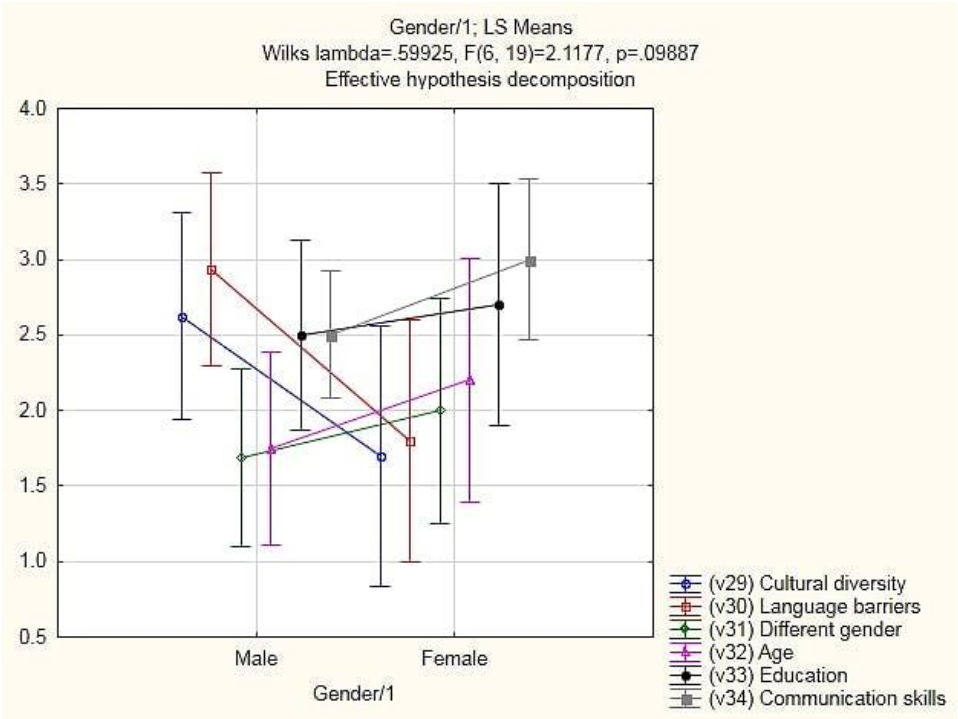


Figure 4.1a. Reason for misunderstanding, variables 29–34

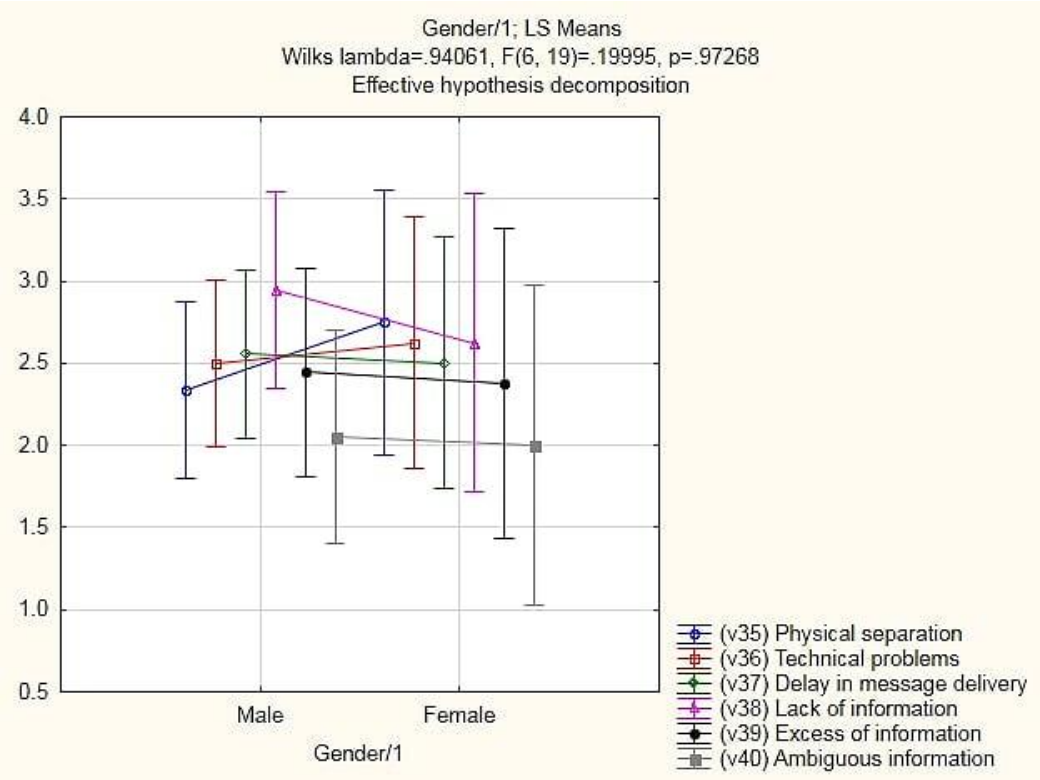


Figure 4.1b. Reason for misunderstanding, variables 35–40

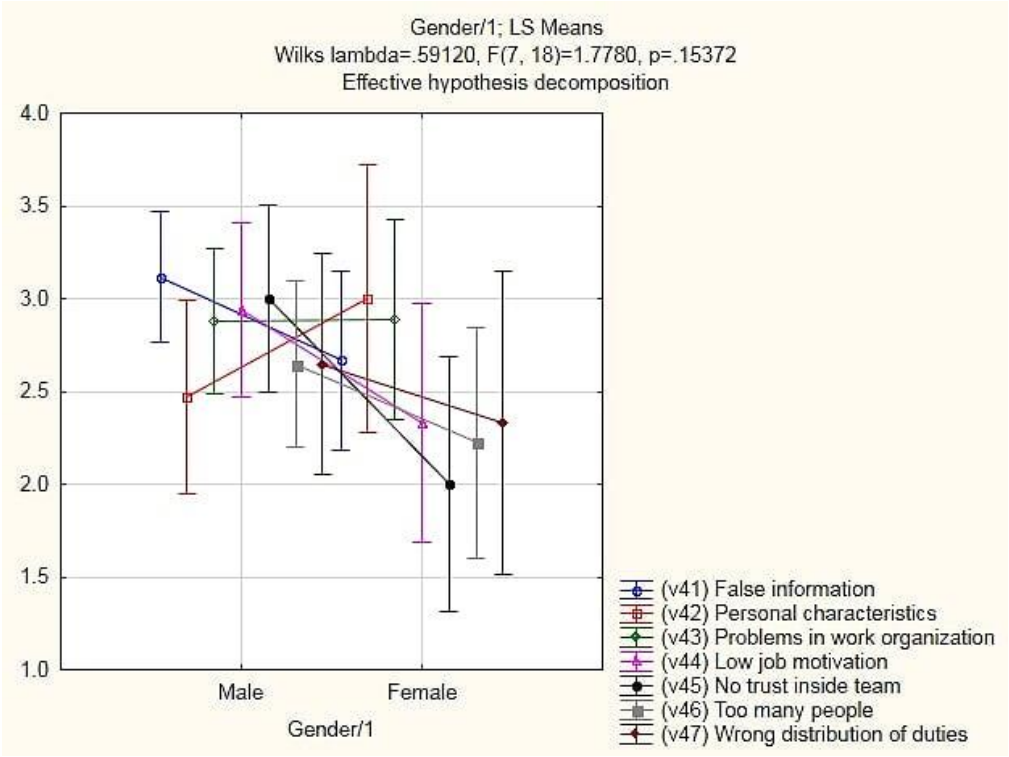


Figure 4.1c. Reason for misunderstanding, variables 41–47

Gender-neutral preferences

The five most important reasons for misunderstanding for everybody: *Problems in work organisation* (73.5%), *False information* (71.7%), *No trust within team* (68.5%), *Lack of information* (66.7%) and *Delay in message delivery* (66.9%).

Gender differential preferences

The ANOVAs show that *Language barriers* (F = 4.5199, p = 0.0421) and *No trust within team* (F = 5.0716, p = 0.0320) are the only variables where males and females differ significantly in opinion. A further analysis shows that in both cases, a greater proportion of males assigns importance to these factors than females.

This is consistent with the literature that females are more relational oriented [122, 123] have higher empathy and verbal ability than males [125, 202] and pay more attention to personal characteristics rather than to achievements or status [129, 203]. Therefore, they may be able to overcome language barriers more easily.

Question 2. Preferable communication means with superiors and subordinates

The gender preferences regarding communication means with superiors and subordinates were explored per questions 20–21. The results are shown in Table 4.2 (for communication with superiors) and Table 4.3 (for communication with subordinates). The equivalent ANOVA decompositions are in Figure 4.2.

Table 4.2. Preferable communication means with superiors

Which communication means do you prefer in relationship building with superiors?	**Support across both genders, %**	**Pearson coefficient of correlation, r**	**F**	**p**	**Direction parameter, d (male)**	**Gender preferences**
Formal meetings	58.8	0.1663	0.9110	0.3470	-0.0842	Both appreciate this communication mean.
Informal meetings	44.1	0.2115	1.4987	0.2298	0.1080	Males tend to have a higher preference.
Phone	41.9	0.2025	1.3690	0.2504	-0.1026	Males tend to be more negative.
Email	23.5	0.1343	0.5877	0.4489	-0.0586	Neither likes it.
Video conferences	14.7	0.3569	4.6698	0.0383	-0.1300	Males are more negative.
Text messages	14.7	0.1558	0.7962	0.3789	0.0568	Neither likes it.
Chats, Blogs	11.7	0.0884	0.2520	0.6191	-0.0293	Neither likes it.

Gender-neutral preferences for communication with superiors

For the communication with superiors, and applying the 45% support criterion, both genders are in favor of formal meetings (58.8%) above other mediums. The support for informal meetings (44.1%) and phone (41.9%) is marginal. Interestingly, the support for email communication is particularly low (23.5%) (see Table 4.2).

Gender differential preferences for communication with superiors

The only significant gender difference is that video conferences are perceived more negatively by males (F = 4.6698, p = 0.0383).

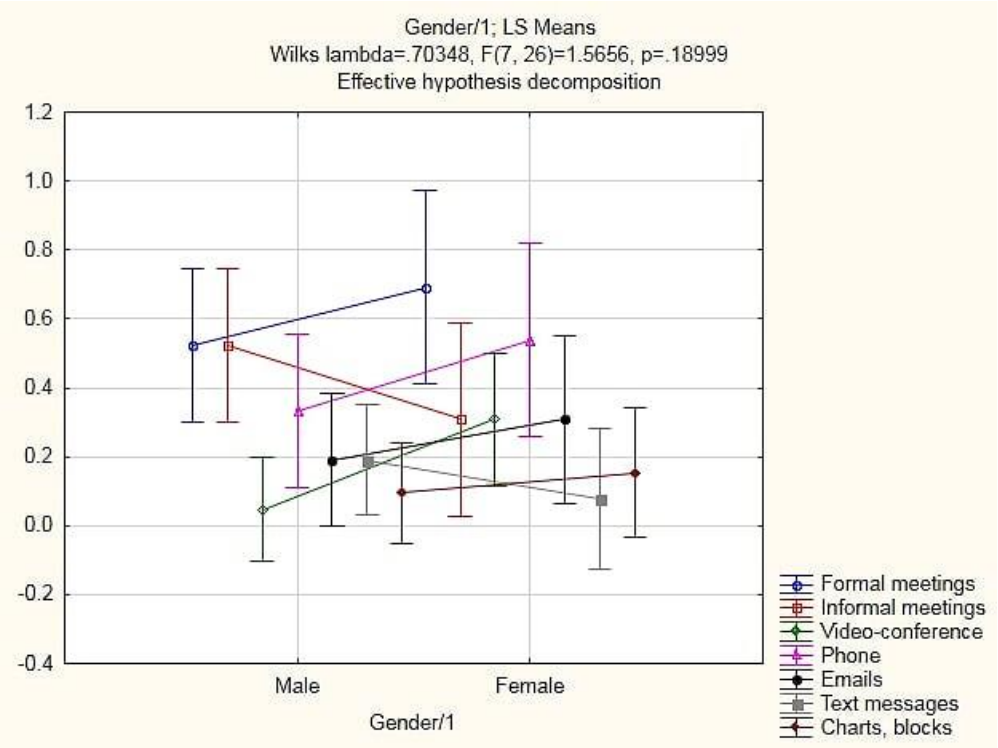


Figure 4.2. Preferable communication means with superiors

Gender-neutral preferences for communication with subordinates

For the communication with subordinates, and applying the 45% support criterion, both genders are in favor of meetings (formal 47%, and informal 53%) above other mediums. Interestingly, the support for the phone is low (26.5%), which contrasts with the results for superiors. Hence, the preferences are asymmetrical: people have marginal support for phone conversations with their superiors but dislike using the phone with subordinates. Email has low support in both cases (see Table 4.3).

Gender differential preferences for communication with subordinates

There are no significant gender differences for this variable.

Table 4.3. Preferable communication means with subordinates

Which communication means do you prefer in relationship building with superiors?	Support across both genders, %	Pearson coefficient of correlation, r	F	p	Direction parameter, d (male)	Gender preferences
Informal meetings	53.0	0.1355	0.5987	0.4448	-0.0696	Both appreciate this mean.
Formal meetings	47.0	0.1070	0.3705	0.5470	-0.0549	Both appreciate this mean.
Phone	26.5	0.0767	0.1892	0.6665	-0.0348	Neither likes it.
Text messages	26.5	0.2138	1.5335	0.2246	-0.0971	Neither likes it.
Email	23.5	0.1343	0.5877	0.4489	-0.0586	Neither likes it.
Video conferences	14.7	0.1860	1.1463	0.2923	-0.0678	Neither likes it.
Chats, Blogs	11.8	0.0884	0.2520	0.6191	-0.0293	Neither likes it.

Question 3. Engineers' first communication contact in case of a lack of information or misunderstanding

This question was about what people in engineering organisations generally do when they do not understand something or feel that the provided information is not sufficient. Gender differences in the responses are shown in Table 4.4, and the ANOVA is in Figure 4.3.

Table 4.4. First communication in case of a lack of information

Who will you contact first in case of misunderstanding?	Support across both genders, %	Pearson coefficient of correlation, r	F	p	Direction parameter, d (male)	Gender preferences
Ask for clarification from the source of information	55.9%	0.0080	0.2591	0.6142	-0.0458	Both appreciate this idea.
Ask colleagues	47.1%	0.0114	0.3705	0.5470	-0.0549	Both appreciate this idea.
Ask superiors	47.1%	0.0659	2.2588	0.1427	0.1319	Males tend to be more positive about this.
Internet	41.2%	0.0837	2.9240	0.0970	0.0751	Neither likes it.
Ask somebody whose opinion is important	32.4%	0.0243	0.7982	0.3783	0.0751	Neither likes it.
Read books or journals	23.5%	0.0001	0.0023	0.9624	0.0037	Neither likes it.
Trust your own experience and knowledge	14.7%	0.0002	0.0073	0.9326	-0.0055	Neither likes it.

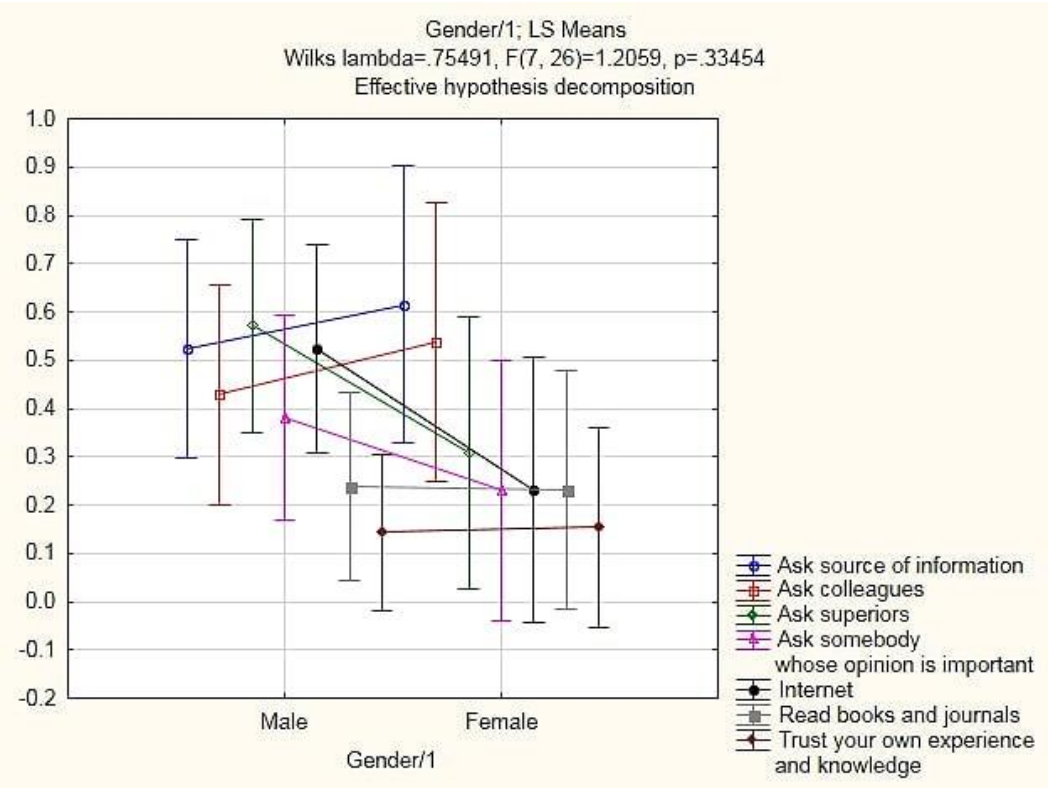


Figure 4.3. First communication in the case of a lack of work information

Both genders would prefer to ask for clarification from the source of information (55.9%) or ask colleagues (47.1%) or superiors (47.1%) in the case of a lack of information or misunderstanding. The ANOVAs do not show any significant difference in opinions between genders.

Question 4. Common communication skills that are the most useful for work

This part explored different communication skills and the importance of them for males and females. Gender differences in the responses are shown in Table 4.5, and the ANOVA in Figure 4.4.

Table 4.5. Useful communication skills

Which common communication skills are most useful for your job?	Support across both genders, %	Pearson coefficient of correlation, r	F	p	Direction parameter, d (male)	Gender preferences
Questioning	52.9%	0.2282	1.7587	0.1942	0.1172	Males tend to be more positive[1].
Listening ability	50.0%	0.0605	0.1176	0.7338	0.0311	Both appreciate this skill.
Resolving conflicts	41.2%	0.1664	0.9110	0.3470	0.0842	Neither likes it.
Presentation skills	41.2%	0.4123	6.5549	0.0154	0.2088	Females are more negative[2].
Negotiating to achieve agreements	38.2%	0.2527	2.1837	0.1493	-0.1264	Males tend to be more negative.
Summarising and recapping	35.3%	0.0745	0.1786	0.6754	0.0366	Neither likes it.
Persuading a person	32.4%	0.2854	2.8371	0.1018	0.1374	Females tend to be more negative.
Read and write technical documentation	23.5%	0.2938	3.0221	0.0918	0.1282	Females tend to be more negative.

[1] Positive means agreed that the communication skill is useful
[2] Negative means disagreed that this communication skill

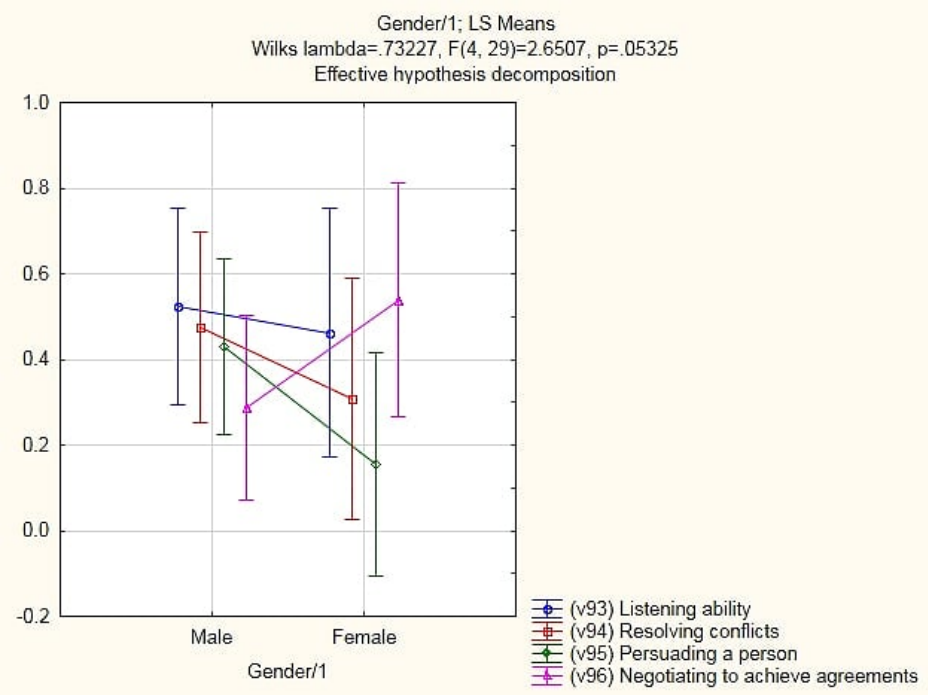


Figure 4.4a. Common communication skills useful for job, variables 93–96

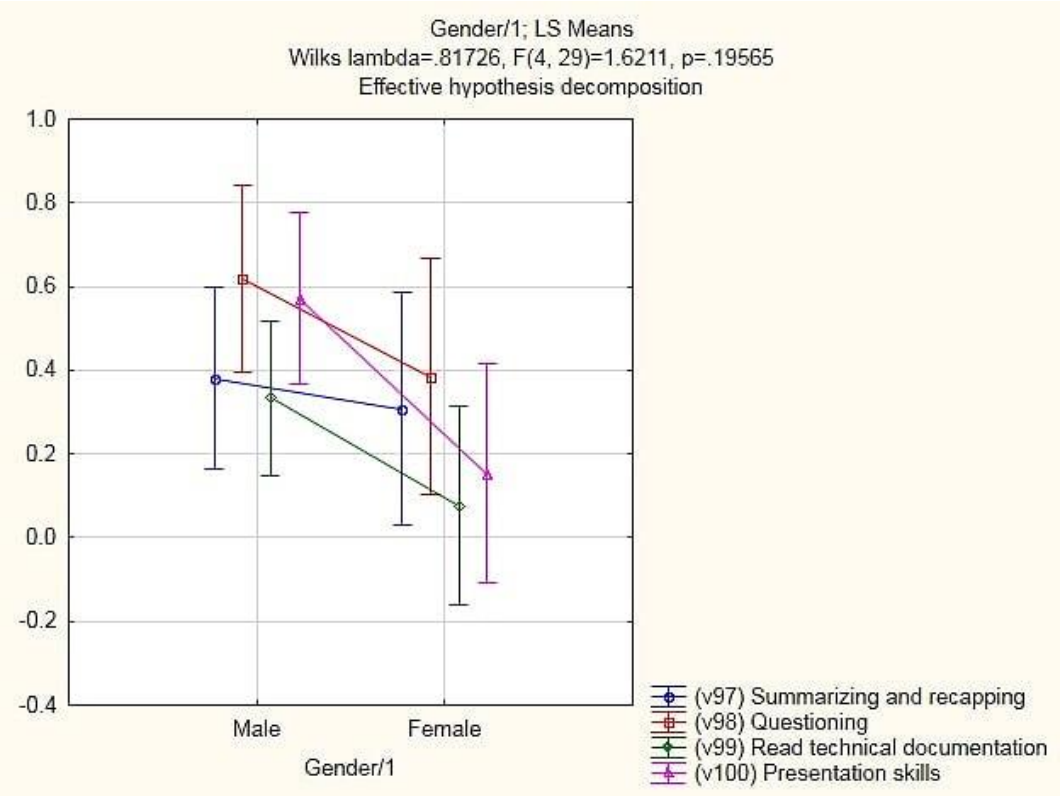


Figure 4.4b. Common communication skills useful for job, variables 97–100

Gender-neutral preferences

Both genders appreciate *Questioning* (support 52.9%) and *Listening ability* (50%) more than other communication skills (Table 5). Interestingly, the support for the ability to *Read and write technical documentation* is relatively low (23.5%). This is unexpected given that job descriptions for engineers invariably require technical documentation activities.

Gender differential preferences

The ANOVAs show significant difference only in *Presentation skills*: males assigned greater importance to this factor than females (F = 6.5549, p = 0.0154).

Question 5. The most problematic communication domain in the organisation

Problematic communication domains (areas with particular communication tasks) were explored and compared for both gender groups. Gender differences in the responses are shown in Table 4.6 and Figure 4.5.

Table 4.6. Gender comparison: problematic communication domain

Which of the following domains are problematic for communication in your organisation?	**Support across both genders, %**	**Pearson coefficient of correlation, r**	**F**	**p**	**Direction parameter, d (male)**	**Gender preferences**
Workshops/Current problems	47.1%	0.0143	0.0065	0.9362	0.0073	Both agree that this domain is problematic.
Meetings with stakeholders	41.2%	0.0796	0.2039	0.6546	-0.0403	Neither agrees.
Project management	38.2%	0.0037	0.0004	0.9836	-0.0018	Neither agrees.
Manager's offices (Strategic plans)	32.4%	0.2854	2.8371	0.1018	0.1374	Females tend to be more negative (disagree with the problem).
Production control	32.4%	0.3615	4.8098	0.0357	-0.1740	Males are more negative.
Design discussions	32.4%	0.0266	0.0227	0.8811	0.0128	Neither agrees.
Interactions with customers	23.5%	0.2770	2.6587	0.1128	-0.1209	Males tend to be more negative.
Marketing and sales discussion	11.8%	0.0884	0.2520	0.6191	-0.0293	Neither agrees.
Negotiations with sellers of raw materials	11.8%	0.0884	0.2520	0.6191	-0.0293	Neither agrees.
Contracts, employee benefits	8.8%	0.1820	1.0963	0.3029	-0.0531	Neither agrees.
Industrial safety and work conditions	2.9%	0.1370	0.6118	0.4399	0.0238	Neither agrees.

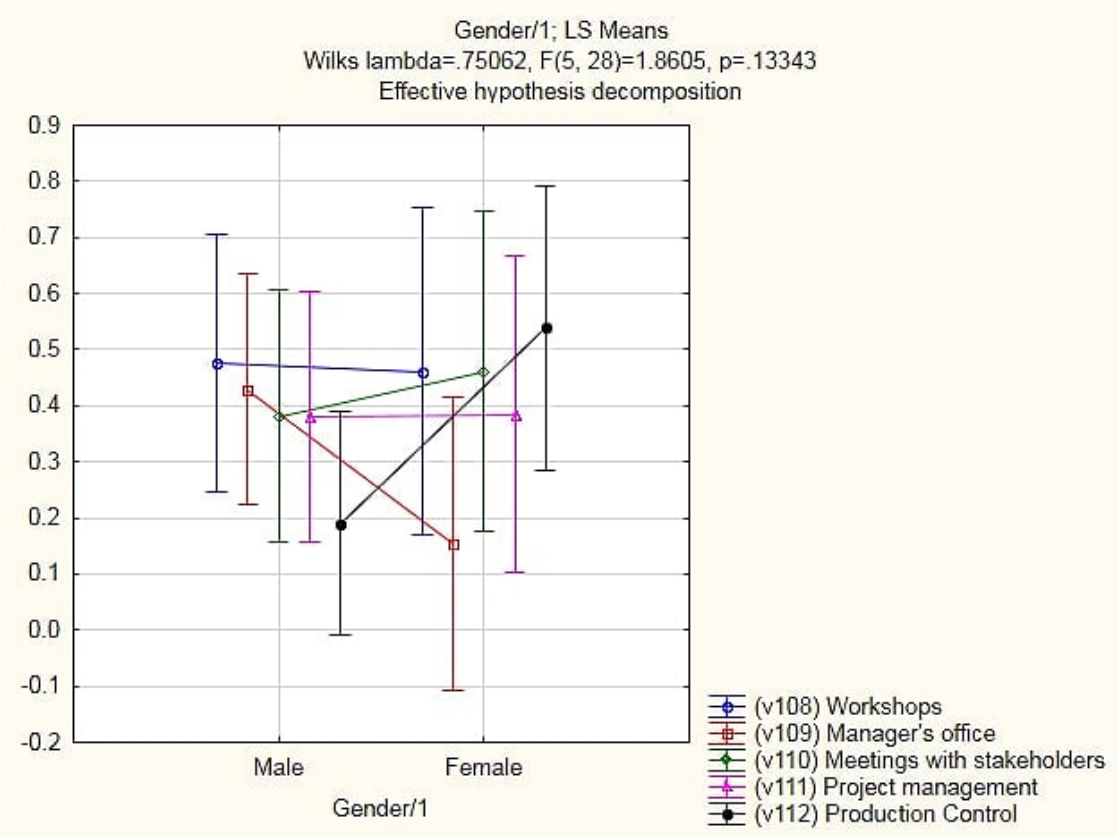


Figure 4.5a. Problematic communication domains, variables 108–112

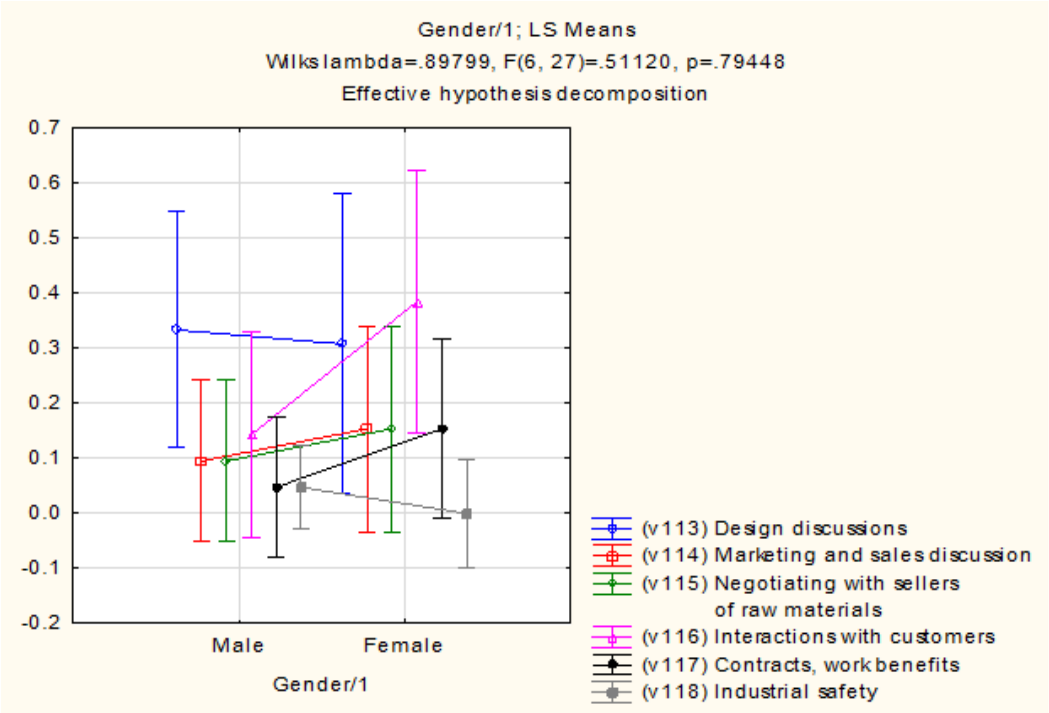


Figure 4.5b. Problematic communication domains, variables 113–118

Gender-neutral preferences

Both genders are in favor of *Current problems in the workshops* as the most problematic place for communication; however, general support is marginal at 47.1% (see Table 4.6). *Meetings with stakeholders* are of somewhat importance as well (41.2%). It is interesting to note that *Industrial safety* and *Work conditions* acquired very few positive responses (23.5%).

Gender differential preferences

The only domain of communication that shows significant gender differences is Production control area, which is perceived more positively by females ($F = 4.8098$, $p = 0.0357$). That is consistent with women having more critical minds and high standards in production [124, 129].

Question 6. Proportion of information generated by a) others that you understand and b) by you that you think others can understand

These questions explored self-estimation of gender groups regarding information that they or other people understand in communication Gender differences in responses are shown in Tables 4.7–4.8, and Figures 4.6–4.7.

Table 4.7. Understanding of information generated by others

What proportion of information generated by other people do you understand?	Support across both genders, %	Pearson coefficient of correlation, r	F	p	Direction parameter, d (male)	Gender preferences
Colleagues	56.0%	0.2045	1.3534	0.2536	0.0489	No significant gender differences.
Subordinates	51.9%	0.2258	1.6659	0.2063	0.0555	No significant gender differences.
Superiors	48.1%	0.5709	14.991	0.0005	0.1465	Males' estimation is higher.

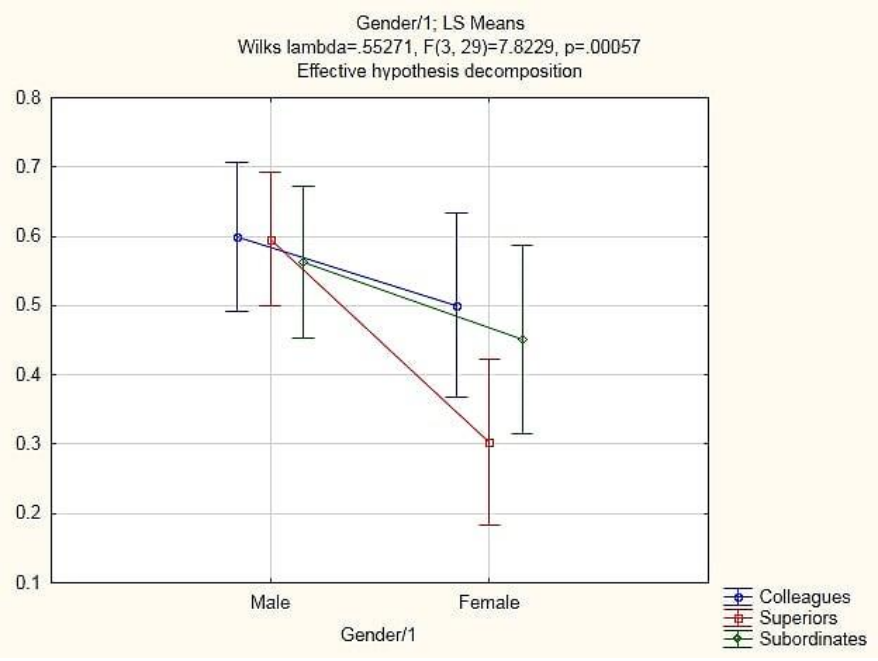


Figure 4.6. Information generated by others that responders think they actually understand

Table 4.8. Understanding of information generated by respondents

What proportion of information generated by you do you think other people actually understand?	Support across both genders, %	Pearson coefficient of correlation, r	F	p	Direction parameter, d (male)	Gender preferences
Colleagues	57.6%	0.2391	1.8803	0.1802	0.0586	No significant gender differences.
Superiors	52.0%	0.4312	7.0812	0.0122	0.1164	Males' estimation is higher.
Subordinates	47.6%	0.5049	10.604	0.0027	0.1290	Males' estimation is higher.

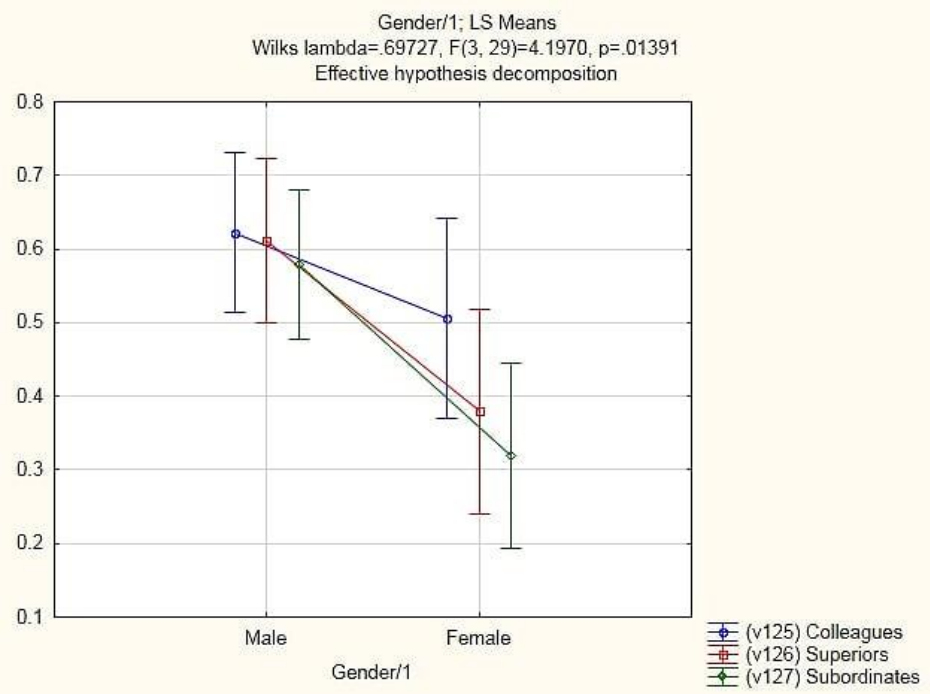


Figure 4.7. Information generated by respondents that they think others actually understand

Gender-neutral preferences

Both genders agree that they understand only 48–56% of information from other people. Furthermore, other people (co-workers) understand only half of the communication messages from them (47–57%). Interestingly, the percentage of mutual understanding is high in communication with colleagues and low with superiors when they talk or with subordinates when respondents talk.

Gender differential preferences

The ANOVAs show significant gender differences in Understanding information from superiors ($F = 14.9911$, $p = 0.0005$), Superiors' understanding of information ($F = 7.0812$, $p = 0.0122$) and Subordinates' understanding of information ($F = 7.0812$, $p = 0.0122$). In all cases, males ranked higher.

Question 7. Impact of project reviews on performance

This question explored how project reviews influence the results of engineer's work and the company's performance. Gender differences in responses are shown in Table 4.9, and in Figure 4.8.

Table 4.9. Impact of project reviews on performance

What impact does project review have on performance?	Support across both genders, %	Pearson coefficient of correlation, r	F	p	Direction parameter, d (male)	Gender preferences
Delay of important technical work	47.1%	0.1070	0.3705	0.5470	-0.0549	Both genders support this (agree).
Reduce misunderstanding and improve the performance	26.5%	0.2138	1.5335	0.2246	-0.0971	Neither supports this.
Reduce misunderstanding but result in wasting time	26.5%	0.0767	0.1892	0.6665	-0.0348	Neither supports this.
Reduce the amount of rework but increase the procedures	20.6%	0.4006	6.1176	0.0189	0.1667	Males more supportive than females.

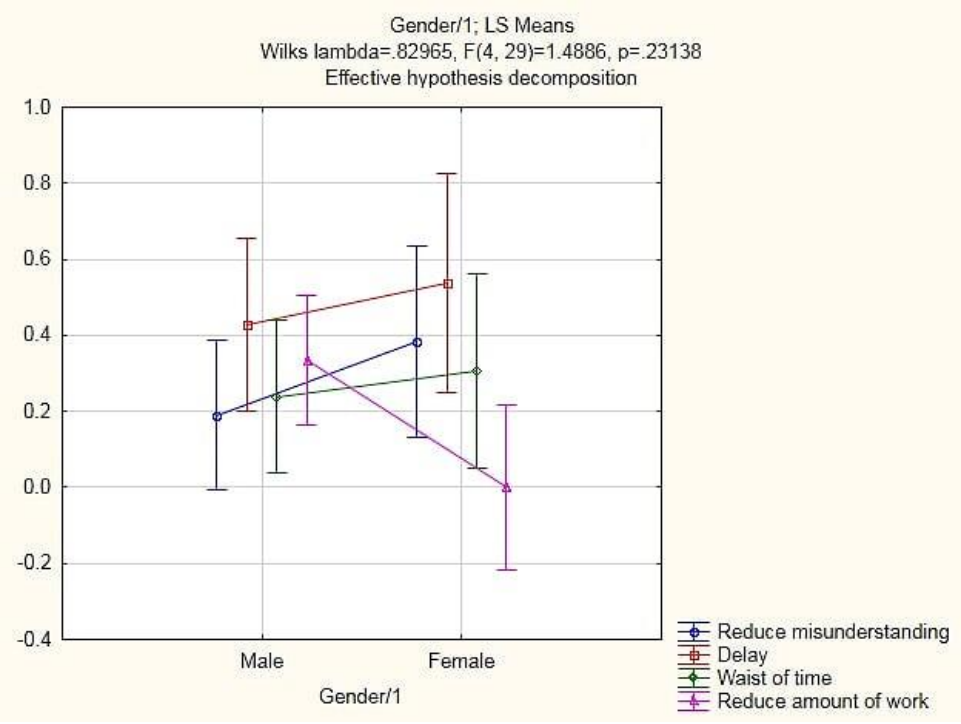


Figure 4.8. Impact of project reviews on performance

Gender-neutral preferences

The support for *Delay of important technical work* as a consequence of review processes is marginal (47.1%). Other effects obtained even less support: 26.5% for *Reduce misunderstanding and improve the performance* and the same 26.5% for *Reduce misunderstanding but result in wasting time*, and 20.6% for *Reduce the amount of rework but increase the procedures*.

Gender differential preferences

The ANOVAs show significant gender differences only in *Reduce the amount of rework but increase the procedures*, where males have a higher preference (F = 6.1176, p = 0.1667). Interestingly, females' support was 0% for this option.

Question 8. Impact of communication structures (protocols, rules) on performance

This question explored what engineers think about communication structures (rules, protocols) and their influences on performance. The gender difference is shown in Table 4.10.

Table 4.10. Impact of communication structures on performance

How do predefined communication structures impact the performance?	Support across genders, %	Pearson coefficient of correlation, r	F	p	Direction parameter, d (male)	Gender preferences
Communication structures	Total – 12.1% (females – 27%, males – 2.5%)	0.2919	2.8876	0.0993	-0.2442	Females tend to be more positive (show higher support).

Gender-neutral preferences

Neither gender is in favor of communication structures. The general support for it is low (12.1%).

Gender differential preferences

According to the ANOVA, there are no significant gender differences in this variable.

Question 9. Frequency of rework because of lack of prior information regarding the capabilities of other interdependent teams

This question explored how often engineers should do rework because of communication problems. Gender differences in responses are shown in Table 4.11 and Figure 4.9.

Table 4.11. Frequency of rework

How often do you have to redo your work because of lack of prior information regarding the capabilities of other interdependent teams?	Frequency across genders	Pearson coefficient of correlation, r	F	p	Direction para-meter, d (male)	Gender preferences
Rework	Females – 2 of 5 Males – 2.8 of 5	0.2893	2.8318	0.1025	0.4000	Males tend to do rework more often.

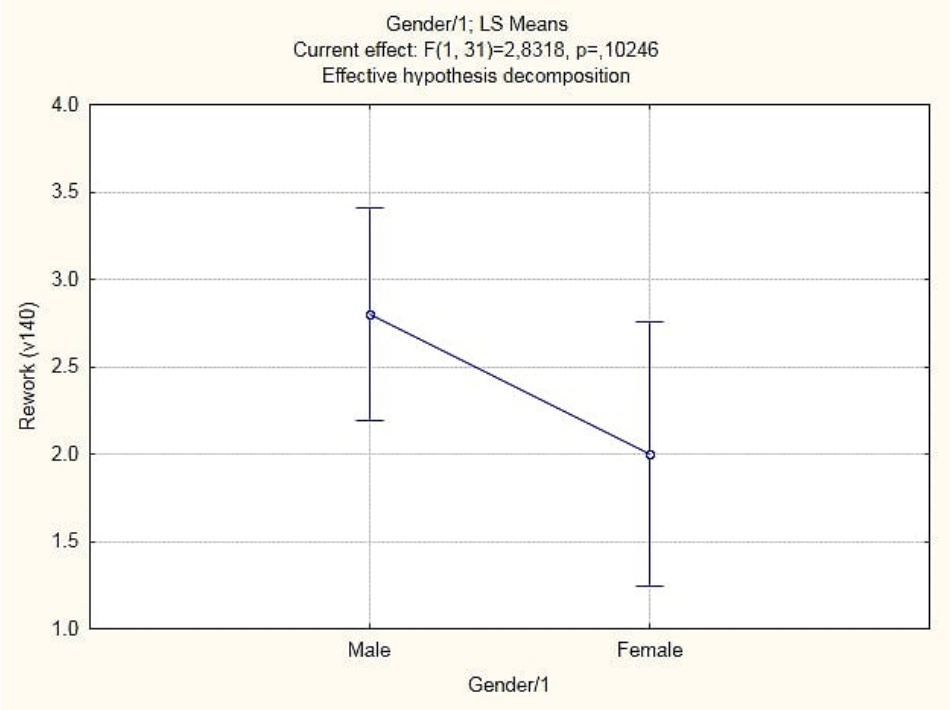


Figure 4.9. Frequency of rework

Both genders answered they should do rework because of communication problems in about half the cases where a misunderstanding occurs. There are no significant gender differences in this variable.

4.4. Discussion

Summary of key findings

The results described in this Chapter show that communication styles are different between the genders. There are specific areas of communication that attract more attention from male engineers and are less important for female engineers. Table 4.12 summarizes the communication aspects.

Table 4.12. A summary of gender communication differences in New Zealand-based engineering organisations

Group of differences	Males	Females
1. Contributory factors to misunderstanding	**Significant:** assign greater importance to the Language barriers and No trust inside team as the main reasons for misunderstanding **Trends:** a) tend to be more sensitive to False information and Cultural diversity b) The most important factors are No trust inside the team, False information, Language barriers and Problems in the work organisation.	**Significant:** assign less importance to the Language barriers and No trust inside team **Trends:** a) tend to be more sensitive to Personal characteristics and Technical problems b) The most important factors are Problems in work organisation, Personal characteristics, Technical problems and Delay in message delivery.

2. Vertical communication	**Significant:** Video conferences with superiors are perceived more negatively. **Trends:** a) preferable means of communication with superiors and subordinates are Meetings. b) tend to have a higher preference for Informal meetings with superiors than females and are negative about Phone communication	**Significant:** more positive about Video conferences with superiors **Trends:** a) prefer Formal meetings with superiors and not negative about Phone talking b) prefer Informal meetings with subordinates
3. Action in case of misunderstanding	**Trend:** first Ask superiors, can also Ask for clarification from the source of information or Search information on the Internet	**Trend:** a) first Ask clarification from the source of information and then Ask colleagues b) do not like to Ask superiors
4. The importance of communication skills	**Significant:** assign great importance to Presentation skills **Trends:** a) the most useful communication skills are Questioning and ability to give a Presentation, also respect Listening ability and ability to Resolve conflicts. b) find Negotiating to achieve agreements to not be a very useful communication skill	**Significant:** consider Presentation skills to not be a very important skill for work **Trends:** a) do not put great importance on any particular communication skill; however, rather positive about Negotiating to achieve agreements and Listening ability b) more negative about Persuading a person and ability to Read and write technical documentation
5. Problematic areas of communication	**Significant:** Production control domain is not perceived to be a very important area of communication. **Trends:** a) the main problematic areas of communication are the Workshops and Manager's office (Strategic plans). Meetings with stakeholders are also somewhat important. b) do not feel any communication problems in Interactions with customers	**Significant:** area of Production control is perceived to be the most difficult communication zone. **Trends:** a) the main problematic areas of communication are Production control domain, Workshops and Meetings with stakeholders. b) tend to feel higher importance for Interactions with customers
6. Confidence in own understanding	**Significant:** believe that they actually understand approximately 60% of information from superiors **Trend:** believe that they actually understand colleagues slightly better than subordinates	**Significant:** believe that they actually understand approximately 38% of information from superiors **Trend:** believe that they understand all people in the workplace equally
7. Confidence that others understand	**Significant:** suppose that superiors and subordinates understand them rather well	**Significant:** hesitate that superiors and subordinates understand them well

	Trend: suppose that colleagues understand them well, too	**Trend:** suppose that colleagues understand them rather well, whereas subordinates and superiors do not
8. Frequency of rework	**Trend:** tend to do rework because of misunderstanding more often (56% of cases)	**Trend:** tend to do rework because of misunderstanding less often (40% of cases)
9. Factors influencing the performance	**Trends:** a) tend to agree that project reviews Reduce the amount of redo-work but increase the procedures b) do not support Communication rules/protocols as a factor influencing the performance	**Trends:** a) disagree that project reviews Reduce the amount of redo-work b) partially support Communication rules as a factor influencing the performance

The findings show that gender groups tend to behave in different ways and use different communication strategies in particular situations.

Implications for managers

The practical implications of these findings include indicating where and how communicational misunderstanding may arise between different categories of engineers.

Managers could consider the gender factor in creating a good work environment for people. Thus, males may benefit from team trust, truthful information, superiors who they can respect, and effective work processes that achieve rapid results. Females may be more relationship-oriented and appreciate the opportunity for informal communication with colleagues and surroundings that provide emotional support. Females appear to prefer to keep some distance from superiors and have more formal interactions through meetings or phone conversation, rather than talking informally. Video conferences with superiors are perceived negatively by both genders, particularly by males.

In the mixed team, the optimisation of roles by gender preferences may be considered. For example, males may prefer presentation tasks, managing the situation, and strategic planning; females may prefer negotiation roles, production control processes, protocols, project plan preparation, and project reviews. Obviously, these are merely general findings.

Limitations of the exploratory study

The main limitation is the small sample size. Consequently, this is considered an exploratory study. A potential area for future research is to expand the study to a larger sample size.

Another limitation is geographical spread. The survey was conducted with engineers working only in New Zealand. It could be interesting to see communication differences between cultures.

In addition, age was not taken into consideration. The respondents were asked about years of work experience, whereas age group is somewhat different from experience. Future research may help to clarify this question.

Future research questions

Possible future research questions could be:

- Explore the extent to which language and cultural barriers might have gender-specific effects in causing of misunderstanding.
- It may be interesting to examine *physical separation*. It receives high support from females (70%) as an important reason for misunderstanding; however, the ANOVA does not show any significant differences in answers between females and males, and there is no noticeable trend in this area.
- There may be value in exploring the gender specific philosophical aspects of *trust* in team situations. Possible there may be different mechanisms involved for the genders. It is possible also that males are more concerned about abstract aspects such as a strong team, where people can trust each other and explain their ideas clearly, and possess full and exact work information, whereas the physical presence of people and a good relationship environment may be what females need for effective communication.

4.5. Conclusion

The outputs of communication studies provide insight into the social aspects of engineering management. The goal of this part of study was to understand better the communication differences between gender groups in engineering organisations in New Zealand. We were interested in many aspects of communication that are significant to engineering management, among them: style preferences for communication with colleagues, communication skills that are most appreciated by different gender groups, where miscommunication may arise, and how males and females differ in their perception of the internal processes of engineering reviews. Results showed measurable gender differences in specific elements of communication styles.

Also, results showed that the most frequent factors of miscommunication for males are language barriers and the absence of trust within the team, whereas females were more sensitive to personal characteristics and technical problems. Females appeared to assume that the communication barriers arise in the production control area and negotiating with customers and stakeholders; males assumed that it was in strategic planning. However, both genders agreed that the workshop is always a problematic area of engineering communication. In the case of misunderstanding, engineers generally identified the need to first ask for clarification from the source of information, and then males tended to want to ask superiors or search on the Internet, whereas females preferred to talk to colleagues.

In the field of communication skills, females showed appreciation for negotiating and listening abilities, whereas males apparently assigned greater importance to presentation skills and questioning. Females preferred to communicate with superiors in a formal meeting and informally with subordinates, whereas males tended to have a higher preference for informal meetings with superiors and either formal or informal ones with subordinates. In addition, the engineering review process was perceived negatively in most cases by both gender groups as a delay in work. However, there was some support from males, who believed that reviews can be helpful because they reduce the amount of rework; females disagreed with this.

Due to the exploratory nature of this study, the findings are tentative and primarily intended to identify potential future research ideas. The following chapters will develop ideas of engineering communication using qualitative tools.

Chapter 5. Development of the interaction diagram method

This chapter is an adaptation of the following paper:

> Nestsiarovich, K.; Pons, D. Interaction diagrams: Development of a method for observing group interactions. *Behavioral Sciences,* 2019, 9 (1), p. 5.
>
> https://doi.org/10.3390/bs9010005

5.1. Introduction

It is hard to imagine work in organisations today without regular team meetings. Team communication is an integral part of everyday routine activities because of the growing complexity of the decisions undertaken. Teams comprise multiple members with different characteristics and temperaments, and consequently teams develop a communication style and habits of interaction. To observe these behaviours, it is necessary to record features of the communication.

However, recording of team processes can be difficult. While video and audio recording can provide a rich record of the interactions for subsequent analysis, there are multiple detriments: issues with privacy; difficulty to interpret because of noise or quiet speech [204]; and distortion of the behaviour of team members [205]. It was found that cameras do not create barriers to productivity, but participants had 'mixed feelings' about how it affected their communication style [206]. Furthermore, more substantial ethics approval processes are required, and this prolongs the preparation stage of a research experiment.

Hence, there is value in developing methods that allow researchers to document key features of team communication with less intrusion than audio-visual recordings. It is also advantageous if a method makes for easier data collection, as existing methods can be laborious both in the preparation and in the post-processes stage. It is especially important for those cases where team members are opposed to giving consent for intrusive forms of recording, such as commercially sensitive cases.

This chapter develops a novel method for recording meetings in organisations. We refer to this as an interaction diagram (ID).

What Needs to Be Recorded?

The most important things to record include date used between one and artefacts per meetings' and time of the meeting, purpose, the sequence of participants' turn-taking, and decisions made as a result of meeting discussion. In addition, other aspects of communication may be of importance: non-verbal interactions, emotions, artefacts (boundary objects), and team roles. Exactly what people said may also be of interest, especially for qualitative research purposes.

An important issue raised in the literature is the process of meeting recall. Which aspects of the meeting do people generally remember well? One of the more comprehensive papers in the field [207] shows that people can remember their own speech and activities very well, together with major topics of the meeting, official roles and seat positions of others, whereas memories about other participants' performance and details such as dialogues, gestures, time sequence, and emotional expression are vague. This appears to be the only recent study on the topic of meeting recall. Evidently, there is a need to pay special attention to a variety of features of meetings.

Tools for Recording

There are different methods of recording communication in meetings: taking written notes or minutes on paper and electronic device; stenograph [208]; recording visible key points; audio and video recording with later possible transcription [209]; phone conferences with telephone recording; automated audio transcription [210] and speech-to-text software [211]. These approaches often overlap.

Electronic technology can record audio and visual interactions of team meetings. The audio may subsequently be transcribed, and the video characterised by some scheme. The problem is that transcription need time, and also retrieval of the necessary part from the long audio stream of the meeting can be problematic [212].

Therefore, many software systems were developed to integrate audio, video recording, and note-taking. One of the first such systems is a combination of audio recording and tablet for handwriting, called 'Filochat' [213]. Another is the 'Audio Notebook' that allows users to capture an audio recording and link it to the notes written on paper [214]. A recent example is 'Livescribe' — a combination of notebook and smartpen [215] that converts handwritten notes into digital text. The camera on the tip of the pen records gestures generated by a user on a writing surface, and then special software allows the user to find and select a necessary word or phrase in the content (written or audio) [216]. The recorded audio optionally can be synced with the written notes. Such systems may help avoid unnecessary transcribing.

Examples of applications include annotated video to examine interactions among forestry workers [217], sport events [218], educational settings [219], and medical interactions in group therapies [220].

However, the focus of all these methods is on the input device and hardware (paper, digital notebooks, and pens) rather than on real data integration [212]. In addition, these systems can be expensive, and it can be difficult to share information between different applications. Another restriction is that they generally only link paper notes to digital information (audio and video), and not the reverse [212].

Recently, there was an increase in popularity of speech systems where the software presents speech as synthesised and standardised voice[221]. Such tools can enhance the clarity of speech, and reduce self-consciousness of the speaker, but make voice less personal and less natural. Most of these interfaces can produce audio transcription[222, 223]. The 'TypeTalker' system can produce transcription as well as edited speech and gesture comments [221].

Shortcomings of these programmes are the time taken to learn them, and possibly the cost. In addition, some personal aspects of speech are lost, such as intonation, emotional expressions, and loudness [221], which may influence the interpretation of dialogues at the meeting. In addition, using speech commenting and speech recognition can be difficult in cases of parallel discussions (when many people speak at once).

Any kind of observation influences the behaviour of team members and potentially distorts the results of the experiment [205], although recording with electronic devices seems to be more invasive. There are many advantages of manual diagrams on paper: they are less sensitive to technical failures, paper diagrams cannot be lost so easily as electronic charts, and researchers do not need to set up any computer programmes. People can visualise the communication situation quickly and easily [224, 225]. In addition, people feel less intimidated by paper than computer recording [224].

Sociogram

There is a place for rapid manual methods that are based on taking written notes. One of the most famous is the sociogram—a method of graphical representation people and interactions between them by using different symbols (nodes, arcs and lines) [226]. It was developed by Moreno and Jennings to analyse group preferences. With the evolution of social network analysis towards software tools and graph theory, the word 'sociogram' was replaced by 'graph diagrams' [225].

Many studies were directed at communication mapping during the 1940s–1960s. The concept of communication patterns, which is similar to sociograms, uses lines and symbols. Leavitt [227] in 1950 identified and diagrammed typical patterns of communication (wheel, Y, chain, circle and network). These patterns and the position of the participants in it were correlated with behavioural differences of people Leavitt [227].

In most of these works, the communication pattern is defined as connectivity between nodes (e.g., [227, 228]), thus the diagrams are evaluated quantitatively (number of connections, symmetry, etc.). The communication is presented as an exchange of messages between participants through channels, i.e., a sender-receiver model.

In contrast, the method shown in the current study differs by using diagrams as a platform for qualitative data, although quantitative data can be extracted too. We were not very interested in the relationship structure of the group at meeting or the position of the team members in the communication network, but rather how people react to others' behaviour, what words and non-verbal signs are used, what proceeds the communication events at the meetings, and how different situations (e.g., parallel discussion, use of artefacts, and appearance of a new person) change the communication environment in the group. In this sense, we were less interested in the communication pattern, and more in the communication behaviours. The ID method provides a mechanism to represent these behaviours by using diagrams with a timeline.

Nowadays, sociograms and graph diagrams are used in the evaluation of the relationship between people within the context of a particular situation, such as project discussions. They help researchers to visualise communication processes and social links in a particular team. Sociograms allow the combining of data from different sources and use of qualitative and quantitative methods of research [225]. Sociograms continue to be adapted. For example, they have also been used to represent the social relationships between people [229]. Typical applications of sociograms have been to ethnic relationships [230], physical education [231], personal relationships [224], skilled migration, online communities [232], and medicine [233, 234].

There are different types of sociogram based on many criteria: similarities (same location, members of the same group, gender, and age group), social relations (roles and friendship), interactions, and information flow (lines of communication) [235]. Each shape (node) on a sociogram indicates a person or organisational unit. Each line indicates a connection between units.

There have been previous attempts to further develop the design of sociograms. For example, it is suggested that diagrams could be enriched with questions, additional notes for qualitative analysis, or statistical graphs for qualitative analysis [236].

The main limitation is that the geometric constructions used in sociograms may misrepresent elements of the communication. For example, the central place in the graph structure is not necessarily the geographical point in the centre of the group [237]. Another limitation is that

sociograms struggle to record communication at the meeting as the method captures the structure of a group and links (relationship) between team members, rather than time and event sequences. Introduction of the time dimension is a key development in the present work.

Summary

Methods involving audio and video recording may ask additional efforts from the researcher to receive consent from people involved in the recording. That makes it harder to receive access to meetings. On the other hand, paper methods such as stenograph, or simply transcribing, are less invasive but require particular expertise, such as stenograph knowledge, good level of language and speed writing. There is a need to develop methods that can combine the advantages of both methods. Sociograms can be used for recording of information at meetings but need to be improved by including the timescale and information about easily forgotten items such as participants' behaviour, including tone, the speed of speech, gestures, and emotional expressions.

The purpose of this exploratory study was to develop a methodology for team observations. The objectives for the system were that it should represent multiple interactions between participants in a time-pressured situation (and in time sequence), distinguish between different types of interactions, identify non-verbal behaviour, and provide a mechanism to quantify the number and type of communication events that a person makes.

5.2. Approach

Our approach was to extend the directed graph nature of sociograms, using arrows to show the direction of member-to-member interactions. We were particularly interested in capturing the time sequence of events: who starts the interaction and who picks it up? As part of that, we also wanted to know how long each interaction lasted, and the type of interaction. We created a categorisation of the type of interaction and devised graphical symbols for these. We found that this categorisation could readily be extended to include broadcast transmissions, parallel discussions, use of artefacts (boundary objects), non-verbal behaviour (such as gestures), and repeating communication patterns. We refer to this as an *interaction diagram (ID).*

To refine the interaction diagram method, we followed five teams of engineering students who were doing a final year project. Typically, there were also one supervisor and one client in every student team. Meetings took place once a week or once per two weeks, for 5–7 meetings.

This investigation included only observations. No audio or video was recorded. The researcher stayed aside taking notes and observing the meeting.

Ethics approval was obtained from the University of Canterbury Human Ethics Committee (HEC 2017/03/LR-PS), and consent was obtained from all participants.

We used these periods of observation ('first stage') to test and further refine the ID method. We were particularly interested in maximising the capture of non-verbal behaviour, within the constraints of a hand-written processes. We developed several refinements to the basic concept, and these are described in the results below.

Communication events at the meeting were divided into several groups. A *point system* was devised to show the contribution of each participant to the team communication. The number of interactions during the meeting was calculated and used to find the density of communication events for each participant and for the whole team, and to identify team roles.

Qualitative data were collected during the observations. After every observation, interaction diagrams were used to extract data and a journal summary was written. This was followed by a process of mark-up (underlining typical actions) and defining patterns of behaviour for each participant at the meeting.

5.3. Results

The interaction diagram provides a graphical method of representation of communication between team members. The system is explained below.

Basic Principles of the Interaction Diagram

Interactions diagrams were built on the basis of the sociogram, with the addition of sequence or order of communication interactions. Communication interaction was considered to be a change of turn-taking among participants or change of conversation addresser.

Communication flow at the meeting was divided into several time intervals—*slides*. The slide was one piece of paper, changing when it was full of information or became hard to read. In our case, we found that one slide could cover approximately 2–8 minutes of a meeting, depending on the nature of team interactions.

Legend

We developed a legend to categorise the type of interaction. This legend includes graphical symbols:

- In the right corner, the researcher indicates *the starting time* for every slide and the current topic of discussion.
- *Numbers* represent the sequence of communication interactions (every interaction starts with turn-taking).
- *Letters* represent the participants of the meeting.
- *A circle* represents a broadcast speech that refers to everybody.
- *Arrows* show the direction of communication.
- *A question sign* represents a question asked by a particular person.
- *Small arrows* near the question mark represent answers and repeating questions (see Figure 5.1)
- *Notes* may be written near participant's letter, about his/her communication style or role
- *Parallel discussions* are shown as big circles around a particular group of participants (see Figure 5.3)
- *Green* shows participants, starting time and special marks; *blue* shows communication processes and notes about team roles; and *red* shows a name or abbreviations of participants.
- *Long monologue speech* is shown as a thick line (arrow or circle)
- *Repeating patterns* are shown as small lines, as a separate group, with numbers of repeating interactions *(*see Figure 5.3).
- *Solid line* means verbal communication interaction, while dotted line is non-verbal (Figure 5.2).

Examples of the method used in the investigation can be found in Figures 5.1–5.3.

Our study followed the communicative approach to the team roles developed by Lehmann-Willenbrock, Beck and Kauffeld [238]. The main idea of this approach is that team roles appear and develop in communication situations and through communication patterns, rather than through the official position of participants in the group [238]. Therefore, roles can be identified in observations and can be changed during the meeting or between meetings.

Case 1: Simple Communication Situation

In this situation (Figure 5.1), two supervisors and four students were discussing problems with model testing at the early stage of a project. This was the team's second meeting, and in the middle of the discussion time.

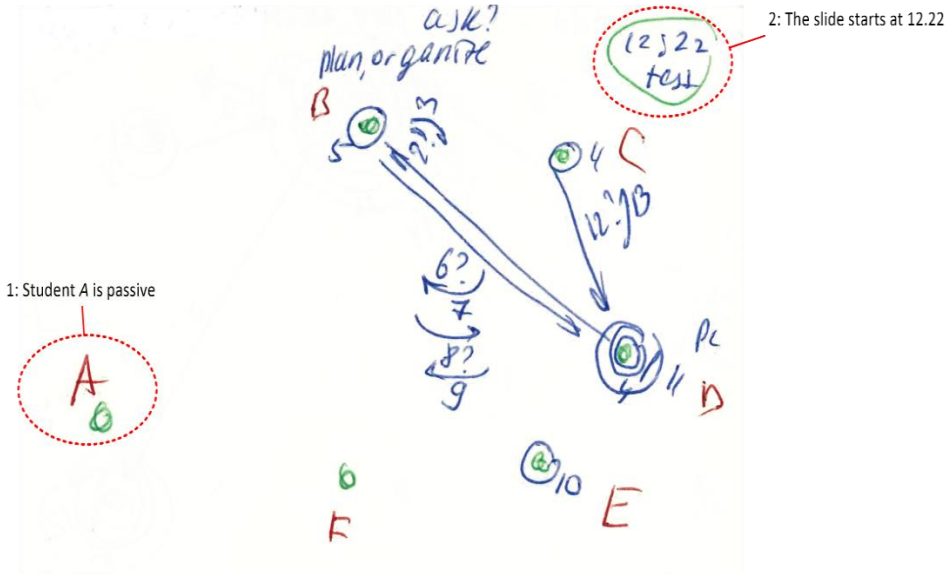


Figure 5.1. Interaction diagram: Communication Situation 1 (see text for explanation)

Persons B and C were supervisors, while the others were students. The numbers that follow indicate the sequence of interactions as found on the diagram.

The slide started at 12:22 when Student D proposed a discussion of model testing by appealing to the whole group (1), and then asked a question to Supervisor B (2). Supervisor B answered this question (3). Supervisor C started their participation by expressing their thoughts (4), and Supervisor B commented on this by appealing to the whole group (5). Then, intensive discussions started between Participants B and D: Supervisor B asked a question (6) and received an answer from the student (7), and then asked something else (8) and received a second answer (9). Student E commented (10), Student D continued the idea (11) (using a laptop, legend: "PC"), Supervisor C asked D (12) and received an answer (13). Special observation (see notes on the diagram): Supervisor B took an active part in the meeting, made plans and organised discussion that defined their team role as '*Facilitator*'. Student D was characterised in this slide as an active Team Leader in this group. Students A and F were passive and did not participate in the discussion at all.

Case 2: Use of Artefacts

The second example shows a variety of communication events. This was towards the end of the third meeting of the group with four participants: three students and one supervisor. It is not the same group as before. The team members were discussing some elements of the project model (scale) and used a whiteboard for graphical representation. This slide started at 12:58 pm.

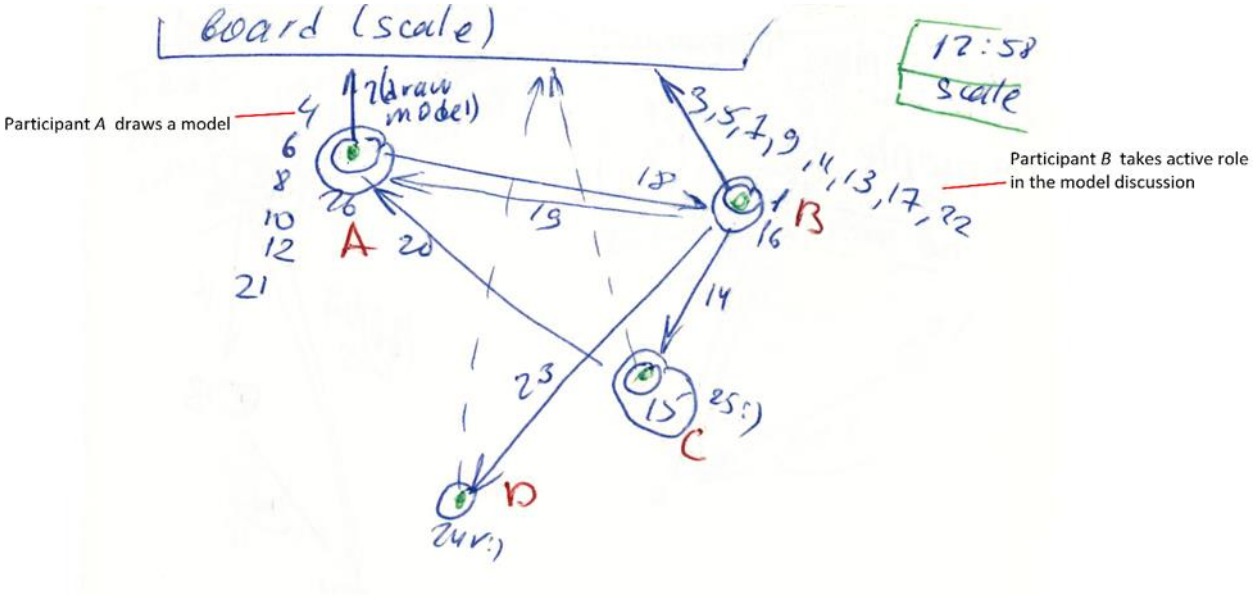


Figure 5.2. Interaction diagram: Communication Situation 2

In Figure 5.2, note the long rows of speech interactions: one arrow and many numbers. That was done because of saving space on the slide.

The top of this slide shows that a material object (artefact) was used by team members for communication. Such an artefact can be presented as a separate graphic object because during communication it possesses some features of an interlocutor (participants generally look at the artefact while talking and not to the other members). The first arrow from the participant to the artefact shows the person who starts using this object (draws a diagram or shows a physical model). Other participants may say or ask something –represented by the solid line. Alternatively, they may show non-verbal behaviour, represented by a dashed line (generally a sign of agreement, disagreement or misunderstanding that can also be annotated with a question mark).

In the current case (Figure 5.2), Participant A (Supervisor 1) drew a diagram on the board (Interaction 2), Participant B (student Team Leader) took an active role in the discussion of this chart, whereas Students D and C mostly watched the board showing signs of agreement and understanding (dashed lines and circles as short commenting without being addressed to a particular person).

Case 3: Parallel Discussions

This case illustrates an extreme situation. This involved a meeting with many team members and the complexity of multiple parallel discussions happening over a short time frame. Six team members (fifth meeting, middle of discussion time) were discussing the physical model, and the discussion was intensive.

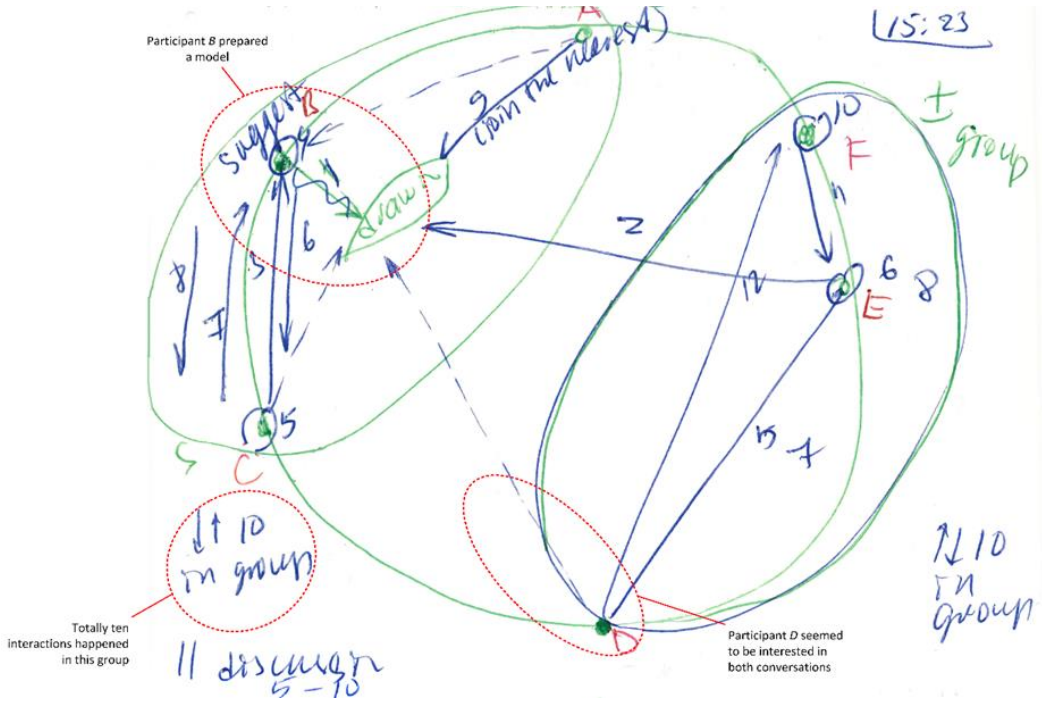


Figure 5.3. Interaction diagram: Communication Situation 3

Figure 5.3 shows there were six people in the room (different people to the previous cases). The meeting led to a parallel discussion in the group. The group was divided into two subgroups: Participants A (Supervisor 1), B and C in one group and Participants D, E and F (Supervisor 2) in another subgroup. Each subgroup had about ten communication interactions. As both communication discussions were very intensive, it was hard for the researcher to catch all of them. Therefore, small arrows and numbers were used to show the quantity of turn-taking among participants of each group.

First, Student B prepared a model (wavy line)—a physical object that was intensively discussed. Then, Student E added new ideas that were discussed in the whole group again. Later, there was a pause. Then, Member B showed a small artefact (chart) after which discussions divided into two different parts. Participants joined the group in the nearest physical proximity.

Participant D seemed to be interested in both conversations (dotted line means non-verbal interaction, interest) and hesitated which subgroup to choose. However, they finally chose the nearest one (specific reactions of participants on the situation are written above or below the arrow).

The challenge in this type of situation is to follow both conversations and do not lose the information. Parallel discussions make observations difficult. Apparently, eight people at the meeting may be a practical maximum for this method. Over this number, the information about communication may be lost for the researcher, and audio or video recording may be superior.

5.4. Discussion

Practicality of Observation and Preparation

We noted that behaviour of students who had a meeting in the supervisor's office was quite different from those meeting in neutral territory. From this, we infer that the place of observation may be important and influence the behaviours. We found it useful if there was a quiet place or corner in the room where the observer could sit and make notes without being intrusive to the

meeting. This place, however, should give the observer opportunity to see participants' interaction. i.e. not only hear the speech but also see non-verbal behaviours.

The other difficulty of observation setup is a preparation of materials. In our experience, the choice of paper may be important. Thin paper produces noise that disturbs the meeting. A small format notebook makes the observer turn pages frequently, during which some details of communication can be missed. A suitable medium was found to be a notebook of A5 size with pale white pages. The ink also should be chosen carefully (bleeding or pale ink makes diagram notes hard to read). The flow chart in Figure 5.4 shows the preparation for experiment.

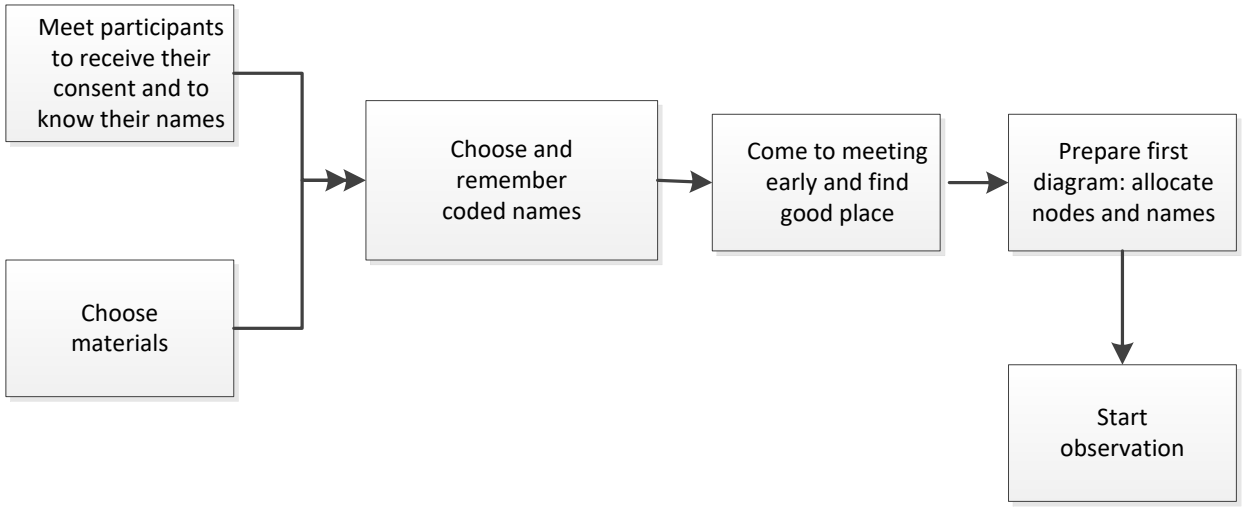


Figure 5.4. Setup of the observation

This ID method does not need special training and can be used by different observers (researchers or managers in the organisation). However, the group size should not exceed about eight people, and all participants should sit or move only a little during the observation. Otherwise, moving, intensive talking, and parallel discussions that sometimes appear in the big group may create difficulties in note-taking (errors and missed turn-taking). In this case, video-recording may be better.

In addition, knowing participants in person as quickly as possible increases chance for better data collection. When observers start their work at each meeting, they need first to recognise the participants and locate points (nodes) with letters (or coded names) on the paper that correspond to people in the room. Each meeting position of participants can be different, so it is important to do the setup quickly and not lose initial information.

After that, each new slide usually has the same position of nodes on the diagrams (provided that people do not move), so the observers' work becomes easier and consists of quick note-taking and line-drawings. When observers feel the data on the slide are enough, they draw nodes on another page in the notebook, thus preparing for the next slide. It takes seconds and does not have big impact on the process of observation. Here, it is important not to forget to fix the beginning time of each slide if observation is conducted for research purposes, otherwise for the purpose of commercial observation that may not be needed.

Advantages of the Method

We have devised a method that may be used to capture major interactions within teams. This method allows uninvasive observation and recording of multiple interactions between participants: time sequence, direction and type of interactions, using of artefacts, participants'

characteristics and group roles. This was achieved without requiring a recording device, other than a paper notebook. In turn, this makes ethics approval much easier. The method can also be less invasive and inhibiting for participants. It can be used in a time-pressured situation, within limits. A further advantage is the method obviates the need for post-event data transcribing, which is otherwise an onerous task for the researcher.

Points of Difference

Points of difference compared to standard sociograms:

- Allows recording time sequence
- Shows direction of member-to-member interactions
- Allows recording specific situational behaviour of different team members
- Records use of artefacts by participants
- Allows recording non-verbal behaviour, but only for a limited period of time
- Shows long monologue interaction
- Shows repeating patterns of the interactions between same group members

Points of difference compared to audio and video recording:

- Several interactions, including non-verbal agreements, nodding or gestures would not be detected with audio, but were captured with the ID method. With audio recordings, there can also be identification problems with multiple people speaking at once, which is less of an issue with the ID method.
- Video could pick up all these and has the additional advantage of being able to be re-played. However, video recording changes the behaviour of participants, and requires more stringent ethics approvals.

Domain Specific and Generic Elements

Domain specific elements in this study were the engineering nature of the work. The purpose of the meetings in this case was engineering problem-solving, hence the nature of the interaction was directed to task progression. In other contexts of human meetings, the nature of the interaction can be expected to be different. The symbols we developed were for the engineering context, and both these and the structure of the interactions may need to be revised in other situations. Nonetheless, we suggest the following elements are generic, and might be expected to appear in multiple areas: *the starting time; numbers*, the sequence of communication interactions; *letters*, participants of the meeting; *circles*, broadcast speech; *arrows*, the direction of communication; *question signs*, questions*; small arrows* near question marks, answers and repeating questions; *notes* written near participant's letter; *solid line* (verbal communication interaction); and *dotted line* (non-verbal).

Limitations of the Interaction Diagram Method

The method is limited to observation of small- or medium-sized groups (maximum about eight people) because of the manual nature of the recording. It is difficult to record the simultaneous non-verbal behaviour of multiple members, or if members constantly move about in the meeting. In addition, this method involves researcher's judgements about what level of detail to choose (for example, any interactions or only verbal ones), what to consider an artefact, personal

interpretation of situation (such as differentiating transmitting from addressing), and data presentation (how to represent new events). These limitations are similar to transcription [204]. The 'observer effect' [205] still exists because of the presence of the researcher. Another limitation is that the method does not provide a written verbatim transcription.

The method has not been directly compared to video recording. It would be interesting to determine whether some interactions might be missed, that might be detectable from video recording. It is to be expected that the observer might miss interactions during busy discussion periods, or in meetings with many active participants. Our initial observation from experience is that not keeping up with the interactions adversely affects the quantitative analysis but is not so damaging to the qualitative analysis. Other action communication situations as crew environments, or construction and operational activities, may require full video recording.

Implications

This method was designed primarily for researchers who need to observe group interactions between team members in an engineering organisation/university without audio or video recording. However, it could also be used by managers of organisations, for example as a supplement to minutes. Other possible applications include: the qualitative part of the ID method might be used for team formation or team recruiting, while the quantitative part might be used for appraisal and performance review. However, we note that the quantitative analysis is time-consuming and may be better for research purposes rather than commercial application.

Finally, ID tools could be used by university educators to collect data about student communication development in the final year teams. This potentially might be included in the curriculum of educational organisation. Data collection could be organised by simple observations on student behaviour during meeting time and note-taking. This data to be correlated with the student study results and then advice on study curriculum made. However, in this case, student team size in observed teams should not exceed 8 people to prevent loss of information'.

Future research questions

This first stage of study was exploratory by nature because of its short-term longevity and limitations (not able to follow participants between meetings and no questions asked during meeting). The purpose was to develop a novel method of observation.

A new line of enquiry could be to further develop the method by including: non-verbal interactions, developing a way to show non-verbal interactions in parallel with verbal ones); artefact abbreviations (create a list of possible artefacts and their abbreviations); and many people in the meeting room (improve method so it can show interactions of many participants).

In addition, it could be interesting to use multiple researchers for objectivity and measure the 'observer effect' [205].

5.5. Conclusions

A method of note-taking of information at observations was developed. It provides a graphical representation of the record of the interaction flow during meetings. It does this without needing video recording. It is also an efficient method, as it does not require subsequent transcription or coding. It also provides a procedure to quickly analyse communication situations, identify team roles, and compare group activity at different meetings (see Chapter 8).

ID method developed in this work require further validation, that will be described in Chapter 6. Implications of the method in industry and at university are studied in Chapter 7.

Chapter 6. Validation of the ID method

6.1. Introduction: Administrative engineering meeting

Background

Administrative engineering meetings are different from project meetings. The main difference is that administrative meetings have a strict topic sequence according to the predefined agenda, and a high status of chairperson that opens and closes with questions needed to be discussed. Each topic question is suggested generally by a chairperson, then discussed by team members and finally comes back to chairperson again who summarised and closed it. As opposed to project meeting, in administrative assembly, free discussion may exist only in a limited timeframe.

Objective

The objective was to validate developed ID method using observation at the meeting that use formal written minutes.

Having developed the ID method, we sought to contrast it to other methods. In this regard, the method that is most diametrically opposite is formally minutes meetings. Comparing the two methods is somewhat of an extreme comparison, because the ID method records the *behaviours* of participants, while formal minutes record the *outcomes* of the decisions, and sometimes the discussion. In undertaking the comparison, we were not expecting to find a great deal of overlap of results from the two methods.

6.2. Approach

We conducted a comparison of the ID and conventional minute-taking process by a single observation of a committee meeting at the University of Canterbury. The researcher sat aside during the meeting – did not participate- and made observations using the ID method. The university administrative staff made an audio recording of the meeting separately and independently. They also and produced minutes in the usual university manner. The minutes were subsequently provided to the researcher, but not the original audio.

Ethic Approval (HEC Application 2017/70/LR-PS) with amendments for the research was received by University of Canterbury Human Ethics Committee (Appendix E). According to this, the researcher could take written notes but did not have access to the audio recording and could not take part in the discussion.

This meeting was audio recorded for minute taking. Also, there were two people taking writing notes apart from the researcher. The official minutes was a combination of information extracted from the audio recording and written notes by some team member and was produced by the university staff, but not the researcher. The researcher used only written notes.

6.3. Results

Characterisation of the meeting

The meeting was one of the regular university committee meetings on postgraduate matters. The membership on the day comprised 14 participants: four postgraduate students, nine university academics, and one administrative staff member.

The agenda for the meeting had been published beforehand. The conduct of the meeting involved the chairperson following the agenda and managing the discussions.

Participants then addressed agenda questions one by one. All members of the group were able to take part in this conversation, including the student representatives. The Chairperson then closed each discussion by summarising the outcome decision or the achieved results.

The venue consisted of a spacious room with an oval table. The duration of the meeting was 54 minutes (0.9 hours).

General observations

The researcher observed that meeting had a strong location focus. People numbered 1–5, and 12–13 near the chairperson on the left side of the table participated actively, whereas other participants seated far from the chairperson mainly listened and showed non-verbal signs of attention. This raises the interesting question as to whether people who intended to be active deliberately sat closer to the chairperson, or whether proximity to the chairperson encouraged greater participation, or perhaps some other reason. As there was no follow-up interview with this study, it was impossible to answer this question.

Analysis of a situation

A typical ID diagram from the administrative meeting is shown in Figure 6.1.

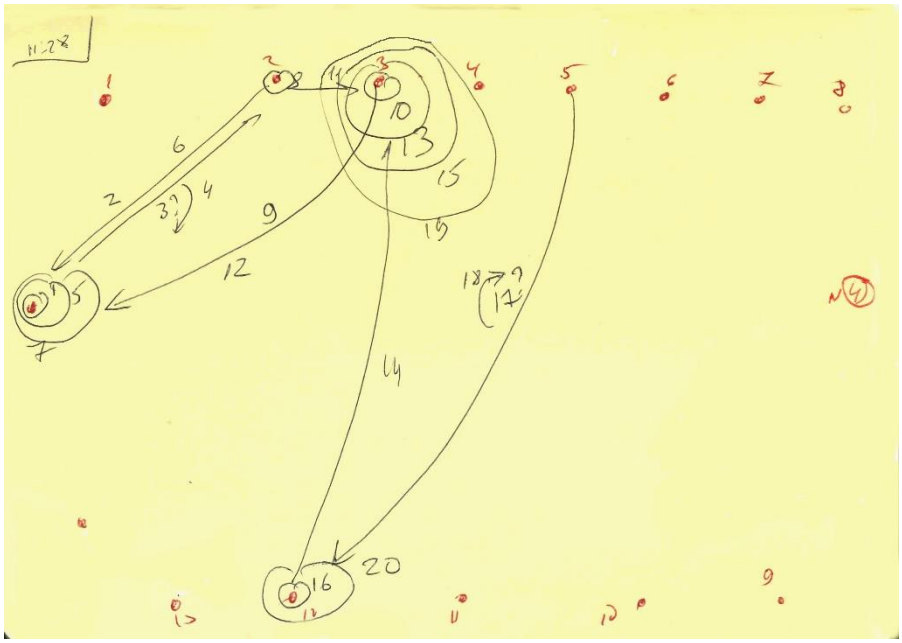


Figure 6.1. Administrative university meeting

This particular slide started 11.28 minutes into the presentation, on the agenda topic of scholarships. The discussion of this problem (number 8) lasted four minutes. In our example, the slide finished at 11.32 minutes. There were 20 interactions between participants during this time. Hence, 20/4 = five interactions per minutes.

6.4. Discussion

Based on the observation results, we could suggest a new characteristic of communication process – '*Robustness of topic discussion'*. It shows how well a question is discussed. The quantity

of communication interactions can be a quantitative measure of such a '*Level of robustness'*. (Later the thesis introduces another measure called *density of communication events).*

A quantitative summary of the number of interactions for the other agenda topics is shown in Table 6.1. The qualitative measure is perhaps the satisfaction that people feel after the discussion finished – how well they could participate in discussion and which goal was achieved (result). This was not investigated in this single observation.

Table 6.1. Robustness of topic discussion

Topic number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Quantity of interactions	1	9	3	5	23	8	3	20	24	13	12	38	7
Time, min	3	5	2	5	6	2	3	4	6	5	6	8	2
Robustness, inter/min	**0.33**	**1.80**	**1.50**	**1.00**	**3.83**	**4.00**	**1.00**	**5.00**	**4.00**	**2.60**	**2.00**	**4.75**	**3.50**

As we can see from the table, the robustness of topics was variable. Some problems were discussed extensively, while others were not. This might be because of the nature of the agenda items, and the importance thereof for participants. Some agenda items may not require intensive discussion and agreement between members of the meeting. Others may be more important and need extensive clarification.

In addition, other parameters that show general communication activity of the meeting were calculated (see the detailed explanations later in Chapter 8). The results are:

1. The level of communication inactivity per hour per team member was 8.6. That is quite a high number in comparison with project meetings.
2. The density of communication event was 3.2. That is a comparatively low number.

We can make a conclusion that the total intensity of communication at this meeting was not very high. Many members of the group were passive (inactive) and did not participate actively in the topic discussions.

6.5. Conclusions

The result showed that officially written minute-taking and ID methods catch two different types of information. We can even talk about two different approach to communication recording. Our approach was *interaction-driven.* We collected information about participants' behaviour during the meeting time: their contributions to the project discussion, participants' verbal and non-verbal behaviour alongside the sequence of turn-taking. Another approach that was used in official minutes is *topic-driven.* Here, the most important pieces of information are suggested topics, decision of the team and the time needed for topic close consideration. Sometimes this approach also includes participants' coded names and what was suggested by them, but in our case names and sequence of turn-taking were omitted. Therefore, the information extracted from meeting in researcher's observation notes was very different from official minutes. The researcher described interactions between people in the meeting, and official minutes – what was discuses and with what results.

Nonetheless, there is still a correlation between these two approaches, as both approaches interpret the same meeting and same people. Information received from our ID method about

communication interactions between people could be used to supplement official minutes. It will add the name and sequence of interaction, and also can help to estimate the contribution of each person to the reached decision, communication activity of the whole meeting group and how well each topic was discussed (that is 'robustness of topic discussion').

Implications for future work

The suggested ID method can be used as an addition to the official minute-taking. Apart from the robustness of topic discussion that help to understand how well agenda was planned, it can be seen a personal contribution of a participant to the problem resolution.

We suggest the following consequence of data extraction:

1. Time on the slides from ID diagrams is divided between topic discussion.

2. Quantity of interactions during this particular period of time is counted.

3. Robustness of discussion for each topic is calculated.

4. Other parameters are calculated: total 'Density of communication events' and 'Level of communication inactivity'.

5. A personal contribution to the common goal of the meeting is estimated.

Limitations

Topic distribution between slides can be different and not always coincide. In this case, we should find a proportion of time devoted to the problem and count a number of interactions there.

However, the main limitation of the use of ID method in the observation of administrative meetings is that data extracted from diagrams is mostly quantitative. Therefore, it should be used only as additional information because it does not catch the most important aspect of such kind of meeting – the details of the problems discussed and what is the results of this discussion.

Using the ID method in observation on regular project meetings can be more useful as ID diagrams not only help to count interactions but also record team roles. These behaviour patterns of each team member will be discussed later in this thesis.

Chapter 7. Industry and student case studies

7.1. Introduction

This chapter describes and compares results of qualitative study collected from teams at industrial organisations and at university. First, general communication features of project meetings were examined: team size, communication setting and parallel discussions. Various factors that may predefine project performance were also analysed, including frequency of project meetings, style of supervisor, and project meeting type. Then, two case studies from industrial organisations were described in detail including results from observations and interview. Finally, distinctions between communication at student project team and project team in observed engineering organisation were suggested.

7.2. Approach

The objective of qualitative study was to understand and describe how engineers and engineering students communicate at the project meetings at university and in industrial organisation. The study also examined the communication problems they encountered: how and why do they accept a particular communication pattern, and what does it mean for them? What is the best size of project team for communication? To answer these questions, an investigation in two project teams in engineering organisations in New Zealand and five student teams from University of Canterbury was conducted.

This second investigation included observation of project meetings when the researcher stayed aside taking notes and observing the team interactions. No audio or video was recorded. Observations on students lasted the whole academic year. Students were from the University of Canterbury, New Zealand and in the final year of a four-year Washington Accord engineering degree. The number of teams was determined by what was feasible for the researcher to follow since the teams tended to all meet on the same day. Later participants were also asked several questions about their typical communication behaviour and team roles. That was done using a structured interview to clarify questions that arose during the study. The participants were interviewed on an individual base, separately from the observation time. The interview happened only once, with every participant towards the end of observation on a particular group. It took around between five and 10 minutes.

In addition, all participants were tested using The Big Five test (Appendix C) that shows main five personality traits: extraversion, emotional stability, agreeableness, conscientiousness, and openness to experience (the degree of intellectual creativity) [50]. We used the ’50-item IPIP version of the Big Five Markers’ test taken from [200]. We selected this test and online resource because of the limited numbers of questions (participants need only 10-15 minutes to answer) and because the data from this test can be processed online.

Preliminary selection criteria for inclusion of a project team from organisation in the study

- The group consists of between three and eight members.
- The group meets on a regular basis.
- At least half of participants have an engineering background or engineering position in the organisation.

- The group includes at least one participant from a different engineering discipline (official position or education) than other team members or
- The group includes at least one person with a higher official position than other members.
- Project discussion is in the initial stage of development (first five meetings).

Interview questions, questionnaire and Big Five taxonomy test questions for engineers in organisations were the same as for university participants except for several questions that cannot be applied to people in organisations (see Appendices B, C and D).

General information about teams

Project teams at university

Twenty-five participants in total took part in the study (five teams with five participants in each). Every team consisted of one supervisor and four students. Among the participants 21 were males and four females (one supervisor and three students). Students were of the same age group of 20-25 years of age and from mechanical or mechatronic areas of engineering.

Students conducted their project as a final year work. These were large projects that needed the whole academic year for completion. Each team had some engineering problem to solve according to the brief providing by an external client. Participants generally had one or two official meetings per week and there could be also other kind of communication between them. However, the focus of our research was on the official project meetings of students and supervisor/client that took place at the university or in the external organisation. Students were assessed by supervisors regularly based on their contribution to the project development and ability to solve problems. Final project grade included many components, and student's communication skill was one of them.

Project team in organisation 1

The nature of organisation and projects

The organisation was an engineering consultancy firm situated in New Zealand, with multiple branches. The nature of the work was engineering analysis and design in the areas of machines, vehicles, and structural engineering. The size of the organisation was less than 40 members in total, which is in the small to the medium category for New Zealand [239].

Projects were short in length – from one hour to one week. Engineers received individual tasks, with Friday as the target day when all jobs should be finished. Sometimes two engineers collaborated on a project, but that was rare.

Participant demographic

We investigated one project team with six participants. All participants were male engineers. They were aged between 18 and 25 years, with between 2.5 and six months' work experience since graduation. The exception was for one participant with a PhD who had 10 years of work experience in engineering.

Project team in organisation 2

Organisational background

The organisation was an engineering manufacturing firm situated in New Zealand, with overseas branches. The nature of the work was engineering design and manufacturing. The size of the organisation was more than 200 members in total, which is in the large category for New Zealand [239].

Work organisation

The firm had many simultaneous projects. The length of a typical project was between three and five years and was divided into several small tasks between teams of engineers in different discipline areas (software team, mechanical team, etc.).

Project management in this company included the scrum framework and sprint cycling.

Scrum is a popular framework that is used in organising project development. During scrum time, a team moves forward to project completion. All team members work together to achieve common goal exchanging ideas and solving problems that arise inside a time periods called sprint cycles.

A scrum generally consists of three main categories: team roles (the Development Team, the Scrum Master, and the Product Owner), artefacts and events [240]. The event category includes sprint planning (called 'technical meeting' in our observations), Stand-ups (everyday short meetings), Sprint review meetings and Sprint retrospective meetings (called 'self-review' meeting in observed team).

A *Sprint* cycle is a period of time in which work should be done. In this organisation the typical length of a sprint cycle was three weeks. At the end of three weeks, project teams had to produce some results and to achieve goals. These results were discussed first at the Review meeting where work was presented to other people outside of the team, then there was a Self-review meeting where engineers looked retrospectively on what had been done during this sprint cycle and talked about their own problems, discussed how to avoid mistakes in future. Self-review was also followed by technical planning meeting with details for the next sprint cycle.

A big common task for the sprint cycle was then divided into small subtasks that were allocated to engineers. Therefore, they all had personal job to do, and at the same time a common goal to complete. Engineers could exchange ideas to help each other, however most worked individually. Sometimes one small task was done by several people.

Participant demographic

The team under observation was a software development engineering team. It consisted of 11 members (all males, aged from 23 to 55). Most of participants had many years of work experience in engineering. There was also one recently graduated team member.

The number of people in *Stand-ups* and other meetings constantly changed. Some engineers from other teams (e.g. Mechanical Engineering) regularly visited *Stand-Ups* of software team to report about their task that had some connections with what the team dis during the current sprint cycle.

7.3. General Results: Communication features in engineering project meetings

Data for this section was received from both university and industrial teams, whereas section 7.4 contains specific results that can be applied only to industry cases.

Team size and parallel discussions

Engineering communication during project completion can be organised in a different way. However, the central part of engineering communication is regular meetings that helps in planning project development, control results and contribute to the information exchange between project team members. Such a project team can consist of several group members. A small group of people create a special environment that helps them to feel more relaxed and

communicative. This environment gives each participant more time to express his or her ideas. The high level of diversity in the group may also support more intensive communication.

There is evidence that quantity of team members presenting at the meeting may influence the communication style and results of the meeting. It is considered in literature, that 'magic number' for creating productive team is seven plus minus two, because people can remember at the same time maximum seven numbers [241], so the span of attention decreases when the number of people in the room exceeds seven. Indeed, Harvard researcher Richard Hackman found that the best team size is four to six participants – with an absolute maximum of 10 – and that work performance decreases with the grow of team size [242]. However, Hackman in this work also mentioned that optimal team size is very complex question to determine. Sometimes, four or five team members provide comfortable environment for communication but is not the best size to perform effectively all team tasks. Other researchers suggest to avoid large teams because it may have an adverse effect on the team performance [243].

Similar findings were found in software engineering. The result of one study demonstrated that there are no clear correlations between increasing of team size and higher software efforts [244]. In the other work, the optimal size of the software team was found to be a medium in a large-scale project [245].

In our research, most of our student teams under observation consisted of between four and five members; usually one supervisor and between three and four students. The exception to this rule was a large team from the first year of observation (Team 1A) with nine permanent members. Sometimes, the team invited other people to participate in the project discussion: clients, guests, product owners or other team members. In this case, number of people participating in discussion increased sometimes to 10–12 people. According to the observation data, this increase in participant numbers by more than five leads generally to the several results:

- *Communication flow in the teams with high number of participants is generally more intensive than with low numbers (below 5):* possible reason for this is the increase in variety of participants' interactions (Figures 7.1– 7.2, from).
- *Fewer people participating in project discussion* or *less time is given to each participant to talk:* the obvious reason for this is that total (fixed) meeting time is divided to the quantity of people in the meeting. However, that is not a rule – it depends on the personality of the team members and their relationship.
- *Duration of the meeting may increase* – that is if duration of the meeting is not fixed or team is not ready to finish discussion;

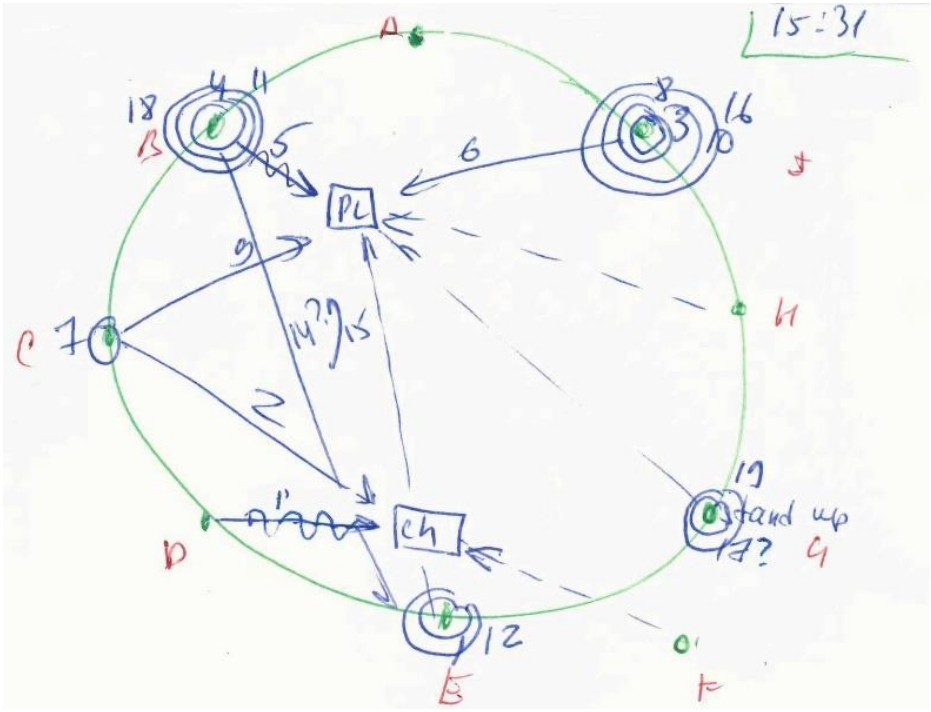


Figure 7.1. Intensive communication in the team of nine people (Team 1A)

- *Parallel discussions may appear when the group quantity exceeds six members* (Figure 7.2). Too many people discussing one problem may result in the group split, when the same problem is discussed by two geographically separated group of participants (for example, sitting on the left). The other reason can be that two different problems need to be addressed at the same time, and so the team may split to do it simultaneously. Also, personalities of participants may trigger parallel discussions, when there are several very active team members that do not wish to wait their turn for a long time to communicate.

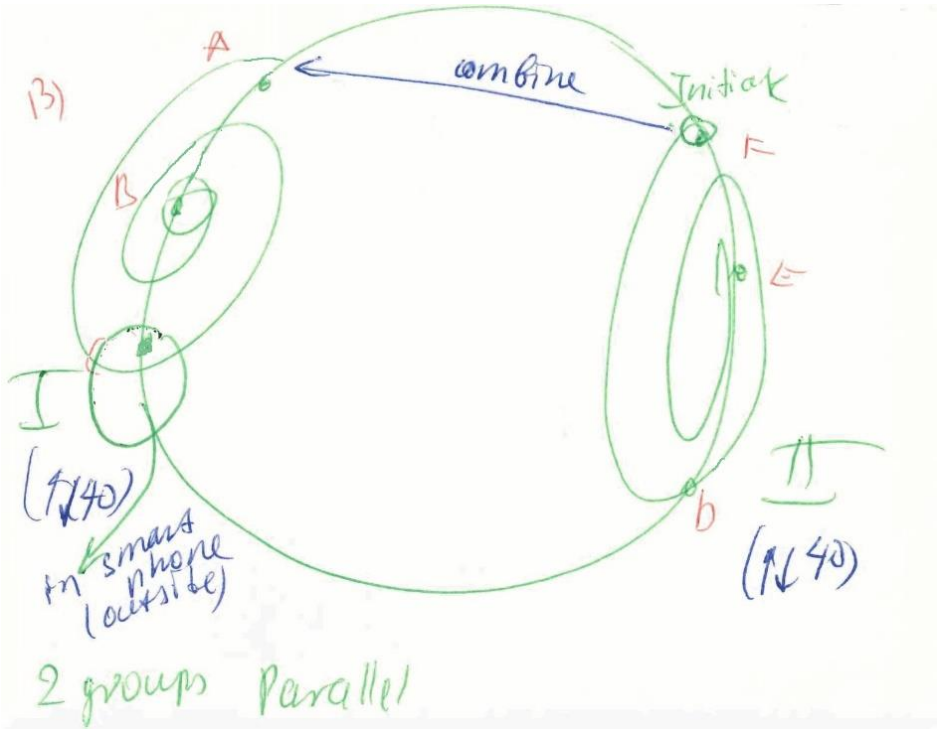


Figure 7.2. Parallel discussions

Figure 7.2 shows participation in a meeting of six people (Team 1A). The meeting led to a parallel discussion in the group that was divided into two subgroups. Each subgroup had about 40 communication interactions.

In our study, we observed parallel interactions only several time with one active student group (Team 1A) and therefore, did not collect enough data to make a conclusion about how these situations appear and how this influence the team performance. It may happen that parallel discussion leads to the team members distraction and time lost, or it might be very beneficial to the team as help people to discuss more information in short time. Further research is needed in this area. However, it was apparent that they came at a cost: of mishearing and information loss. Participants were observed choosing which group to join (generally join the closest one). Also, it was observed that questions discussed in parallel sub-groups were not answered nor always brought back to the whole group – there was unfinished business. The team might benefit from a more united discussion with all team members.

Typically, parallel discussion proceeds:

- Presentations of the model on a computer or another electronic device or
- A joke (participants switched to a more relaxed communication environment)

Typically, parallel discussion finishes with:

- A question from outside of communication subgroup, *or*
- A person monopolising discussion by making a presentation, starting a long explanation, *or*
- One active communicator gave up from their active role in the discussion.

Generally, a team is made up of two or more people. However, according to our observation data, communication in the meeting with only two people differs from what we observed in three-members communication. In a two-person communication, the discussion is more private, personal (more jokes, discussions on other topics) whereas with three and more people in the room, participants are more goal-oriented: the main focus is on problem-solving and not on personal relationships.

The information above was collected in Teams 1, 3 and 4 when one or two project participants left the meeting room or did not come to meeting. We do not have enough data to make strong conclusions in this area. However, our observation is consistent with the literature, which revealed different types of interactions that happen in the group of two-three people or more. Communication between two people who have common ideas to share belong to the pure interpersonal relationship, whereas communication between three and more participants of the meeting is already called a group communication which is less personal and more official. Previous studies found that group discussions leads to a polarisation of opinions, when group decisions become more risky and extreme than the individuals [246]. The group is also able to solve more problems because more people create a higher variety of skills and abilities in the team: therefore, group communication is more creative and effective. When only two people communicate, they solve disagreements quickly, but in the group communication this can be problematic because of fewer personal contacts.

Different types of project meetings

Data from observations allowed us to classify project meetings into four main types from a communicative perspective: *fully interactive (open), reporting (closed) and limited interactive (mixed).*

The first type of meetings we can call ***fully interactive (open for discussion) meeting with a communicative centre*** – when members of the group communicate between each other. There is however a communicative centre that is active in information emission. That may not be necessarily a supervisor (manager), could be also one of the students and engineers. Example see below (Figure 7.3).

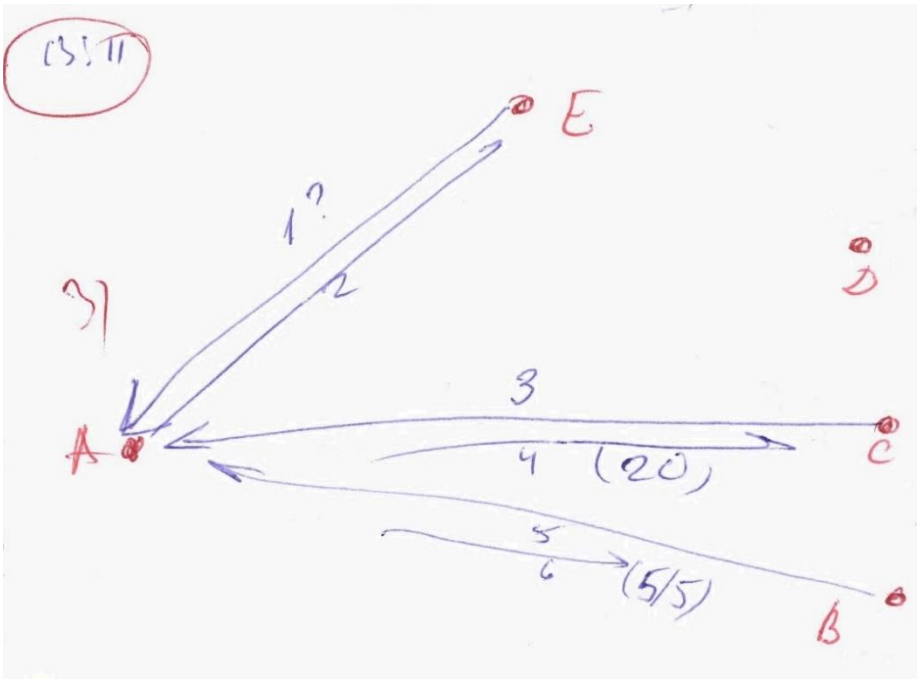


Figure 7.3. Open project meeting with communication centre (A) -Team 1
[from observation notes] '*Supervisor (A) behaved like a transmitter of information for the whole group (communicative centre) – 20 interactions to student C, 5 to student B and 1 to student E. Other three participants also discussed project results with supervisor and added some new information, however activity of supervisor was higher. Participant D was a passive member of this group*'.

There can be also ***open meeting without a communicative centre*** where all participants discuss information between each other and there is no prevailing direction of communication flow (nobody is in the centre of attention for a long time) (see Figure 7.4).

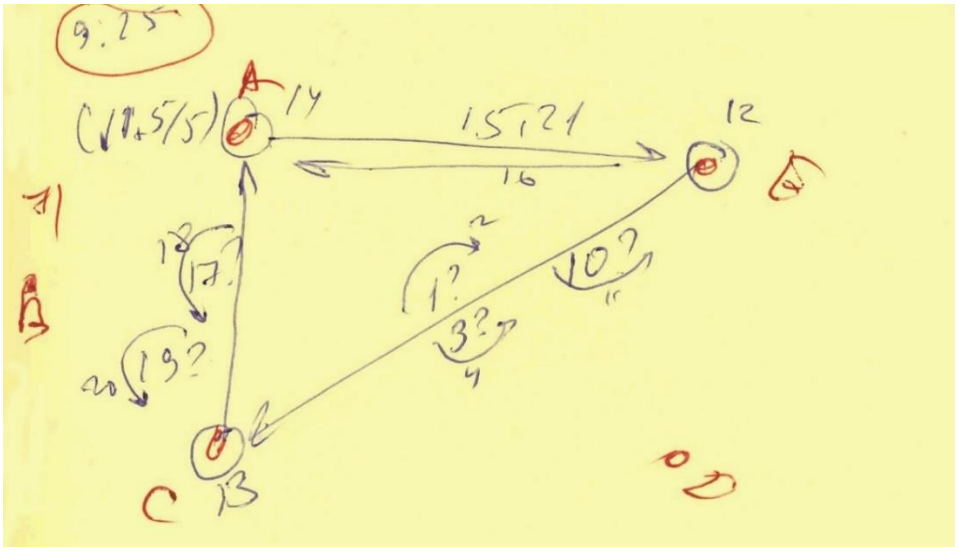


Figure 7.4. Open project meeting without communication centre -Team 2

In Figure 7.4, participants A, C and E actively discussed project problems between each other (created 'a communication triple'), while students B and D were apparently in active listening.

Reporting type of meeting (closed for discussion): In such a meeting, there is almost no communication between participants. Students (engineers) report their achievements to the person with power (supervisor, manager). There are almost no interactions between other group members (see Figure 7.5 below).

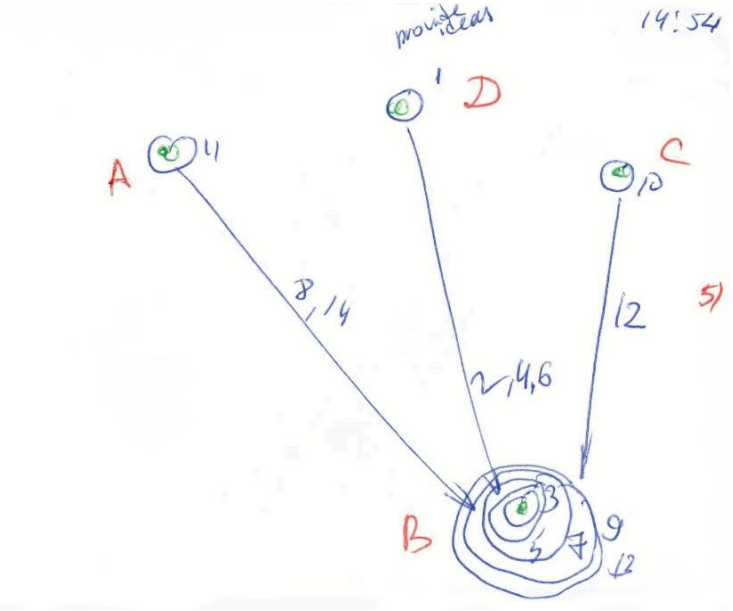


Figure 7.5. Reporting style of project meeting – Team 3

Figure 7.5 shows that participants A, D and C all made some kind of report to the central participant (supervisor).

Limited interactive (mixed communication) meeting: Participants reported the main achievement and issues to the one person with power, such as a supervisor or manager, and also sometimes discussed current problems between each other (Figure 7.6).

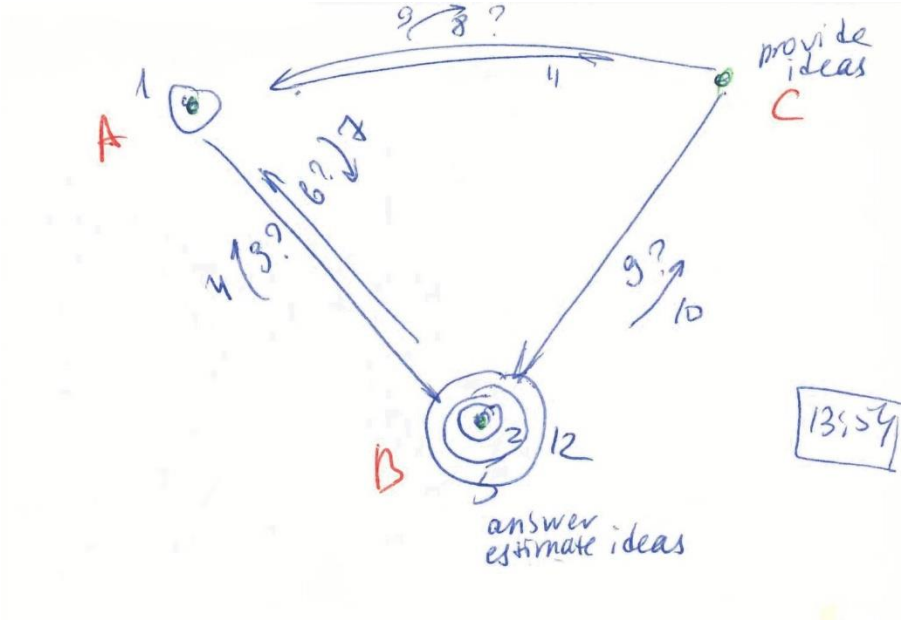


Figure 7.6. Limited interactive meeting **–** Team 1

Figure 7.6 shows that participant B was a person (supervisor) who accepted reports and also transmitted information to the whole group, and according to the discussion data monopolised the discussion several times. Meanwhile, there was a free discussion between other team members (A and C), with some questions and comments addressed to supervisor B. This was an interactive communication, however, limited by one person.

Communication settings

There are many factors that may influence the communication in the team of engineers at the meetings. Among them, one person could mention location of the meeting, location of the participants inside meeting place, using of technical device, noise, table, sitting versus standing.

Participants in the organisations and at university were asked a question in interview: *'Do you feel that location and sitting/standing in the room at meeting predefines your communication style?'*

The results for **organisations** was that central position in the room inclines people to talk more, whereas if somebody wants to stay aside, he/she may choose to stay aside near the door**:** *'If I prefer not to be involved much, stay aside near the door'.* Most participating engineers would also prefer to sit as sitting is more relaxing, less formal, and provides them with more confidence: *'I would feel more confident in communication when [I] sit'.* However, standing meetings are generally faster and gives a feeling of freedom: *'I feel more freedom,* [and a] *friendlier environment when we stand'.* It should be mentioned that type of engineering organisation and type of meeting could influence participant comments because communication settings are different there.

At **university,** the responses were quite different. Half of the participants just mentioned that location in the room is not important for them at all. Another half had something to say about position. Most people preferred to sit in front of the person with whom they talked such as a supervisor. Some students mentioned that round table discussions gave all people equal opportunities to talk. One student complained that meeting in the supervisor's office does not make them feel comfortable: '*I associate* with the *office negatively and did not enjoy being there'.*

To sum up, location inside the meeting room may be of somewhat important for active participants or for those who do not wish to communicate at all. The positioning of people relative to the person with power (manager, client or supervisor) could also be an important factor predefining communication style too.

Factors that may predefine project team performance

We think project communication can be called *effective* when the team complete project in time with high individual marks, and when participants are happy with their communication at the meetings. Levels of satisfaction with team communication can be found in interview answers. And project team performance (for students) can be seen in the final individual and common team grades.

There are also many factors that may predefine team performance. Among them we may assume frequency of the student meetings, personal characteristic of group members, communication activity, type of meeting and a style of supervision.

Frequency of meetings

Other researchers [247] found that frequency of communication depends on the phase of the task and group development as they are correlated, and influences the team effectiveness.

Teams that meet frequently and discuss engagement of participants in early stages of group development generally have better performance than those that do not ([247] reviewed by [248]). It could be interesting to check this information; however, our project is mostly based on the qualitative data and we do not have enough quantitative data for any statistical correlations. Therefore, all judgments below are just our assumptions in accordance with our observations on five student teams during the whole academic year and several teams during a short period of time. Further research is needed in this area.

In our study, student teams had regular official meetings with supervisor once or twice per week. However, two of the teams did not install regular meetings immediately at the initial stage of project development (Team 1 and Team 5). They preferred waiting until the time pressure raised. We did not notice any relationship between frequency of the project meetings among these five student teams and final project performance. Teams that missed frequently meeting times were late in their reports and experienced problems with middle project results, however, their final results were still good (Team 2). Furthermore, two groups of students from the first stage of study had rare meetings during the whole academic year, once or twice per month. However, they came in time with the project reports and received high marks at the end of the year. Those who had significant problems in the beginning and in the middle of the project development, increased their activity by putting more efforts to their job and intensifying communication during the same regularity of meetings (Team 3).

Therefore, we may propose, that project performance in student teams depends more on the effectiveness of the communication during meeting times rather than on frequency of the meetings.

Personal characteristic of group members, communication activity and frequency of meetings

By combining results of the Big Five tests for the whole team, we could draw conclusions about the team's characteristics (see Table 7.1). It is possible that a team with highly introverted people may not have a need in frequent meetings and could do well without intensive and active communication interactions. Other teams with high passiveness and low '*Openness to experience*' in the Big Five test may need strong control by supervisors and have a regular meeting once or twice a week. Also, a style of supervision is important too, as it should suit the needs of the group.

Table 7.1. Big Five test results, communication activity and student team performance

TEAM		O*	C	E	A	Em	Communication activity	Frequency per week	GRADES
01	**Mean**	**65.8**	**75.8**	**44.8**	**44.6**	**44.6**	**4.0**	1	**79**
	Stdev	15.3	30.8	19.5	42.4	28.1			
02	**Mean**	**49**	**67.8**	**37.8**	**44.8**	**53**	**3.3**	1	**80**
	Stdev	16.6	26.1	27.8	28.3	21.3			
03	**Mean**	**57**	**44.8**	**33.5**	**52.8**	**24.3**	**3.9**	1	**65**
	Stdev	19.7	34.4	26.6	9.9	12.6			
04	**Mean**	**81.8**	**71.8**	**66**	**64.3**	**47.5**	**4.3**	2	**87**
	Stdev	8.7	14.9	18.5	28.5	21.6			
05	**Mean**	**27.3**	**71.5**	**47.3**	**60.8**	**35.5**	**2.9**	1	**91**

	Stdev	13.1	19.4	25.4	8.5	29.9			

*O – Openness to experience, C – Conscientiousness, E – Extroversion, A – Agreeableness, Em - Emotional stability

In the Table 7.1, 'Frequency per week' is the frequency of the official meetings with the supervisor only. 'Communication activity' shows how active was team in communication during the project meetings and will be introduced later in Chapter 8 (as a 'density of communication event').

Table 7.1 shows that Team 4 that had meetings twice per week did not receive the highest grade. This can be explained because of many factors that constitute to the student team results.

It is sometimes considered that the more active is the project group in communication the higher the performance it may achieve. However, there may no such direct correlations. According to the interview with participants, most of them would prefer middle activity in communication in the teams: *'Middle. Accuracy is important but quick idea exchanging is more creative'.* However, this depends apparently on personality, some members prefer quick discussions, others slow: *'Slow but accurate discussion'.*

Observation on several student teams did not allow us to make statistical correlations between communication activity and total group performance. However, it can be seen from the Table 7.1 that Team 5 did not communicate very actively, and received the highest team grade. A possible explanation is that team members felt comfortable to interact at official meetings rarely and discussed only the most important details there, whereas small issues were apparently discussed somewhere else or through electronic communication.

Type of project meetings

It should be noted that we observed two student teams with reporting types of meetings and participants of that teams completed projects with different results: one team got excellent marks (Team 2B from the first stage of observation), whereas there were problems in the other team and its final grades were much lower (Team 3). The same happened in the teams with other meeting styles. Therefore, apparently, a type of project meeting does not have great influence on the project completion and possibly depends on participants' personality, skills and other factors.

Supervisor's styles

As for supervisor's styles, students were asked in interview '*Which style of communication 'students-supervisor' at project discussions do you prefer? (extensive freedom, less freedom, total control). Do you think it predefines the results of project performance? Why?'.* The answers showed that among students the majority (16 out of 20) preferred extensive freedom because *'it allows to express own ideas and it is a student team rather than supervisor's'.* Only four students mentioned that they are still not experts and prefer *'Less freedom overall to keep meetings to the point'.*

Our observations showed that Team 3 had a 'total control' supervision style. However, students received the lowest marks, and according to interview were unhappy with their project team communication at meetings: *'The barriers were that the project was simple but became complicated by misunderstanding and expectations to do things that did not need to be done. A lot of time was wasted on things we did not think was necessary, but supervisor did'.* We think that too many factors may predefine the situation when students may need 'total control style', among them personal characteristic of the participants, nature of the project, level of students'

knowledge, different cultural background of participants. Also, final team grades are not actually a result of only communication problems among team members. This can also be predefined by other factors. Project performance is a complex area that is not limited by communication aspects only.

7.4. Specific Results: Industry Case study

Case study 1: Communication in engineering organisation 1

Communication routine

Engineers were aggregated into several teams marked with an assigned colour. Every team then met every day in the morning in some meeting room coloured with the team colour. Each team had its Project Team Leader with special duties to control and to distribute the workflow.

At these morning meetings, one by one, all team members reported on their progress to the Team Leader. At the same time, the Team Leader was watching closely to the monitor and checked the current plans and workload of every engineer. If one project was shared between two team members, they then discussed project issues individually, rather than at the meetings. If some team members needed special attention (generally graduate students), the team members arranged an additional meeting with the Team Leader, and they solved the problems there.

Each team also met in the same room every Friday afternoon. They discussed issues and good events that happened over the last week. During the week at any moment, team members had the right to come to the whiteboard and write issues (right side of the board) and good points (left side). Then these would be discussed on Friday. However, this meeting had a more informal character. Participants did not discuss the project problems as all jobs should be completed by that Friday.

Observation results

How communication at meetings predefines project results?

Regardless of the team type of conducted project meetings at the organisation, communication there can be defined as active reporting – a series of personal interactions of engineers and Team Leader. According to the observation data, participants had almost no communication with each other, except for comments about others' actions from some team members. Also, sometimes participants communicated to solve minor problems, but that happened rarely, generally when two engineers shared the project tasks and helped each other in reporting.

However, the organisational style of work at this company as many individual tiny projects did not require prolonged discussion between several members. Therefore, this type of communication is assumed to be the most natural for them and apparently resulted in successful project performance. Indeed, most of the projects were completed by the scheduled Friday.

How are team roles formed over time and distributed among members? What communication pattern may indicate or predefine the adoption of team role?

The team can be presented as a group of people working together to achieve a goal. If the goal is project completion than this definition cannot be applied to the teams in this organisation. Therefore, there are no observed team roles, apart from the 'passive' and 'active' communication behaviours. Engineers take an active role when they wish to communicate with the Team Leader and passive when there is not their turn to do this. In rare cases, the roles of 'communication assistant' and can be defined as when two people are working on the same project.

Interview results

1. Do you feel that your organisational position predefines the choice of your team role? Why?

Participants felt that the organisational positions predefine their team roles to some extent. They felt that in a different situation they would behave differently. To some extent they felt restricted by the expectations placed on them by the work situation. For example, one respondent mentioned that: '*When people look at you, you feel ...what is expected from you*' (paraphrased).

Two main categories of responses were evident to this question. One group of engineers were able to communicate with what we call *active confidence*. They were task-focused ('*I do not like delays*'), and knowingly adopted a direct communication style ('*I do not wait if I need to say something*').

The second group was passive. In some cases, this was because they felt comfortable in this role, and in other cases it was because they felt unconfident or new in the role. However, some of the engineers who identified a preference for passive communication at this question were found in the ID (interactive diagrams) observations to behave in active ways. This implies that there may be different constructs for passive communication. Hence, we propose that there is a *passive confident* style, as well as a *passive unconfident* style. Engineers in the latter group may feel an element of stress during communication.

Some engineers appear to adopt an active role, even though they would naturally prefer a passive one. Hence it appears that the situation partly determines the role taken. This is consistent with the findings above. It is also consistent with Lewin's field theory – behaviour is a function of the person and environment [249].

2. Considering a typical meeting, what is your intuitive perception of your communication style and behaviour, and how that affected the communication during the meeting? How do you feel in this role?

Team members felt comfortable in their new roles except for newly graduates that needed time to adapt to a work environment *('I feel very unconfident because I still do not know my job and these people very well'*). According to the responses, participant's communication styles and behaviour derive from the personal traits and the practical aspects of meeting, such as who was present at various meetings: *'If I know the job very well, I would be more talkative and active'; 'I am generally passive. This is probably a character'.*

3. Did you feel that you changed your communication behaviour at different meetings? Why was that?

Most participants feel that their communication behaviour depends greatly on the situation: the status and quantity of team members ('*many participants give less chance and desire to talk'*), type of meeting, and the professional level of communication *('more professional level of communication is more challenging')*. It was observed that participants behaved differently in meetings based on their mood (emotional state), and this created different communication environments.

4. Do you feel that location in the room and standing/sitting at meeting predefines your communication style? Why?

There was a big variation of answers to this question. Some participants feel more relaxed when seated than when standing, and so they would prefer to sit at the meetings. Others, on the contrary, feel more relaxing when they stand, and they find standing meetings to be faster ('*I feel more freedom, friendlier environment when we stand').* People with the passive unconfident style of communication appeared to feel better while sitting *('I would feel more confident in*

communication when sitting'). When asked about preferred positions in a meeting room, it was found that a central position inclines people to talk ('*more active come closer, passive stay aside').* Participants that do not want to be involved in a hot discussion for some reason may try to stand to one side, near the door.

5. a) To what extent do you feel that miscommunication occurs in your meetings? [never, sometimes, most times, always]. b) What forms do you think miscommunication takes? What do you think were the typical causes of the miscommunication? c) Did this change the way you communicated?

Participants feel that miscommunication at meetings happens rarely. Answers range from 'never' to 'sometimes'. The main reasons for such problems – a lack of experience leads to the situation when engineers do not see the full picture and misunderstand the Team Leader. Responses included: *'If I do not understand, I ask my Team Leader, and they explain everything to me'; 'They* [team members] *think that it is going very well, whereas I see that it can be some problem.*

At other times, team members do not understand each other because their speech was not clear: *'When I say something, and it was not very clear to others, so they do not understand me').*

Miscommunication may arise from not discussing an important problem that should be discussed. In addition, external communication with clients is apparently a big issue for engineers that may cause misunderstanding because of its non-direct nature at this organisation.

As a result, engineers sometimes change the way they communicate by adapting to the situation: they try to be clearer in conversation, use precise words, and avoid the possible problematic area. If miscommunication continues, engineers can have a one-and-one meeting with Team Leader and receive a full explanation.

6. Sometimes people in meetings make use of physical objects like drawings, papers, computer screens, physical models, whiteboard images, etc. a) To what extent do you find it helpful when people present these types of objects? [never, sometimes, most times, always]. b) Why do you think that is helpful/unhelpful to you?

All participants agree that physical objects that are used during the meeting and the whole work week are very useful for them. The most useful object is the computer program that helps in time management and progress visualisation: to track the progress of engineers and to plan their new achievements *'it is very useful because it helps us to keep on track'*. It is especially important for such organisations with many small projects that should be done during the short period.

The whiteboard system implemented in the organisation seems to work well. It helps to unite people, make them work as a team, also it is very engaging. *'The whiteboard is very engaging and unites people'.*

7. Would you like to change something in your team communication?

Participants with short work experience do not have suggestions. They are still learning by listening to others and are not experienced enough to give any advice. More experienced engineers could suggest something to improve team communication. However, their opinions were very different and sometimes even opposite to each other.

From the Team Leader's perspective, there appears to be interest in extending meeting times, such as introducing another meeting in the middle of the week. It was felt that this might avoid miscommunication. However, comments from other participants suggest that this might not be as productive as it might seem. It seems the deeper issue is engagement. Comments that indicate this are: *'our meetings in the morning are too long*', *'everybody could be more engaged*'.

The issue appears to that the members feel bored because the discussion is not relevant to their project. Engineers report to the Team Leader, and others just listen and cannot participate in the discussion, e.g. '*people feel bored while listening to others*', '*we do not have much to discuss together'.*

Another participant supported this idea and suggested to engage people in morning meetings more, e.g. *'engineers should take efforts and share their opinions with each other'.* For example, Team Leader may consider deliberately asking people for their opinions about various issues.

Also, one more suggestion was about structuring the meetings, so they are implemented task by task, day per day *'I think that our meetings can be more structured'*.

Analysis - Summary of what happens at meetings

There appeared to be three main issues at regular morning meetings:

1. Operational need for the meeting (functional perspective of Team Leader).

The Team Leader feels that more meetings cause clearer communication. Other members of the team would rather prefer separate consultation in case of misunderstanding. They suggest decreasing the meeting time.

2. Engagement of individual engineers.

Engineers feel disengaged. They think that the reporting type of meeting is not very interesting. The evidence for this came from observations:

- While one team member is reporting, others keep silent and rarely comment on the project.
- People may be distracted and do some other activities.
- Participants change the topic to the area that engages all the group.

3. Development of team cohesiveness in the workplace.

The team may need to develop group cohesiveness, and therefore, some kind of team meeting is necessary for people to unite them.

Potential implications for the organisation

Implications for development of young engineers

Recent graduates who join the organisation may be feeling burdened by the constant need to behave in a way that is expected by the role, irrespective of their mood. In other words, they may be feeling less freedom about the communication styles that are available to them to adopt. This is not an issue that appears to be considered in the literature. Nonetheless, possible courses of actions for team leaders might be managing the transition for these engineers. For example, giving them specific individual tasks and slowly building up their involvement with larger project teams. It may also be valuable for team leaders to consider helping new staff build relationships with others in the organisation, and again initial involvement in smaller rather than larger project teams may be beneficial.

Managing competing communication styles

Some engineers appear to be using a style of *active confidence*. These engineers find it easy to interject into a conversation. There is a possibility that this may stifle the contributions of those engineers who use the *passive confident* style. Team Leaders might like to consider deliberately including opportunities in meetings for the quieter engineers to contribute, perhaps by directly asking for their input.

Case study 2: Communication in engineering organisation 2

Communication routine

Communication in engineering teams were organised in accordance with the scrum framework. There were several engineers in each Development team chaired by a Scrum Master. The Scrum Master was not a permanent team role. Sometimes, the role transferred to other members at each sprint cycle (in the team under observation there were three engineers that rotated the role of Scrum Master between each other). Product Owner may also take active part in the project discussions.

Communication between engineers happens at each stage of sprint cycle. Generally, every engineer does their part of the common job and reports about the progress at everyday Stand-Ups. However, if some big issue arise that need close attention, then it is discussed at the special additional meetings that happen twice per week. There, all team members share and try to find a solution to the problem.

We observed several types of engineering meetings there (4 *Stand-Up* meetings, one Review meeting, one Self-review and one Technical meeting), and communication routine were different in each meeting type.

In *Stand-Ups*, there was generally a sequence in which team members communicated. First, the Scrum Master announced the first task. Then the participant to their left reported results to the Master and to the whole team. This continued in turn in clockwise rotation. The turn-taking was controlled by passing a pink stick – the person with the stick had speaking rights, though others could ask questions. If a person had nothing to say about this problem, then they just passed the turn (stick) to their neighbour to the left and so on. Sometimes a team member would break the order and comment, but this happened rarely. Once the pink stick returned full circle, the Scrum Master announced the second problem, and discussion continued in this way.

At *Review meeting*, engineers make presentation of their job to the people from outside the work group. This looks more like a report-style of communication. This meeting is then followed up by the Self-review and Technical report meetings with more freedom in communication and team roles.

Team members at *Self-review* prefer to sit in separate room and to discuss problems of the last sprint cycle inside the team. Only a few people may be invited to this part of the project discussion. Then, at the *Technical report* meeting, engineers in the team stay in the same place and continue closed discussion about technical problems and also discuss future plan for the next sprint cycle.

Observation results

1. Does communication at meetings predefine project results?
Engineers actively communicated during the meeting time and that obviously contributed towards common goal of project completion. However, as projects take a long time – generally years – it is hard to see correlations between project success and communication inside one sprint cycle.

2. How are team roles formed over time and distributed among members? What communication pattern may indicate or predefine the adoption of team role?
The formation of roles was not observed, and roles were not observed to spontaneously change. Instead roles appeared to be set by organisational responsibility and delegations.

The Scrum Master was always active because of their duties. According to the observations, recent graduates were generally very passive because of the time they needed for adaptation. Other engineers just reported about their achievement in current task or discussed problems with colleagues without revealing a particular behaviour style (unlike student team members).

Comparing *Stand-Ups* and other meeting types, difference was observed in engineers' behaviours. *Stand-Up* meetings had more routine and formal communication.

In contrast, the behaviour in *Review meetings* was subtly different. It tended to be more natural, less formal, more spontaneous interactions, and roles became more apparent. Team members tended to talk according to their own preference style rather than official procedures. According to the observation data, the presence of new people from outside the work team changed the patterns of behaviour. It appears that the review meetings gave more chance for people to behave freely.

Immediately after the *Review meeting* was the *Self-review* and then the *Technical meeting*. Observations showed that these latter two meetings were characterised by higher freedom in communication, more jokes and casual behaviour style than at previous meetings types. These meetings were closed, only team members were presented, and had no people from outside the group.

Interview results

1. How comfortable do you feel in this team communication? What do you like? What was wrong?

Most of engineers feel comfortable in these stand-up meetings:

(+) People like that they do not have a team leader with permanent status. Therefore, they feel they are all equal and can speak freely with each other. If really necessary, they can communicate directly with a senior manager. There are also many opportunities for each participant to talk and to present their ideas during the meeting time. Everybody has a chance to talk. *'Able to communicate directly with senor engineers. People are always available to ask for input on a problem'; 'Everyone is free to speak their mind, and disagreements are not taken personally'*.

In addition, engineers like organisation rules of the meetings: brevity, regularity, accuracy, clear focus, and that meetings are generally finished in time: *'I like the way brevity is encouraged -side trades are deferred to a separate discussion. I like meetings that are encourages to finish in time'.*

(-) According to the interview answers, the main communication problems at Stand-ups are that sometimes discussion goes too much in detail and the main topic can be lost; also, some people may move from the topic to the items irrelevant to the main discussion. *'Sometimes people go into too much detail. This is meant to be a summary and repeating the meeting.' 'Sometimes there were too much technical discussion that would be better in a smaller group after the meeting.' 'Too much details on some topics. Not enough on what is going to be done in the next 24 hours*.'

Another complaint is that it can be difficult for a new member to get comfortable in such quick and brief communication meetings, and this may take some time to adjust to this.

2. How productive do you think is your team in problem-solving? According to you, what are the barriers for team productivity and successful problem-solving? And what were the strong aspects of communication in your team?

(+) Strong aspects of communication: Openness – *'everyone is encouraged to participate in discussion and to share ideas'. 'Participants treat disagreements professionally and never make them personal'.*

(-)The biggest complaint is that team members sometimes pay too much attention to technical details or semantics of names and so lose focus of the actual problem: *'We get caught up on small details and waste a lot of time on them'*.

Some participants also think that the team may spend too much time on the interesting part of the problem and not on finding the real cause of it.

Another problem may be an '*over-commitment to follow rules or procedures'* instead of the focusing on problem-solving and involving all the best people: '*Rules should be disregarded if it helps you to reach the end goal quicker'.*

3. To what extent do you feel that miscommunication occurs in your meetings? *[never, sometimes, most times, always]****. What do you think are the typical causes for this?***

Engineers think that miscommunication at their team happens sometimes but not very often. Typical causes are complex or ambiguous terminology, and quick changes of context: *''Sometimes team members use own experience to create message and others may not this understand. Also, deep technical discussions can be of great problems when some people are not familiar with the topic and miss important information'.*

4. What is your intuitive perception of your own communication style in this team?

Engineers' answers were quite positive about their communication: *'I like to think that I communicate clearly, close to fact, reason and logic with occasional humour), also allowing plenty of room for others to speak freely'; 'My communication is short, to the point, and focused on what I think the team needs to know about the overall program. I question points which I think have an effect on the program'.* Also, introverted people communicate less *'I try not to communicate unless my input is directly require'*, while new participants felt some anxiety: *'sometimes worry not to make mistake', 'often quite but willing to speak when needed'.*

5. Do you feel that you change your communication behaviour at different meetings? Which communication situations caused that?

Most engineers agree that they change their communication style in different situations. The most common reasons are:

1. **Meeting context**. Engineers are more active in communication when they have much to say about the problem. *'I am an Initiator and Information Provider, when I am hosting a design proposal meeting for the work I am doing*'. '*In some meetings I am the prime driver, in others I am a low-level participant'.*
2. **Level of expertise.** Participants are more talkative when they feel confidence in the area of discussion. *If I am the expert, I will do more information providing'.*
3. **Type of meeting.** '*Stand-up' tends to be providing progress updates versus high level design which is more of a how should we do the meeting*'.
4. **Audience.** Official style of meetings or presentation generally require more official behaviour than at team only meeting where engineers feel more freedom. Also, different team may have different style of communication. '*Meetings with the software teams are different form the meetings that includes management*'. This was also apparent from observation.

6. To what extent do you feel that other people's discussions prevented you from making a contribution at meetings?

Some participants are apparently more sensitive to other's needs to talk than others. The most active members, the three participants that rotate chairing, generally leave space for other people to talk: *'I like to leave space for people, so if the discussion goes somewhere that others are more familiar with, then I generally speak less and let them speak'.*

7. What is your preferable style of communication at meeting: slow but accurate discussion, middle intensity of communication, or communication at high speed with quick exchanging of ideas? According to you, which meeting style is the most helpful in problem-solving?

Most participants prefer a mixture of styles depending on situation or a middle intensity discussion – '*this is most helpful in problem-solving as it leaves intricate details to later but allows enough depth to fairly gauge the likely success at the proposed solution'.* One engineer with a passive character prefered slow discussion, and while another valued a swift exchange of ideas.

8. Do you feel that location of the meeting and your position inside the room predefines your communication style? What position was the most comfortable for you?

According to the opinion of participants, they would choose the seat at the head of the table when running a meeting and a back-row location when not planning to interact actively with others and give way to other people to talk. One participant mentioned that they would choose to stay in the middle of the room: *'Only when I am in the middle of the room. That usually means I am the Initiator. I do not mind the position and I will be in the front or the middle when I need to'.*

In addition, according to the observation and interview answers, the Team Leader's preference is to keep people facing each other in a circular arrangement: that option had unanimous support.

9. Sometimes people in meetings make use of physical objects like drawings, papers, computer screens, physical models, whiteboard drawing, etc. To what extent do you find it helpful when people present these types of objects? Why do you think so? Are there situations where these objects were distracting or caused miscommunication?

Most of the engineers in the team under observation found visual representation to be very helpful, even though it may slow down the meeting. *'I think this is the best way to give accurate communications although this often slows down the meeting'.*

However, an artefact should give precise and clear information, otherwise it can distract. *'Usually drawing out a problem helps with visualising it, especially when you are not sure on the relationship between different components. If you do not have clue, a poor drawing does not help'. 'Helpful, as long as they are used to present specific information relevant to the meeting'.*

The most helpful boundary objects (artefacts) were whiteboard, pink stick, computer presentation in PowerPoint (though not too long), different programmes and document on computer screen: *'Drawing diagrams on whiteboard can make it a lot easier to explain a complicated idea than words. Excessive use of PowerPoint can stifle discussion in a meeting though'.*

One participant also complained that using of whiteboard is not enough and could be more often: *'Whiteboard tend to be used less often in this organisation that I am used to'.*

10. Do you have any comments on the difference between project meetings during your university studies, compared to the workplace? For example, did you find yourself comfortable

when you first came to the organisation and took part in the project discussions? What are your feelings about this? Do you think that university students need to be better prepared for the communication in organisations?

One participant mentioned that they did *'a real-world team project'* in their final year of university. They found that communication processes at projects meetings in organisation and university are similar. Team communication skills gained at final year project were very helpful.

Two other participants had similar opinion *'Judging by how recent graduates have fitted into our team, I think that students are being adequately prepared for communication in our organisation'. 'Most young engineers we interviewed have decent communication skills. I really have not seen stereotypical 'Steve Urkels'.*

However, one participant also suggested that, judging by newcomers, undergraduate degrees should have a stronger focus on teamwork. '*I think undergraduate degrees do need to focus more on working in a team'.*

In addition, those engineers that remembered well their study at university and could compare communication at project meetings there and at their job place mentioned several differences:

1. Students have a much smaller diversity in age than the workforce. They communicate mostly with their classmates, whereas at organisation age groups are different and that may predefine the choice of communication style.
2. University meetings generally happen among people with similar work skills and knowledge whereas at organisation the difference in experience can be huge.
3. University meetings are more academic-oriented and idea-based, whereas at organisation project meetings have stronger focus on achieving current goals and solving problems.
4. Meetings at organisations are generally more structured and better organised because they should fit schedule of busy people in the shortest time.
5. At university project meetings everyone could take a team role that they wished whereas at organisation it is hard to be active for a new starter.

'At Uni we often have similar levels of understanding of the project. Everyone can be Explorer or Information Provider. It is a bit hard to become active in the meeting at work for a new starter. I did not want to interrupt the meeting too many times because of me asking questions all the time. As I gain more knowledge on the project, I become more and more comfortable'.

Analysis - Summary of what happens at meetings

According to the interview and observation, most of participants are quite happy with their communication at the project meetings. However, there are some possible areas for improving communication:

1. Discussions could be less technically detailed and could follow the main topic of the meeting.
2. On the other side, the focus of meetings could be more on how to solve the problem than on describing the situation and over-commitment to follow rules and procedures.
3. New members may need more time to adjust to the team's communication.
4. According to the interview responses, the main cause of miscommunication was ambiguous terminology that is specially a problem for new-comers, and quick context

switching. Team members could work on improving their communication styles so that all members of the team understand each other well.

7.5. Discussions

Combining observation and interview data we could suggest several distinctions between communication at student project team and project team in observed engineering organisation:

1. **Official positions of members.** Official positions appear to be far more important at the organisation than at university. Students at university may elect a Team Leader for the next meeting. However, this election is completed upon agreement between them. On the contrary, at the observed organisation, the Team Leader is an official position and has rights and duties.
2. **Predefined team roles.** Team roles at project meetings in the organisation are mostly predefined by the position of the participant, whereas university students may change their communication behaviour spontaneously. There is a self-organisation inside student teams, where members take roles that are most suitable for them in such a situation or because they are linked to their character or just a mood.

Our observations lead us to propose that there is a *freedom effect* at work. Engineers at organisation have less freedom about their self-expression. They are expected to follow instructions, complete their duties (e.g. report to Team Leader every day), and behave in ways determined by the organisational culture, such as speaking only when asked. The need for greater freedom was expressed by one respondent, who said: '*I felt more freedom at university, there were more communication styles to choose*'.

Therefore, we propose that team roles in the commercial organisation are more fixed and stable, whereas roles at the university are more flexible. The academic supervisor in the student team is an official position. However, they may behave differently and not always become a Team Leader.

3. **Structural communication.** Teams at the observed organisations have more structural communication at the meeting: at organisation A participants first reported about the main problems and issues, then all team discussed minor questions or big events that unite the group. There was always a limitation for the meeting time. The similar structure was at Organisation 2 (*Stand-Ups*): Scrum Master announced the task and some participants reported results to him and to the whole team.

   In contrast, every observed meeting at university was special, with its own flexible structure, different positions and roles of members, and time durations.
4. **Boundary objects (artefacts).** Participants of project meetings at the observed organisations used artefacts in the form of whiteboard and one large computer screen. These boundary objects became an integral part of the meeting. The whiteboard was used for creating lists of positive and negative events and factors. Meanwhile, the computer screen was used for monitoring project progress. To compare, at the university the artefacts were more varied and included paper engineering drawings, paper charts and diagrams, physical objects (models), viewing of personal laptop screens. There was a great diversity of different artefacts being used at different meetings. The location of the meetings at the university was also more changeable, and this may have affected the type of boundary object used. In particular, the university rooms did not always have a large computer screen or even a whiteboard.

However, the attitude to using boundary object at industrial organisation and university was similar. As mentioned above, engineers at organisation agreed that artefacts are very useful. However, several persons were concerned that they may slow down project discussion. At university, all participants except for one student also mentioned that boundary objects are very helpful in engineering communication as they help to visualise the problem and to represent results to others: *'That was extremely useful. Because some solutions can be developed only after you visualise the problem', 'Physical objects are always useful as they make verbal communication more concise', 'It is very helpful to have visual aid when describing things, especially abstract things'.* And one student remarked that sometimes artefacts can be distracting.

5. **Miscommunication.** Organisation and university also differ in how they manage situations with misunderstanding. There existed specific procedures in the organisation that define the sequence of actions in the case of misunderstandings. Members were aware of these procedures and reported that they used them occasionally. For example, in Organisation A, engineers that felt misunderstood were able to arrange some time to meet with Team Leader and ask for additional explanations. Moreover, every engineer there could write on the whiteboard and thus attract the attention of other team members to that problem, enabling a discussion of the issue later at the special meeting).

   At university, miscommunication problems were observed of a minor nature. There were no formal processes for solving these. Instead, these issues were approached in different ways, such as changing the behaviour of the supervisor, changing room layout, and moving discussions to a round table. Mostly the problems were addressed by attempting more communication. Possibly this relates to the freedom factor identified above, in that students at university have more freedom in the responses available to them.

6. **Cooperative communication.** At organisation, every engineer was responsible for him or herself. Nobody helped the engineer to communicate with managers whereas student team acted more cooperatively. Students helped each other to explain common ideas to the supervisor or client, answer questions. In the case of passive communication style of supervisors, students approached them only if a serious problem happens that requires their power or knowledge; in other situations or minor issues, they first tried to solve all problems inside the team by active discussion and then somebody talked with supervisors on behalf of all the group.

7.6. Conclusions

1. Communication at project meetings **at university and in commercial engineering firms** was compared. Several distinctions in communication patterns were identified: official positions mostly predefined communication in industrial organisations, whereas at university participants seemed to have more freedom to choose their communication style, also communication in organisation was more structural than at university where the schedule of meeting was more flexible. The way to deal with miscommunication could be also different: there are special procedures that regulate such situations in commercial engineering organisations whereas at university participants change their behaviour or room layout according to the situation.

Also, many common features uniting engineers everywhere were found, such as importance of team size, communication settings, similar types of meetings, and attitude to boundary objects.

2. The collected data showed possible connections between team size and appearance of **parallel discussions:** parallel discussions generally appeared when the group quantity exceeds six

members. Several events were observed that could trigger these situations, such as computer presentation or just a joke.

3. **Engineering project meetings were classified into several different types**: interactive meetings, limited interactive, and reporting style. Examples of each type of meetings were illustrated by the interaction diagrams.

4. **Communication setting** of project meetings were analyses. The main finding was that location inside the meeting room may be of somewhat important for some categories of participants. Also, position near the person with power could predefine communication style too.

5. There were not found any links between project performance in student teams and **frequency of the meetings** with supervisor. The same appealed to the style of supervision. Project performance is a complex area that is not limited by communication aspects only.

The next Chapter is devoted to the measurement of communication flow from quantitative perspectives. We shall try to quantify some frequencies of communication interactions between participants of project meetings. It could be useful as additional information that shows how often events may happen.

The question 'how and why engineers accept a particular communication pattern and what does it mean for them?' will be investigated in detail later in the Chapter 9.

Chapter 8. Measurement of communication activity for industry and student teams

This chapter is a partial adaptation of the following paper:

> Nestsiarovich, K.; Pons, D. Interaction diagrams: Development of a method for observing group interactions. *Behavioral Sciences,* 2019, 9 (1), p. 5.
>
> https://doi.org/10.3390/bs9010005

8.1. Approach

This Chapter uses data from observations on the teams of student and engineers. Quantitative records from ID diagrams were gathered, the number of times that a particular communication event took place in time periods counted, the results analysed statistically.

This gathering and analysis extracts additional data from observation to prove the consistence of this results received by qualitative methods, such as how active participants were at meetings. Some data could be received only quantitively, such as how often participants use boundary objects (artefacts). It can be described only by numbers.

In addition, it is difficult to observe behaviour of team members and at the same time counting the numbers of time this event takes place. Using ID diagram methods developed earlier allowed researchers to count this kind of events later and used for data analysis.

The data from the first stage of observations was used to develop a procedure of the quantitative data processing. The results from the second stage, which followed five student engineering teams and two industrial organisations, were used to refine this approach. Some additional parameters were introduced and included into the later calculation procedures (*Addressing-transmitting ratio, Artefact frequency, Level of communication inactivity*), whereas other calculations were decided to be redundant as similar results could be received in qualitative part of research and was therefore left out here.

Sequence of data processing

1. A counting of a particular event was done using ID diagrams.

2. Parameters of communication flow were calculated using numbers of communication events and a time period.

3. Statistical indicators was calculated, such as standard deviations or coefficients of variation.

4. Quantitative and qualitative data were compared where possible.

5. The data from different observational sets (university and organisations) was compared to give additional information about the difference in communication style at student and engineering teams and in different settings.

8.2. Results: Measurement of communication flow

The following data was extracted from the interaction diagrams. Qualitative analysis yielded results similar to the coding of videos. The quantitative analysis gives frequencies of different types of interactions:

- Total meeting time and time spent on every slide (observed communication part).
- Distribution of communication interactions among participants

Point system

Communication events at the meeting were divided into two main groups: sending information and receiving information. The first group includes: *addressing* – appealing to a particular person; *transmitting* – appealing to the whole group or commenting without particular addresser; *information providing* – answering questions and *artefact providing* – showing artefacts for an explanation. The second group is *receiving information* and may include answers or any other addressed information from the participants of the meeting.

A point system was devised to show the contribution of every participant to the possible type of main team interaction:

- *Addressing*: initiates two or more interpersonal interactions, excluding artefacts
- *Transmitting*: comments three or more times (circle interactions on diagram)
- *Information Providing*: provides two or more answers
- *Artefact Providing*: shows any new artefact (e.g., models on paper, electronic models, physical objects, and presentations)
- SENDER: This is the sum of the points for outcoming information (addresser, transmitter, and provider roles)
- RECEIVER: Receives two or more addressing interactions including answers
- OUTSIDER: Has fewer than two interactions (any)

Therefore, the scoring determines the number of interactions per slide, against each of the above interaction types. These are summed into SENDER and RECEIVER categories, or OUTSIDER if the member had few interactions of any type. Note that these categories apply only to the slide in question, and in the next time period a group member can change their interaction.

These slide points were summed up to receive a final result indicative of the distribution of roles for each participant during the meeting. The proportion of the main three parts (sender, receiver and outsider) show the prevailing type of communication interaction in the team.

Example of data extraction

The example of the team interaction distribution among participants is shown in Table 8.1. This group included many participants (the number was different at every meeting). At the first meeting, there were no supervisors among students. The following data are for the whole meeting, i.e., multiple slides. The letters A–F indicate members of the group. The numbers indicate the quantity of a particular type of interaction.

Table 8.1. Distribution of team interactions among participants of Group 1 at first meeting.

Addressing	Transmitting	Information Providing	Artefact Providing	Sending (sum)	Receiving	Outsiding
A	4A	2A	-	7A	2A	-
-	2B	-	-	2B	-	3B
3C	2C	-	-	5C	C	2C
-	4D	-	-	4D	-	-

-	4E	-	-	4E	3E	1E
4F	2F	F	F	8F	-	1F

Table 8.1 shows that Participant A received seven points for communicating as a *Sender* (four points for transmitting information, one point for addressing to other members of the team and two points for providing answers). In general, the quantitative interaction of *Sending* was taken by Participants A, C, D and F (assuming 'take interaction role' means have twice as many points as for any other column), whereas Participants B and E had a wider distribution of interactions.

The density of communication events for each participant

Communication interaction can be understood as a change of turn-taking among participants or change of conversation addresser. The number of such interactions during the meeting was calculated and used to find the density (interactions per minute) of communication events for each participant.

Example of data extraction

This example refers to the first meeting of the Team 11. Table 8.2 shows the calculation of the density of communication events for each participant and the average density per meeting.

Table 8.2. The density of communication events in the Team 11 at the first meeting.

Slide	Time, min	Quantity of interactions, per person							Density of communication events, interactions per min					
		A	B	C	D	E	F	Total	A	B	C	D	E	F
1	17	4	2	5	3	3	1	**18**	0.24	0.12	0.29	0.18	0.18	0.06
2	7	3	4	4	3	3	6	**23**	0.43	0.57	0.57	0.43	0.43	0.86
3	5	7	2	1	1	2	4	**17**	1.40	0.40	0.20	0.20	0.40	0.80
4	6	5	1	4	3	5	5	**23**	0.83	0.17	0.67	0.50	0.83	0.83
5	5	5	0	1	4	0	4	**14**	1.00	0.00	0.20	0.80	0.00	0.80
6	6	3	0	3	6	5	2	**19**	0.50	0.00	0.50	1.00	0.83	0.33
Total	**46**	**27**	**9**	**18**	**20**	**18**	**22**	**114**						
Density for every participant * (arithmetic mean)									**0.73**	**0.21**	**0.41**	**0.52**	**0.45**	**0.61**
Density for every participant * (average per meeting)—total quantity of interactions divided on total time									**0.59**	**0.20**	**0.39**	**0.43**	**0.39**	**0.48**
Standard deviation between slides (for all group)									0.43	0.23	0.20	0.33	0.34	0.34
Standard deviation between participants (from arithmetic mean)									SD = 0.18					
Standard deviation between participants (from average)									SD = 0.13					
Coefficient of variation CV (slides)									0.59	**1.10**	0.5	0.63	0.76	0.55
Coefficient of variation CV (participants) from the arithmetic mean									0.37					
Coefficient of variation CV (participants) from average									0.31					
Total group activity—2.48 inter/minute														

* This can only be determined within one meeting unless the identity of the participants is preserved from meeting to meeting.

From the results in Table 8.2, the most active team members at the meeting were A and F. Total time spent for this meeting was 46 minutes. Total group activity was 2.48 interactions per minute. The coefficient of variation between slides exceeds one (CV > 1) only with Participant B (high

variability). That suggests that this member of the team changed their behaviour during the project discussion more often than other participants.

Total group activity

Total group activity can be determined from the total quantity of interactions divided by total meeting time. These indicators can also be compared between meetings.

Example of data extraction

The example of total group activity is shown in Table 8.3. The density of communication events for all seven meetings of Team 11 were compared.

Table 8.3. The density of communication events of Team 11

Meeting	Total time, min	Group communication activity, interactions per minute [Mean]	Standard deviation SD and coefficient of variation CV between meetings
1	46	2.48	SD = 1.82 CV = 0.37
2	55	4.24	
3	42	4.93	
4	50	5.34	
5	49	4.76	
6	58	8.48	
7	52	4.15	

In our case, we cannot compare communication activity between meetings, because, according to the ethics agreement, a participant's identity could not be followed and recorded through the meetings. Therefore, identification codes of people were different every time. However, in other situations, it could be interesting to make such a comparison and to follow communication activity of every member across the project completion time. Figure 8.1 illustrates the density of communication events at different meetings of Team 11.

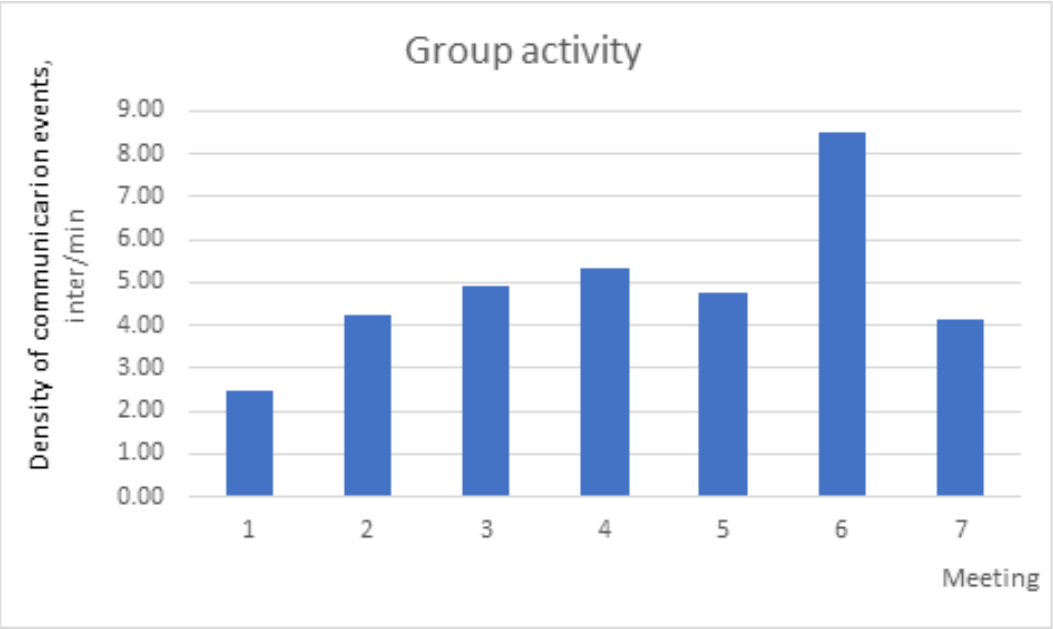


Figure 8.1. Group activity of Team 11 through Project Meetings 1–7

In Figure 8.1, the project team has maximum communication activity in the sixth meeting. To understand why this happened, it is necessary to conduct a qualitative analysis of the same meeting.

As shown above, the interaction diagram method has the ability to be analysed quantitatively.

8.3. Discussions

Second stage of observations. Corrections to previous calculations.

The second stage of observations on student teams and in two engineering organisations gave us more data about participants' interactions. We found that parameters identified previously (density of communication event and total group activity) were not complete and added *Addressing-transmitting ratio*, *Artefact frequency,* and *Level of inactivity.*

Some information extracted from the ID diagrams quantitatively was found to be redundant, as it repeats qualitative data. For example, *Information Providing* interactions could be seen as a team role (discussed in Chapter 9), which is easier to receive. Furthermore, quantitative data could be not be a very reliable source of information because of the high chance of error-counting during the observation time. All parameters received in such a way should be considered as approximate numbers that give some additional information to the qualitative data.

Therefore, only selective interactions were left in thesis: quantity of points per *Addressing*, *Transmitting*, *Artefact Providing*, and *Outsiding*. That gave us possibility to calculate *Addressing-transmitting ratio*, *Artefact frequency*, and *Level of communication inactivity* (per hour per team member).

Parameters of communication

Table 8.4 is an example of data extraction from the second stage of observation (Team 4).

As was explained above (see Chapter 8.2), *Addressing* is when a person initiates two or more interpersonal interactions, excluding artefacts; *Transmitting* – comments or addresses the entire team three or more times and *Outsiding* – has fewer than two interactions per meeting.

Table 8.4. Selective communication interactions in student Team 4

Meeting	Name	Addressing	Transmitting	Artefact Providing	Outsiding
1	**4B**	6	10	0	0
	4D	1	3	2	6
	4E	5	3	1	4
	4A	7	1	0	5
	4C	6	1	0	2
2	**4D**	2	3	0	4
	4C	2	0	0	3
	4A	2	0	0	5
	4E	6	9	2	0
	4B	1	3	0	2
3	**4A**	1	0	0	1
	4C	0	0	0	6
	4D	3	0	0	2
	4B	2	6	1	0

	4E	2	0	0	3
4	**4C**	3	0	0	6
	4D	0	0	0	4
	4B	8	0	1	0
	Guest 1	0	4	0	0
	4E	0	0	0	7
5	**4C**	0	1	1	3
	4A	0	0	1	4
	Guest 2	0	0	0	8
	4B	3	2	2	2
	4D	1	0	1	3
	4E	3	1	1	0
	Total	**64**	**47**	**13**	**80**

Addressing-transmitting ratio (A/T) is a summary of addressing interactions divided per summary of transmitting interactions. It shows which aspect of team communication is more developed at meetings – addressing (approaching only one person) or transmitting information (talking to everyone in a team). Meetings with high A/T shows that participants approach each other directly. This can be in cases of an active discussion between individual team members, or when participants report to the one team member with high status (reporting a type of meeting). Meetings with low A/T (high transmission of information) are typically meetings when one or several participants lead the discussion, talking to the entire group.

Artefact frequency is a quantity of artefacts used by participants at project meetings (see *Artefact providing* in Table 8.4) divided per quantity of meetings, that is how many artefacts are used on average every meeting.

Level of inactivity (per hour per team member) – 'Outsiding' (Table 8.4) divided per total quantity of meeting hours and per quantity of team members.

The Team 4 results were: A/T was 1.4. That is comparatively low, perhaps because this team had multiple team leaders transmitting information, speaking to the whole group. Furthermore, according to the interview answers, all participants of this project discussion had a preference in the transmitting ideas to the whole team rather than talk with individuals: *'Transmit to the whole team to keep everyone involved and updated'.*

Artefact frequency ratio was 2.6. That means that participants used 2–3 boundary objects every meeting. That is a higher number than in other teams.

Level of inactivity for Team 4 was 5.3. That is also comparatively low. The reason for this (from observations): all team members were very active in communication.

The results of calculations for five student and two organisation teams are shown in Table 8.5.

Table 8.5. Parameters of communication for teams at university and in industrial organisations

Parameter	Team 1	Team 2	Team 3	Team 4	Team 5	Team 6 (org 1)	Team 7 (org 2)
Addressing/ Transmitting ration	1.5	3.0	2.5	1.4	1.7	6.0	2.3
Artefact frequency	1.8	2.0	1.5	2.6	0.1	1.9	0.8

Level of inactivity per person per hour	7.3	5.2	8.4	5.3	5.3	7.4	5.9
Density of communication event, interactions per min	4.0	3.3	3.9	4.3	2.9	5.9	5.5
TEAM FINAL GRADES	**79**	**80**	**65**	**87**	**91**	-	-

Addressing-transmitting ratio

Table 8.5 shows that the A/T ratio was very different for organisation (high in organisation 1 and low in organisation 2). This possible was because of the different nature of the meetings and different management styles there. The first organisation used a meeting style characterised primarily by reporting, with participants reporting to the manager one by one. The second organisation, however, utilised active discussion between team members and transmitting results to the entire group.

Maximum A/T ratio was in Teams 2 and 3. According to the observational data, students in Team 2 had very active discussion between each other, whereas supervisor was not very active in transmitting information and did not interfere much in the group communication. As for Team 3, it could be characterised as a team with reporting style of meetings. Also, according to the interview answers, most students in these teams preferred addressing to a particular person, rather than transmitting information.

Student Teams 1and 4 had comparatively low A/T ratio. Observation showed that team had multiple team leaders that transmitted information to the entire group. This was consistent with interview answers: '*I prefer transmit to the whole team to keep everyone involved and updated', 'Whole team, as we all accept ideas of others'.*

Artefact frequency

Most of teams from our observations used between one and four artefacts per meetings. Team 5, however, was an exception – almost no artefacts were used during the time of project completion. This can be explained by the nature of this project that did not require model representations at meetings.

Level of inactivity

Level of inactivity has similar meaning with the *Density of communication event* (quantity of interactions per minute). However, these two parameters were calculated in a different way. We used a points system for the *Level of inactivity* and direct counting (quantity) for the *Density of events* (for a team level it can be called *Group activity*). Furthermore, it should be considered that inactivity is calculated per hour and per team member, whereas disparity in communication behaviour is not considered in the second one (*Group activity).*

According to Table 8.5, *Level of inactivity* was comparatively high in Team 1, 3 and 6. Team 1.

Teams 3 and 6 had reporting style of meetings so members of that team were inactive quite often. High level of inactivity for Team 1 could be explained by the big difference in communication activity among participants. According to observational data, there were three main centres of communication at the meetings (three active members), and other two participants were passive most of time. They complained in interview: '*Some members would talk for the duration of the meeting, and as a result I was unable to express ideas'.*

Using our observations, interview results and Big five test, we tried to analyse typical causes of inactivity among project team members at meetings:

- *Personal characteristics* – participants with low score in *Extraversion* (Big Five test) were more passive than others.
- *Personal choice* – difference between expectations and real communication situation (organisational settings, supervisor style, etc.): *'It seemed like I would get attacked at meetings, so I stopped speaking unless I had to'.*
- *Lack of communication balance* – some team members are too active and prevent others from active participation in discussion *('Some members would talk for the duration of the meeting, and as a result I was unable to express ideas').*
- *Predefined communication rules* (official team roles and communication setting). Participants in organisations should follow their job duties and so they may have predefined rules of communication behaviour, such as being passive and not to asking questions until permitted. An example of this tendency is Organisation 1 under observation (see 7.3).
- *Elected roles.* Sometimes other group members asked a particular student to become a Team Leader, to do undertake other communication activities or to stay passive because others would represent their job. This should be considered.
- *New environment* (different location of the meeting). According to our observational data, some students behaved in different way at the university meeting and at the meeting with the same team, but in organisation. Generally, they became more passive. However, that was different and apparently depends on person and the individual objectives of participant at the meeting.
- *New participant*. New participants and guests of meetings were more passive that other team members (we observed this only with student teams).
- *Long turn-taking.* Long turn-taking may lead to the natural passiveness of other team members who are listening. Communication in student teams generally require some explanations from supervisors, that may cause less turn-taking that in industrial teams. However, this also depends on the nature of meetings in organisations. Sometimes engineers there need to make a long report to manager of the team. In this case (see organisation 1), levels of inactivity would be also comparatively high.
- *Casual circumstances* (sick participants, telephone calls, etc). Sick participants were observed to be more passive.

It should be also noted that team with the highest level of inactivity received the lowest final grade for project completion. However, a low grade here may be explained by other team problems.

Combination of Observational Data

Quantitative and qualitative methods can be combined for broad analysis of team communication (see Tables 8.1 and 9.1). This shows that the team roles and interactions identified by the methods are similar.

Table 8.6. Combination of observational data for the team roles and communication interactions (see Chapter 9)

Participant	Team role	Main team interactions (see Table 8.1)
A	Information provider	Sending
B	Outsider	Outsiding/Transmitting
C	Information provider	Sending

D	Passive collector	Transmitting
E	Information provider	Not defined (equal distribution)
F	Facilitator	Sending (very active)

It should be noted that the *Outsider* team role (discussed below in Chapter 9) is not the same as *Outsiding interactions* from this quantitative part of study*. Outsiding interactions can* be merely passive observation – the observer is not included in active discussion at that particular moment, but only collects visual and verbal information. Therefore, *Outsiding* here is a degree of active participation in the project discussion, whereas a team role of *Outsider* means that a person is not involved in passive interactions too. The combination of observational data (quantitative and qualitative) for the total group activity is shown in Table 8.7:

Table 8.7. Combination of observational data for the group activity

Meeting No.	**Qualitative analysis of the total group activity (notes from observation)**	**Quantitative analysis of the total group activity, (interactions per minute)**
1	The team members defined their tasks and goals. Middle communication activity.	2.48 (middle)
2	The dynamics of communication was at the low level initially and then increased towards the end of the meeting.	4.24 (high)
3	The communication activity was rather high. There were nine people in the room. They all talk at the same time, and there were many discussions happened in parallel.	4.93 (high)
4	The communication activity was very high. There were nine members of the team again. However, discussions in parallel were not observed. The appearance of boundary objects (computer model) intensified the communication strongly in the middle of the meeting.	5.34 (above high)
5	The communication activity was high even if there were only four participants at the meeting. First, one of the students prepared the physical model, which was very intensively discussed. Then, another student explained their ideas on paper charts. Later, the third student showed video-presentation. That attracted big attention and caused an intensive wave of discussion again.	4.76 (high)
6	The communication activity was extremely high. Discussion started intensively from the very beginning and continues until the end of the meeting. Participants talked at the same time, and there were many discussions happened simultaneously. The students and supervisors discussed the submission of the project proposal during the next week. Team members also used artefacts for explanations. In general, it was hard to record the communication in the team because of the high speed of turn-taking, and many discussions happened in parallel.	8.48 (very high)
7	The discussion was not very intensive at the beginning and the end but revived in the middle when the	4.15 (high)

	supervisor came into the room. There were some parallel discussions only over the last five minutes of the meeting. The project proposal had already been submitted.	

The results show that the quantitative and qualitative methods complement each other. In our case, we defined communication activity below 2 as 'low activity', between 2 and 4 as 'middle', 4-5 as 'high', 5-6 as 'above high' and more than 6 as 'very high'. These thresholds were determined based on the range observed, which ran from 2 to 9. It is acknowledged that these thresholds are subjective.

8.4. Conclusions

This chapter used data from observations on the teams of student and engineers and analysed it statistically. This method yielded some additional data about different types of communication interactions, such as addressing and transmitting, the frequency of artefact using, and the inactivity of project teams and team members. In addition, received quantitative data was compared with qualitative. The results show that the quantitative and qualitative methods complement each other.

However, received information is not enough to understand the behaviour of participants and their team roles. Further analysis is needed to identify typical communication patterns of team members during the project meetings.

Chapter 9. Team role assignment

This chapter is a partial adaptation of the following papers:

> Nestsiarovich, K.; Pons, D. Interaction diagrams: Development of a method for observing group interactions. *Behavioral Sciences,* 2019, 9 (1), p. 5.
>
> https://doi.org/10.3390/bs9010005
>
> Nestsiarovich, K.; Pons, D. Team Role Adoption and Distribution in Engineering Project Meetings. *Behavioral Sciences*, 2020, 10 (2), p. 57.
>
> https://doi.org/10.3390/bs10020057

9.1. Introduction and literature review

General context

The behaviour of team members in organisations is crucial to its performance. What does it mean to operate effectively as a team member? It means individuals should do their job and perform team roles in a way that moves the whole group towards accomplishment of its objectives. However, team communication has the potential to result in misunderstandings, technical disagreements, and conflict. Hence the roles that members take can affect the team outcomes. The main purpose of communication is to coordinate the collective activities of multiple people.

Some engineers prefer to be passive in communication during the meetings time. They may collect information, actively listen and continue with their job duties, but do not want to be involved in active discussion. Others prefer to be very active, ask many questions and give instructions, organise communication flow in the whole group. The choice of team role apparently depends on many factors. A team role could be different at each meeting because of current tasks or just because of mood. That is consistent with the other research showing that people in positive emotions (good mood) pay more attention to the attractiveness of the source of information than to the information they receive from this source; they also more often rely to the stereotypes [250, 251]. However, if we look at team communication with the large scale, the difference in the everyday mood can be ignored, and other factors like personality may come to the first place.

Inventories exist for team roles, but the question of how and why people adopt one role rather than another is poorly understood. This Chapter explores the process of team role assignment and distribution among members of engineering project meetings.

Literature review for team role adoption and distribution

There are two separate issues. The first is the need to identify the types of roles that exist. This is primarily addressed by various inventories, though as will be shown they have different constructs. The second is team role adoption, which relates to the processes whereby individuals intrinsically have preferred roles and adopt those rather than others. Related to this is role distribution, whereby role adoption is influenced by the roles taken by others, and the needs of the team as a whole.

Since our study is about engineering communication at project meetings, we have special interest in how people organise their communication behaviour there, that is by team roles we actually mean in this work *communication team roles*.

Classification systems for team roles (inventories)

A team role can be defined as a way in which people interact with one another while performing a task in a team [4]. There are two different approaches in the team role literature [252]. The first is anthropological-sociological, with a role as position. From this perspective team role is the behaviour that individuals show in relation to their social position and status [253]. The second approach is role as a person, where role is defined as a combination of values, attitudes, and behaviour of a person. Roles then emerge from members' natural preferences [254].

There are many taxonomies of team roles in literature. The largest number of roles (fifteen) belongs to the Davis taxonomy [255] and the least (four) to Parker [256]. There is also overlap between different sets. The most well-known are Belbin's team roles.

Key differences between the various inventories for roles are number of roles, focus (on conflict, positive or negative behaviour, formal status), how personality or role preferences are included, method of data collection of teams behaviour (observation, interview) and area of research (e.g. business, engineering). The wider literature is extensive, but the application to engineering is sparse. The key ways of categorising roles are briefly reviewed below.

Belbin's team roles

The eight-role model was introduced [257] and a team role was defined as a pattern of behaviour characteristic of the way in which one team member interacts with another in order to facilitate the progress of the team as a whole. Belbin [258] identified eight team roles and later added a ninth role as a result of further research: plant, specialist, monitor evaluator, implementer, shaper, completer finisher, team worker, coordinator, and resource investigator. Each role was proposed to have its strengths and weaknesses. For example, plant people are creative, imaginative and can solve different problems. However, they are too preoccupied to communicate effectively. Team workers are mild and diplomatic, but sometimes indecisive in critical situations [258].

Furthermore, Belbin found that certain combinations of team roles lead to high team performance. This association between team performance and balance of team roles received some support by other researchers [259, 260]. A mathematical model was built by others to assign the most suitable roles to team members and in this way to create a balanced team with high performance [261]. However, Belbin was also criticised for this team balance idea as no statistical correlations were found between team composition and performance [262].

Benne and Sheats' team roles

According to Benne and Sheats [263], team roles are subdivided into three main categories: task roles, building and maintenance roles, and individuals roles. 'Task roles' refer to goal achievement, 'building and maintenance' were designed to maintain the group performance and 'individual roles' were directed to the satisfaction of participants with their individual need in group.

Group task roles [263]: initiator-contributor (proposes new ideas), information seeker (ask for clarifications), opinion seeker (asks for clarification of team members' values), information giver (offers fact or generalisation), opinion giver (suggests, gives opinions), elaborator (offers explanation for already made suggestions), coordinator (clarifies relationships between ideas), orienter (summarises ideas of the team), evaluator-critic (evaluates group tasks), energiser (stimulates team members to act), procedural technician (performs routine tasks), and recorder (records group decisions).

Group building roles [263]: encourager (encourages other members), harmoniser (mediates the differences between members), compromiser (offers compromise in conflict situations), gatekeeper (keeps communication channel open by regulation participation of team members), standard setter (express group standard), group-observer (record group processes), follower (follow team movement passively).

Individual roles are typically dysfunctional [263]: aggressor, blocker, recognition-seeker, self-confessor (use group audience for expressing personal feelings or ideology), playboy (cynicism, bad jokes, lack of involvement), dominator (manipulate people), help-seeker, special interest pleader.

Comparison between Belbin's team role inventory and that of Benne and Sheats'

Dulewicz [264] tried to correlate Belbin's team roles [257] between each other. The results showed a low discrimination between roles, which was attributed to underlying personality factors. In other words, personality traits are the basic components in a constructions of team roles by Belbin [252].

Belbin's inventory assumes that people adopt roles based on their personal preferences, and that in doing so they implicitly consider how their behaviour interacts with that of other team members. In contrast to Belbin, other researchers focused not on a preferred team role but rather on extracted personal styles [263, 265]. However, Benne and Sheats' team role inventory components are based more on functions of each individual in the team rather than on personality traits that could arise in this situation per Belbin.

Other taxonomies

Another well-known taxonomy of team role is the team management system (TMS). It was originally developed by Margerison and McCann [266]. Those authors created a model with eight key role functions that were associated with personal characteristics. These roles are similar to Belbin's role as they both made similar assumptions: people choose their team roles according to their personal preferences.

Parker identified four main types of behaviour in teams [265]: contributor, communicator, collaborator and challenger. For example, individuals with a contributor style of behaviour in some situation may adopt a tactical, statistical, specific, measurable, and conservative approach ([265] reviewed by [254]). Parker called his inventory 'team players' style', and not team roles.

Other researchers created different classifications from existing roles in literature. This includes the development of a classification of 120 team roles into 10 categories, with each category having a context or 'essence' [267]. Then those authors clustered every team role again into three broader groups: task, social and boundary-spanning roles. Social roles included maintaining social environment; task roles were about goal achievement and work performance; boundary-spanning roles connect team members with individuals outside of the team [267]. However, there is a problem with this classification system – it is complicated and includes 27 different roles, which are hard to observe and analyse in a real working situation.

Existing theories/explanations for team role adoption

In the work of Ruch [198], a model of team behaviour was proposed with several roles: idea creator, information gatherer, decision-maker, implementer, influencer, relationship manager and energiser. Results showed that some roles were positively correlated with job satisfaction and character strengths. Also, they distinguished current and ideal team roles: current roles depend on situation, whereas ideal roles were related to personality. Where current team role corresponded to a person's ideal one, there was higher job satisfaction [198]. This is consistent

with the theory that people may choose jobs that fit their ideal team roles or craft their jobs [268].

Another group conducted a survey (questionnaire), from which they developed a model of relationship between personality traits, team roles, behaviour and role orientation [269]. It was asserted that different team roles (they used Belbin's inventory) have different power and influence on society; also, how people see themselves depend on their social positions and on what is expected from them [270].

Fujimoto suggested the novel idea to count a 'role-acquisition frequency' to study team role adoption processes [271]. In this work, two researchers separately classified the patterns of behaviour of each participant during the meeting time into ten roles. The discussion time was divided into equal 5-minute sections, and all behaviour expressions were then identified. Typical length of discussion was 5-7 sections. A frequency of appearance was calculated for each 10 'discussant-roles'. They created a three-criterion model based on these parameters, and transformed the team roles into a scale system with 11 points [271]. They proposed that participants could use this scale to understand which role teams were needed and how they might acquire them to improve group performance. The main limitation of this study is that it was not 'real-world' observation but merely laboratory experiment where people were given tasks to have a 30 minutes discussion. Also, main discussant-roles were received by questionnaire (self-report of people after meeting time) and not supported by observations. In addition, the participants of discussion had equal social status. It could be interesting to see role adoption in teams with different social status of members.

Team Roles in Project Communication

A team role can be understood as a behaviour pattern, that is an interaction between the participants of a project team while performing a task [4].

Team Roles in Standards

While the standards identify the need for teamwork, e.g., 'Teamwork is a critical factor for project success' [20], and the need for awareness of team role models [272], they do not identify the types of roles that might be important. The standards appear to implicitly assume that team roles correspond to technical functions, e.g., 'setting out the team roles and critical path for the project' [272]. In contrast, the broader literature on team behaviour presents roles as casual behaviour patterns, i.e. styles of behaviour in different circumstances [238].

Furthermore, there is an expectation that 'the individual chooses the appropriate way of communicating' [272], but there is no guidance in the standards on how this choosing process might operate. Furthermore, it is unclear what these different styles of communication are: 'The individual chooses the appropriate way of communicating for the target audience. The individual is able to communicate on different level and through different channel' [272].

Team Roles in Management Journals

Many studies are devoted to the questions of improving communication inside project groups, and in findings correlations between team diversity, performance, leadership and project success [273]. Team roles (a match between team member's skills, interest and assigned tasks) are considered to be one of the factors that predefine individual communication competency and project success [274, 275].

Another work [276] found that there is a strong correlation between team role clarity and individual participant' satisfaction with the project performance. Team members should know what contribution they are supposed to make in a project development.

However, these team roles under considerations were formal (predefined by job duties). There is still a lack of work about informal participant behaviour in project communication, and how these roles may change over time

Team roles in engineering

Communication in the engineering context has been investigated from different perspectives: communication as a technical process, engineering cycle, engineering communication style, communication problems, skills and artefacts. However, the literature is sparse in the specific area of team roles in engineering student teams and in engineering practice. Work in this field is mostly focused on applications in business process re-engineering and construction areas [277, 278]. The few relevant studies are summarised below.

The work of Dainty [279] studied communication between project participants from different perspectives ranging from interpersonal interactions to the organisational level of communication. Team roles taken by participants in construction teams were found to affect their ability to communicate effectively. An incorrect choice of role assignment resulted in communication barriers.

Loosemore [280] found that participants of project construction team sometimes showed excessively formal behaviour because of contractual procedures, and that created anxiety and tension inside the team. They concluded that some level of flexibility is required, especially in crisis situations. In another paper, Loosemore [278] studied the effectiveness of information transfer between project participants, finding weak associations between the centrality of communication structures and the efficiency of communication.

However, it should be noted that the works of Dainty and Loosemore look at communication from sender-receiver perspectives and do not consider how participants feel in these team roles, how participants perceive information, or how participant behaviour patterns might change during the timeframe of a single meeting.

In business process re-engineering, it is generally accepted that team members should have various roles for effective task completion. In the research of [195], team roles were identified for BPR of five manufacturing units (electronic industry) using a case study approach. The data were collected through interviews, questionnaires, group methods and observations. The results showed that classification of team roles by Platt [194], which is a modification of Belbin's role taxonomy, was the most suitable for re-engineering teams. This role set comprises innovator, resource investigator (brings information and ideas from sources outside the group, chair (team leader), shaper (implement ideas), evaluator, team-worker (promotes harmony in the group), organiser and finisher (prevail group from time-wasting). Another finding of this work was the role of leader in re-engineering projects: leader should provide professional skills and should be able to change their role when moving between different teams if they have missing skills [195]. In summary, those authors showed a method for determining team roles by adapting an existing taxonomy to a specific area under examination.

Gaps in the body of knowledge

The matter of how people adopt roles has limited coverage in the literature. Most of the research literature suggests that team roles arise from individual preferences and personal characteristics of team members. There is a paucity of work that examines how team roles emerge as a response to the communicative processes between participants.

Previous authors had a strong focus on formal roles – that is the way individuals meet job demands [258, 281] rather than individual ones. However, the actual behaviour is a combination

of formal and informal roles [282]. Each individual can be identified with at least three types of roles: formal (job task), informal (personal content), and dramaturgical (created in interaction between members-actors) [282]. The last type of team role – dramaturgical or role as communication interaction (protagonist, antagonist, team member, auxiliary and audience) [283] was not widely studied or adopted by others.

Another problem is that most research about team roles relied on self-assessment, participants' assessment, and less often on peer rating or personality tests, whereas only few studies consider observation as the main method of data collection [238].

There are a number of gaps in the literature about engineering team behaviour, and these are potential areas for further research:

Effect of status. It could be interesting to see how presence of formal leaders influence the participants' behaviour. What is the difference between communication with manager/ supervisor and without?

Multidisciplinary team composition. Engineering problems often involve inter-disciplinary teams, hence non-homogeneity of professional background. There appears to be little or no research into how people from different disciplines influence the participants' behaviour, or what factors contribute positively or negatively to team performance in these situations.

Role assignment. There is a shortage of studies about team role assignment that are based on observations in engineering teams. It is the observation of the present authors that engineering communications tend to be characterised by high importance of visual artefacts in communication, strict time frame and regularity of project meetings. There may also be large differences in professional expertise, resulting in differences in communication style. Use of specific technical terminology may contribute to misunderstandings. However, the effects of these variables have not been formally reported in the literature. Most of studies in the area of engineering communication have a strong focus on performance, boundary objects (artefacts) and personality rather than team roles. Finally, there are several areas where the literature is sparse, and which could benefit from further research. One of these is to develop a better understanding of the process of team role adoption in engineering teams. It would also be useful to better understand the reasons behind role adjustment.

Stability of team roles. There are unexplored questions about stability of team roles: how team roles change over time.

The current study focusses on the question of role assignment.

9.2. Approach

The results of this part of study are based on investigated communication in several 10-peron teams of engineering students who were doing a final year project. Students had regular meetings with their supervisors typically once per week at university and at organisations with clients. During the meeting time, team discussed project progress and problems that arise, reported results to supervisor or client, asked questions to them. The data in this chapter was collected from two stages of observations: first stage was used for the developing of ID method and some basic data collection (exploratory study). The second stage gave us detailed information about participants' behaviour and the meaning of communication events for them (data from interview).

Data were collected via an initial questionnaire, observational study, and structured interview, as follows:

Observational study. Students had regular meetings with their supervisors typically once per week at university and occasionally at external organisations (with clients). During the meeting time, the team discussed project progress and problems that arose, reported results to supervisor or client, and asked questions to them. The researcher observed team meetings on a regular basis, typically weekly, during the whole academic year. The researcher did not participate in discussion but sat aside taking notes. There was no audio or video recording, only written notes using the previously developed interaction diagram (ID) method (Chapter 5). Participant identity was recorded using a code. This helped to track the longitudinal observation across multiple team meetings.

Initial questionnaires. We gave a small questionnaire to participants (seven questions) to identify their education background, age, gender and social links between members of the group (Appendix B). Also, we used the '50-item IPIP version of the Big Five Markers' test created by [199] and taken from [200]. We selected this test and online resource because of the limited numbers of questions: participants need only 10-15 minutes to answer (see Appendix C for questions).

Structured interviews. At the end of the observation period a structured interview took place with each participant to clarify communication situations and team behaviour. Questions are shown in Appendix D.

Ethics approval was obtained from the University of Canterbury Human Ethics Committee (HEC 2017/70/LR-PS), and consent was obtained from all participants before commencing.

Sequence of data extraction

Notes and symbols on interactions diagrams were used to extract data about participants' behaviour to the research journal (after every meeting). Typical behaviour patterns (keywords) were underlined and grouped in research journal using NVIVO software (version 12 Pro) for qualitative analysis.

Several team roles were identified and assigned to each participant of the project meeting. We adopted the general approach of [195] in the way that team roles were inferred.

Data about team roles for the whole period of observation were summarised and compared with interview answers (self-reports). In the case of inconsistent results, we trusted our observations. The final data were then analysed for communication progress and problems in the teams.

The flowchart below depicts the sequence of the research methodology in team role assignment (Figure 9.1).

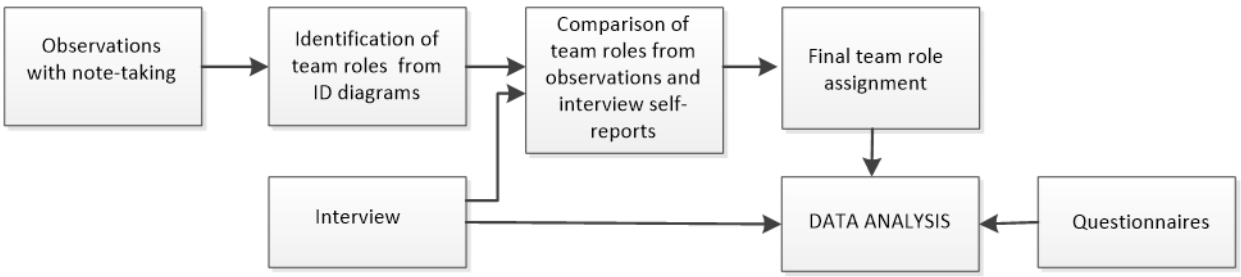


Figure 9.1. Sequence of research methodology

Communicative approach to the role-taking

The main factor nowadays that predefine team roles in engineering teams is a job duty. This is especially important for engineers in organisation that have strict list of tasks that they should perform every day, and therefore, their communication is more predefined by organisational rules that for university students. University staff also have some predefined communication duties, such as organising student groups, solving problems that arise. From this perspective, it is possible to divide team roles into two big categories: official roles (formal) and spontaneous (casual or informal). Casual behaviour patterns appear when people react to the communication situation spontaneously – not because of the job duty, but because of the communication circumstances and personal attitude to the other team members and to the situation in particular (that is called 'communicative approach' developed by [238]).

In our study we follow the communicative approach and observe team interactions using previously developed note-taking system [201].

9.3. Results: Typical behaviour patterns and suggested team roles

Example of data extraction from project meeting

Six members of Team 2 came to the first meeting: one supervisor, one assistant (postgraduate student), and four students (undergraduates). The data below were extracted from the diagrams (11 slides in total) and later described in the research journal. In addition, the keywords were identified and underlined there.

In this meeting, we observed two particularly active communication couples. The first was supervisor F and student C. The student asked questions to a supervisor, gave answers and provided specific information when others could not. Supervisor F communicated a lot with the participant C and with other students, defined tasks in the beginning and at the end.

Another communication couple was assistant E and student C. Student C listened to the assistant E carefully, consulted with him, asked many questions. Assistant E often provided information when others asked him (including the supervisor). Apparently, that was not only because of their higher official position than undergraduates but also because of high status in the team (specific team role). Student B was very passive, did not ask a question or participate in the discussion.

According to the observational notes, participant D (undergraduate student) typically agreed with others (verbally and non-verbally) and sometimes participated in the discussion by asking a few questions (mostly to student E), but not actively. As opposed to B and D, participant A was always active during the meeting, answered to the questions of other group members, however they apparently preferred referring comments and explanations to the whole team rather than appealing to a particular team member. In addition, participant A expressed group feeling several times, summarised ideas.

The dynamics of communication changed significantly over the time of this meeting: the F-C communication couple was more active at the beginning of the project discussion. In the end, it became *quite passive*, only asking questions to each other. The E-C communication couple, on the contrary, increased its communication activity towards the end of the discussion time.

In addition, in the middle of the meeting time, assistant E showed a diagram on the computer to the supervisor F, and this changed group communication dynamics. Everybody then started listening and watching closely to this participant and their interlocutor (supervisor, however, added something, asked questions, and collected information from students). Two students (the

one from the first couple C and passive B) did not show any signs of interest in this model. It is possible that the long physical distance from the provider of the artefact (model) may have contributed.

During the last few minutes of project discussion, the density of communication events was equally distributed between participants, with the exception of the consistently passive student B.

In addition to the keywords that were identified and underlined in the journal, there are also groups of keywords (or communication patterns) that came directly from the diagrams. They are written on the ID near the person that talks or shows non-verbal signs and may change from slide to slide. Non-verbal behaviour can be shown in diagrams using dotted lines. These behaviours include attention to the written model on the whiteboard, gestures, and smiles). However, these interactions are challenging to record as generally they happen in parallel with verbal ones.

Identification of Roles

We devised a categorisation for team roles. To do this, we noted the team roles identified in [254, 263]. We then added the roles that we observed over multiple interactions. These were based on the above keywords, which we grouped into common themes. In this way, we created a set of team roles, with associated communication patterns (see Table 9.1). We do not claim that this categorisation is validated.

Benne and Sheats' inventory was selected in preference to Belbin's, because we had observed that team role assignment was in practice primarily based on functional rather personal preference, at least in engineering teams.

Table 9.1. Suggested correlations between communication patterns and team roles.

N.	Team Roles	Typical Communication Pattern
1	*Initiator* (initiate process)	Active participation proposes new ideas and tasks, new directions of work.
2	*Passive collector* (collect information)	Passive data collecting, non-verbal signs of agreement or just short yes/no answer, low verbal participation in team discussion, attentive listening, and keeping ideas inside (non-vocalisation).
3	*Explorer* (ask questions)	High verbal participation, active data collecting: ask general questions, ask for different facts, ideas or opinions, and explore facts. Ask to clarify or specify ideas, define the term, and give an example.
4	*Information provider* (provide information)	Provide detailed and excessive information: take an active part in the conversation, but mostly talk rather than listen.
5	*Facilitator* (summarise, control discussion)	Define the task or group problem, suggest a method or process for accomplishing the task, provide a structure for the meeting, control the discussion processes. Bring together related ideas, restate suggestions after the group has discussed them, offer a decision or conclusion for the group to accept or reject. Get the group back to the track.
6	*Arbitrator* (solve disagreement)	Encourage the group to find agreement whenever miscommunication arises, or group cannot come to a common position.

7	*Representative* (express, answer)	Verbalise group's feelings, hidden problems, questions, or ideas that others were afraid to express, provide an answer to questions that were referred to the whole group.
8	*Gatekeeper* (fill gaps, sensitive to others)	Help to keep communication channels open: fill gaps in conversation, ask a person for his/her opinion, be sensitive to the non-verbal signals indicating that people want to participate.
9	*Connector* (connect people)	Connect the team with people outside the group.
10	*Outsider* (stay outside)	Do not participate in project discussion.

Key differences between this categorisation of team roles and the literature [254] are the use of more than six team roles to explain participants' behaviour. Some team roles were elaborated and changed. For example, the role of *Innovator* was turned into *Initiator* because our observation is that initiating of conversation does not always lead to generation of new ideas. Other roles were considered but abandoned. For example, *Challenger* [254] was described as someone who pushes the team to solve the problems and find different solutions. In our case, the nature of communication suggested *Initiator* or *Facilitator* were a better description of the behaviour we observed.

Most of the roles below came from [263], but were adapted to the engineering project team environment by the authors. We also considered the practicality of identifying these roles using our diagrammatic method, i.e. the measurability. Thus, *Explorer* (ask questions, ideas and opinions) is the simplified version of *Information seeker* (ask for clarification, suggestions and facts pertinent to the problem) [263]. We found that the role of *Explorer* can be identified from the ID notes even after several months after observations, whereas the content of speech cannot be recorded so easily.

The *Gatekeeper* role came directly from [263] without changes. Other team roles from [263] were skipped (Individual roles) or combined (*Compromiser* and *Harmoniser* were joined into *Arbitrator*). We also suggest new roles that characterise the nature of discussions: *Connector*, a person who connects the project team with other groups outside the organisation; *Facilitator*, elected Team Leader at particular meeting (not necessarily supervisor or manager); *Representative*, a person who talks on behalf of others in the team and thus represents group ideas or feelings (for example, one student reported to the supervisor about the team achievements or answered their question); and *Outsider*, a person in group who does not participate in the discussion, which is similar to *Playboy* in [263] but without the negative connotation.

Many other team roles could be envisaged, but this may make the process of identifying such roles overly complicated. The ten team roles suggested in Table 9.1 are what can be easily observed and identified while letting the observer simultaneously write other notes and build diagrams. In addition, these team roles can be correlated with the 'main team interactions' described above, hence the quantitative part of the observation can be correlated with the qualitative.

Example of team roles: In our example (first meeting of Team 2), this qualitative analysis helped to identify the following team roles at the first group meeting:

- Participant A – *Information provider* (providing detailed and excessive information) and *Representative (*verbalising group's feelings, providing an answer to the question that referred to all group)

- Participant B – *Outsider* (passive communication behaviour, almost did not participate in project discussion)
- Participant C – *Information provider* (providing detailed and excessive information), and *Explorer* (asking many questions)
- Participant D – *Passive collector* (non-verbal signs of agreement or just short yes/no answer, low verbal participation in team discussion, attentive listening)
- Participants E – *Information provider* (providing detailed and excessive information)
- Participant F – *Facilitator* (defining the task or group problem)

As this shows, participants may have several team roles. In addition, some roles may intersect with each other, and it can be difficult to define them.

Observational data: Refinement to previous team role classification

The second stage of observations on student teams gave more information about participants' behaviour. We found that the previously identified list of team roles was not complete and needed some adjustments. Thus, we found that *Information Provider* can be active or passive, and even neutral. By active *Information Provider* (we consider this as a subrole) we mean a behaviour when participants collect all information actively, e.g. give report or instructions – a typical behaviour of student team leader or supervisor. Being a passive *Information Provider (Passive IP)* is a type of behaviour when people provide information in response of some external communication impact (give an answer).

The same with the role of *Connector*. We originally supposed that this role was a passive one, because people working with emails cannot actively participate in the project meeting at the same time. However, several observations showed that such connections with outside-of-team people as video or audio conference (by telephone) need active participation and involve communication processes for connectors. Therefore, *Connector* was also divided into two subroles: active and passive.

Interview data

All participants were asked 14 questions about their team communication in written form (see Appendix D). Five questions were about team roles.

Self-report of team role adoption

Two questions specifically addressed participants' own assessment of their team roles. Participants first described their own intuitive perception of communication style (using free text) and then chose team roles from a list. The list of suggested roles contained a description of typical behaviour patterns (see Table 9.1).

[question 5] What is your intuitive perception of your own communication style in this team?

[question 6] Please tick all team roles (communication patterns) that you think describe your typical communication behaviour.

Quantitative data from question 6 are presented in Table 9.2.

Table 9.2. Statistical data from question 6.

Team role	Quantity per teams 1-5
Initiator	16
Passive collector	9

Explorer	14
Information Provider	9
Facilitator	14
Arbitrator	9
Representative	9
Gatekeeper	13
Connector	7
Outsider	1

Table 9.2 shows that the most popular chosen team roles among observed participants were *Initiator*, *Explorer*, *Facilitator,* and *Gatekeeper*. The least popular was *Outsider* and *Passive Collector*.

Possible explanation for this: even if this study considered only casual team roles, *Facilitators* among students were sometimes elected by other group members. Also, *Initiator* (provides new suggestions) and *Explorer* (asks questions) were popular among active students and supervisors which comprised the majority of participants. That is possibly because completion expectations elicit active communication behaviour from participants. It was observed that *Passive Collector* and *Outsider* were chosen by fewest participants.

Each answer from the interview was compared with observational notes. Interestingly, team roles chosen by participants were not always the same and even sometimes opposite to what were observed by the researcher (e.g. a very passive participant considered themselves being quite active and asking many questions, whereas in fact they asked only three or four questions for the whole academic year). This can perhaps be attributed to egocentric attitudes. Social comparison theory [284] suggests that we evaluate ourselves by comparing with other people that we believe are similar to us. When we assess our behaviour by others' reaction and estimation, there is the potential to be biased towards favourable assessment [285].

The *Gatekeeper* role is worth commenting on further. A *Gatekeeper* regulates communication flows, address questions or comments to those participants that incline to be passive and try to keep members from dominating the communication.) The first comment is that the popularity of the *Gatekeeper* role was somewhat unexpected. Perhaps participants may have been anticipating that regulation of communication flow was important for good organisation of discussions, and hence participants may have putting their agency towards this. However, the second comment is that observation data often contradicted the interview results. Participants whose behaviour was similar to gatekeeping sometimes failed to recognise they had adopted this role. And on the contrary – sometimes participants who thought of themselves as acting as communication regulator did not actually behave in this way. Possible explanations for this might be wrong understanding of the role, biased self-perception [285] or pretending to be good.

Results of the interview showed that sometimes participants would be happy to adopt different team roles but could not do it because of some reason. A typical reason was these roles being occupied by other group members: *'If other people covered information there may be no reason for me to contribute'.*

Adjustments to communication behaviour

Whether communication behaviours changes, and why, was the subject of question 7: *'Do you feel that you changed your communication behaviour at different meetings? Which communication situations caused that?'*

The majority of students (17 out of 20) reported changes in their communication behaviour in different circumstances. The causes may be summarised as follows:

- Presence of supervisor or client/boss (two students).
- Chairing a meeting or not (two students).
- Less personal progress in project tasks, unprepared meetings, or relatively unknown topic lead to low desire to contribute in discussion (three students).
- Some students were sensitive to negative critique and hence intended to be passive (two students).
- Other students became active when they felt that team or a person needed their active contribution (‘*At some meetings where there was a talking point that was getting stuck I tried to shift the conversation’, ‘When one of our team members was away, I filled the role of Information Provider’*) (four students).
- Confidence: *‘throughout the year I gained more confidence in the work I had completed’* (two students).
- When participants felt tired, unwell or just in a bad mood, they were less likely to be active (two students).

Other students became active when they felt that team or a person needed their active contribution:

> *‘At some meetings where there was a talking point that was getting stuck I tried to shift the conversation’.*
>
> *‘When one of our team members was away, I filled the role of Information Provider’.*

Activity of other team member may be also a factor that determines communication position: *‘if the rest of the room was quiet, I chose to speak more’*

Confidence: *‘throughout the year I gained more confidence in the work I had completed’*

When participants felt tired, unwell or just in a bad mood, they were less likely to be active

As for supervisors, changes of their communication behaviour at meetings apparently depend on students’ project progress or client needs: *‘I became more assertive half way through when the client had expressed a concern regarding team achieving goals’, ‘I changed communication style when there were unsolved problems or slow progress in the team’.*

Suppression of communication by activity of others

Question 8 addressed the extent to which contribution was inhibited by others: *‘To what extent do you feel that other people’s discussions prevented you from making a contribution at meetings?’* Most students (16 out of 25) mentioned little or no prevention from making a contribution at meeting. However, several participants complained they were unable to express their ideas because of excess activity of others: *‘Some members would talk for the duration of the meeting, and as a result I was unable to express ideas‘*. This is consistent with the concept of production blocking. Generally, it was other students who were dominating the conversation, and some students themselves admitted to being too active. One respondent mentioned the style of supervisor that ‘*did not allow me to express ideas’.*

According to the observational data and data from other interview questions, in such teams, there were no *Gatekeepers* in those teams. A *Gatekeeper* helps to balance the communication flow and to distribute communication turn-takings between team members. If this role (casual or official) is absent, then some participants may be too active or too passive.

Physical Location

For each team the meeting location tended to be the same throughout the year. Question 13 explored the extent to which location affected communication: *'Did you feel that location of the meeting and your position inside the room predefines your communication style?'*

Half the participants mentioned that location in the room was not important for them at all. The other half had something to say about position. Most participants preferred to sit in front of the person they were talking with. Some students mentioned that a round table created the sense of giving equal opportunity to talk. One student complained that meeting in the supervisor's office did not make them feel comfortable: *'I associate the office negatively and did not enjoy being there'*. To sum up, physical location in the room may be also considered as one of the factors that determine communication style and perhaps even team role adoption.

Table of team roles. Main and secondary roles

During the academic year, we observed multiple types of behaviour for each participant. If some behaviour patterns were repeated several times during the meeting, we assumed that this person adopted the relevant team role. At every meeting, team roles of participants could be the same or vary significantly. Apparently, this depended on communication environment of the meeting: quantity of people, level of discussion, physical location, and other factors. Some of these factors were quite obvious and it was easy to recognise them (e.g. presence or absence of supervisor), others were difficult to know, such as personal circumstances, mood & health.

Combining information from interviews (questions 5 and 6) with observational data, we chose for each participant the most frequent four roles: two main roles that were the most obvious in their repetitive use (or just one mentioned twice), and two secondary roles that appeared less often on in special circumstances.

The resulting team roles assignment are in Table 9.3. Bold type denote supervisor. According to our observations, all supervisors had *Facilitator* as the first main role, perhaps because of job duties. Letters from A to E represent coded names of the participants, number represents team. For example, 1B – participant B from the team 1.

Table 9.3. Team roles of the student teams 1-5.

Participant	Main role 1	Main role 2	Secondary role 1	Secondary role 2
1A	Explorer	Initiator	Representative	Passive Connector
1B	Passive Collector	Passive IP [1]	-	-
1C	Facilitator	Explorer	Passive IP	Representative
1D	Explorer	Explorer	Initiator	Gatekeeper
1E	**Facilitator**	**Initiator**	**Active IP**	**Explorer**
2A	Explorer	Active IP	Gatekeeper	Representative
2B	Representative	Representative	Active IP	Gatekeeper
2C	Representative	Gatekeeper	Passive Collector	Explorer
2D	Passive Collector	Representative	Explorer	Gatekeeper
2E	**Facilitator**	**Passive IP**	**Passive Collector**	**Explorer**
3A	Passive Collector	Passive Collector	Passive IP	Outsider

3B	**Facilitator**	**Explorer**	**Passive IP**	**Initiator**
3C	Passive Collector	Representative	Arbitrator	Explorer
3D	Active IP	Passive Collector	Connector	Explorer
3E	Initiator	Representative	Explorer	Arbitrator
4A	Explorer	Active IP	Initiator	Gatekeeper
4B	Facilitator	Initiator	Active Connector	Passive IP
4C	Explorer	Initiator	Passive Collector	-
4D	Explorer	Representative	Active Connector	Initiator
4E	**Facilitator**	**Passive Collector**	**Passive IP**	**-**
5A	**Facilitator**	**Explorer**	**Passive IP**	**Active IP**
5B	Passive Collector	Passive Collector	Explorer	Passive IP
5C	Facilitator	Gatekeeper	Passive Collector	Active IP
5D	Facilitator	Active IP	Representative	Initiator
5E	Initiator	Gatekeeper	Facilitator	Active IP

[1]IP - Information Provider

As mentioned earlier, team roles chosen by participants themselves were not always the same as assigned to participants by researcher. In the case of controversial results, we trusted our observations.

Role assignment and team needs

An aggregation was made of the various data:

- Team needs were inferred by observation.
- Personality of each team member from the Big Five personality test. Here we only report on the *Agreeableness* variable.
- Personal attitudes were determined from the question *How comfortable did you feel in this team communication?* 10 – very happy, 9 – happy, 8 – good, 7 – satisfied, 6 – not satisfied, 5 – unhappy, 4 and below – very unhappy. This primarily address aspects of feeling of participants.
- Main and Secondary team roles were as identified by participants, informed by observation (see above).

The results are shown in Table 9.4.

Bold type represents supervisors of the team, whose main team role – *Facilitator* is fixed by their official position. Green text highlights a team role that corresponds to team needs as from interview and observation data (column 'Team needs' in Table 9.4). For example, according to the observations and interview data *'I felt disengagement of some team members'*, Team 1 needed *Gatekeepers* and *Connectors*, and participant 1D took a role of *Gatekeeper* from time to time, that is responded to team needs. Apparently, this was not enough, and team needed more *Gatekeepers*.

Table 9.4. Team role assignment in student teams 1-5

Team	Team needs	Participant	Agree-ableness	Personal attitude	Main team roles	Secondary team roles
1	Gatekeeper *'Disengagement of some team members'* Connecter Communication problems with a client	1A	40	good	Explorer Initiator	Representative Passive Connector
		1B	17	good	Passive Collector Passive IP	-
		1C	51	unhappy	Facilitator Explorer	Passive IP Representative
		1D	45	very happy	Explorer	Initiator Gatekeeper
		1E	**71**	**happy**	**Facilitator** Initiator	Active IP Explorer
2	Arbitrator, Facilitator *'Lack of communication when problems arise'* Information Provider *'Sometimes lack specific details to truly enable progress'* Gatekeeper Some team members were regularly prevented from talking by other too active participants; *'lack of engagement from some team members'*	2A	21	satisfied	Explorer Active IP	Gatekeeper Representative
		2B	14	good	Representative Gatekeeper	Active IP -
		2C	76	good	Representative	Passive Collector Explorer
		2D	40	happy	Passive Collector Representative	Explorer Gatekeeper
		2E	**83**	**good**	**Facilitator** Passive IP	Passive Collector Explorer
3	Facilitator, Arbitrator *'Team was not very good at planning early'* *'A lot of time was wasted on things we did not think was necessary'*	3A	2	satisfied	Passive Collector	Passive IP Outsider
		3B	**30**	**unhappy**	**Facilitator** Explorer	Passive IP Initiator
		3C	67	good	Passive Collector Representative	Arbitrator Explorer
		3D	35	good	Active IP Passive Collector	Connector Explorer
		3E	40	good	Initiator Representative	Explorer Arbitrator

4	Passive Collector, Gatekeeper *'Too much people talking at once'. 'One person talks too much. Other person is reluctant to put their ideas formed'.* Some students regularly monopolised talking time	4A	45	happy	Explorer Active IP	Initiator Gatekeeper
		4B	83	happy	Facilitator Initiator	Active Connector Passive IP
		4C	80	very happy	Explorer Initiator	Passive Collector -
		4D	56	very happy	Explorer Representative	Active Connector Initiator
		4E	**67**	**happy**	**Facilitator** Passive Collector	Passive IP
5	Initiator, Explorer Lack of active interactions between participants	**5A**	**67**	**happy**	**Facilitator** Explorer	Passive IP Active IP
		5B	30	unhappy	Passive Collector	Explorer Passive IP
		5C	71	good	Facilitator Gatekeeper	Passive Collector Active IP
		5D	21	happy	Facilitator Active IP	Representative Initiator
		5E	51	very happy	Initiator Gatekeeper	Facilitator Active IP

Summary for the team role assignment

Team 1. As found from the observational data and interview, team 1 had some communication problem with their client: '*What I did not like is our communication with clients. They always change their mind and students were frustrated. That was not the students' fault'.* Hence, the team needed a role of *Connector*.

Also, according to the interview answers (*'I felt disengagement of some team members')*, the team needed someone who could regulate communication flow involving passive students in the communication, suh as a *Gatekeeper*. Table 9.4 shows that these roles were fulfilled only partially, not on regular basis (secondary team roles). Participants 1A and 1D with relatively high agreeableness (40 and 45) sometimes became *Connector* and *Gatekeeper*, whereas 1B with low agreeableness remained passive all the way through the project and did not respond to the team needs.

A student 1C was unhappy with the team communication because *'People not listening well, poor recollection of previous discussion; laziness'*. They felt themselves as a '*driver who pushed others'*. According to the observations, they took roles of *Facilitator* and *Representator*, however apparently would prefer other people being more active. As evident from Table 9.4, this student had quite high level of agreeableness (social sensitivity), that is possibly why they followed team needs for organising and pushing, rather than own preferences.

Team 2. From observations, only one student (2A) in the team 2 was very active. This student was not happy with the team communication and thought that other team members had a *'Lack of regular engagement and involvement in all workstreams'*. However, according to the other participants of this team, their passiveness might arose from over activity of 2A: *'I felt that other people's discussions prevented me from making a contribution at meetings due to conveying of their own ideas'.*

Team 3 apparently had some problem in communication. According to the observation, there was much misunderstanding between team members. Participants, both supervisor and students, were not happy with the project meetings. The supervisor complained that the team was not good at planning and self-organising *'Sometimes I really had to ask what the individual meant when they make a statement (vague). I often had a feeling that the team was unclear of their actions. They seem to be reactive in communication'*, whereas students were convinced that supervisor '*did not understand the project'* and the style of supervision prevented them from active participation *'It seemed like I would get attacked at meetings, so I stopped speaking unless I had to', 'He seemed like they had no interest in the project from the get-go', 'A lot of time was wasted on things we did not think was necessary but supervisor did'.*

From the perspectives of team roles, this team lacked a person among the students who could facilitate (*Facilitator*) the project alongside with the supervisor – organising and distributing duties between students. Also, the role of *Arbitrator* might be beneficial in such situations.

We think these communication problems cannot be explained only by chosen role. There may be other possible reasons. For example, as the Big Five test showed, both students of this group and the supervisor had low levels of emotional stability and social sensitivity (except 3C), that might predispose them to conflict situations from the very beginning. That is consistent with the literature that shows low emotional stability and agreeableness leads to low satisfaction with the team communication [286]. Another possible explanation is the nature of the project did not provide sufficient role opportunities: *'The testing part of the project could have simply been done by one person which made it harder for us four to split the work evenly'.*

Team 4 seemed to have good communication and participants were happy with it. The social sensitivity of team members was high too. The only problem was that one or two participants tried to monopolise discussion. In other words, there were too many active roles in the group (*Initiators*, *Active IP*s, *Explorers* and *Active Connectors*), and therefore more roles of *Passive Collector* (only the supervisor took it regularly) and *Gatekeeper* might be beneficial here.

Team 5. The main problem of team 5 was that it consisted of people with different levels of technical knowledge and different understanding of the project. Thus, according to interview data, student 5B felt lack of confidence due to limited experience in the technical side of the project, and also comprehension difficulties. Also, according to the observational data, most participants (four out of five, including the supervisor) were very passive and did not interact much during project meeting time (almost no discussion, no questions). Only one student 5E regularly took the active role of *Initiator*.

9.4. Discussion

Dependence of satisfaction on social sensitivity

Social sensitivity is an aspect of empathy (personal ability) that helps a person to understand feelings of others in a group [3]. Previous study on students performing long-term research showed that team sensitivity was highly correlated with project team performance [287]. It is

one of the most important factors that helps team to successfully perform a variety of tasks [3]. Team members with high level of sensitivity to team needs find it easier to trust each other and they are not afraid to share their opinion. In situations with miscommunication, such people keep their focus on problem-solving, rather than start personal conflicts. Social sensitivity was found to be even more important than general intelligence [288]. The *Agreeableness* attribute of the Big Five personality traits can be taken as an approximate measure of social sensitivity. It captures some aspects of how well a person interacts with other team members and responds to team needs. The maximum score for *Agreeableness* was 100 points, minimum was 0. We selected 50 and 35 as the cut points for a descriptive scale of high, middle, and low agreeableness.

Based on our findings we suggest that social sensitivity is a key variable for team members to feel satisfied in the communication experience. We simplify this to four combinations of social sensitivity and communication satisfaction:

High social sensitivity (*Agreeableness* over 50) and low satisfaction from team communication (unhappy, satisfied). Participants may accept a role that is needed in their team; however, they are not happy with the communication processes because their roles are not consistent with the individual objectives and expectations.

Low social sensitivity (*Agreeableness* below 35) and low satisfaction from team communication (unhappy, satisfied). Participants follow their own ideas and preference in communication, however there are some problems in the team (or personal problems) that cannot be solved by this.

High social sensitivity (*Agreeableness* over 50) and high satisfaction from team communication (happy, very happy). Participants may accept the role that team needs and this is consistent with their individual objectives and expectations, so they feel happy. However, the operational needs of the team may not be met.

Low social sensitivity (*Agreeableness* below 35) and high satisfaction from team communication (happy, very happy). Participants follow their own ideas and preferences in communication, and this apparently makes them feel satisfied with the team communication. However, the operational needs of the team may not be met.

The combinations of team satisfaction and social sensitivity of team are in the Table 9.5 (green colour is the best combination) along with our proposed descriptive summaries.

Table 9.5. Social sensitivity and satisfaction in the project team

Social sensitivity	**Satisfaction in the team**	
	Low satisfaction *(unhappy, satisfied)*	**High satisfaction** *(happy, very happy)*
High social sensitivity (*Agreeableness* over 50)	**Reluctant cohesiveness** Participants may accept a role that is needed in their team; however, they are not happy with the communication processes because their roles are not consistent with their individual objectives and expectations.	**Team coherence** Participants may accept the role that team needs and this is consistent with their individual objectives and expectations, so they feel happy.

Low social sensitivity (*Agreeableness* below 35)	**Behavioural divergence** Participants follow their own ideas and preferences in communication, however there are some problems in the team (or personal problems) that cannot be solved by this.	**Parallel compensation** Participants follow their own ideas and preference in communication, and this apparently makes them feel satisfied with the team communication. However, the operational needs of the team may not be met.

On its own this model presents difficulties. The first is the obvious problem that if satisfaction depends on social sensitivity, which in turn is an agreeableness character trait, then teams that lack members with the necessary trait are going to be in difficulty. Trait models of personality that the premise that such attributes are relatively fixed, and while not immune to change, will only change slowly. The model suggests such teams will tend to either not get the work done to the same standard (which has adverse implications for the client of the engineering project) or will have low satisfaction (which has adverse implications for the manager of the project). We tentatively suggest a solution which is for project managers to encourage social sensitivity in meetings, perhaps via setting of behavioural expectations and organisational culture. This is a call for engineering managers to exert leadership in the way they shape the organisational culture of their subordinates.

The second difficulty with the above model is that *satisfaction* relates to what participants feel, and this is not the same as project performance. People can feel personally satisfied, even while a project fails. To address this, we needed to introduce an attribute of quality of outcomes. This in turn resulted in a different conceptualisation of how team roles are adopted, as shown below.

Model: Circumplex of team roles

Our results implied the existence of two independent behavioural dimensions to team communication. These are *quantity* of communication and *quality,* the latter being how effective this is in problem solving. However, we propose not using these names for behavioural dimensions but rather the following: *Social engagement* (degree of communication involvement – how active was a person involved in the communication) and *Personal agency/Communion* (was this behaviour effective to solve job tasks or resolve social problems).

A team role is a particular behaviour pattern. From the team role perspectives, *Social engagement* refers to how active a person could be in communication with this team role. Some team roles have high degree of communication involvement, e.g. *Initiator, Facilitator*. Other team roles such as *Passive Collector* or *Outsider* imply minimum communication with other team members, and therefore they can be understood as roles with low *Social engagement* (or high *Social disengagement*). Social sensitivity discussed earlier refers to the personal perception of social problems and cannot be used as a measure of communication involvement.

Personal agency-Communion defines behavioural orientation to social needs or to the project task completion. *Personal agency* is the ability of a person (actor) to put efforts to make things happen [2]. It represents what people believe and how they can regulate themselves to change the situation. Adapting this to the team role perspectives, *Personal agency* is a participant's behaviour (team role) that commits effort and perseverance to get a job done – that is, a 'result-oriented' team role. We propose that the opposite to *Personal agency* is *Communion* – a tendency to prioritise interpersonal relationship [1], or in our case – on team processes rather than individual actions. High communion means the role is more 'team-oriented' or 'social-

oriented'. In other words, team roles that are high in *Communion* help to solve social problems, whereas *Personal agency* helps get individual jobs done.

Furthermore, we propose that the team roles may be represented by a circumplex. The main principal of a circumplex is that variables (components) are arranged around a circle in two-dimensional space [289]. In general, a circumplex can be viewed from three different perspectives: as a pictorial representation, as a representation of circular order – components that are close to each other are more correlated and opposite components are negatively related, or as an exact circumplex structure when all components are equally spaced [290]. In our work, we understand *circumplex* as a circular order of components. It is similar to well-known 'interpersonal circumplex' – a model for describing and organising interpersonal behaviour [291]. That model used a set of variables organised as a circle, and two dimensions – *Dominance (Personal agency) and Affiliation* (*Communion*) [291, 292].

In our study, however, we used *Personal agency -Communion and Social engagement-Social disengagement* as primary axes of the circumplex as they better describes team role behavioural dimensions. The elaborated roles per Nestsiarovich & Pons may be used as a set of variables and put into circular order around these axes. Each point within the circumplex represents a weighted mixture of *Personal agency/ Communion* and *Social Engagement* (see Figure 9.2).

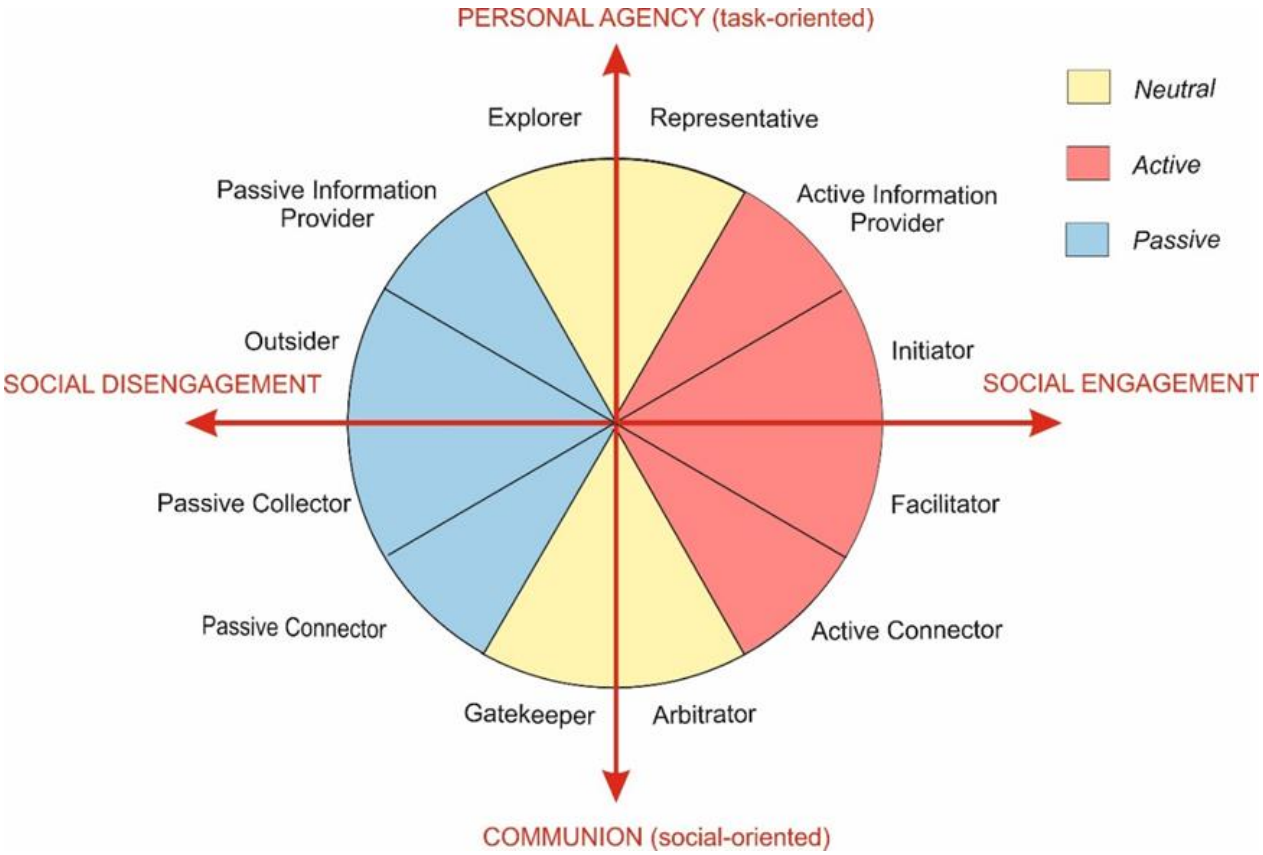


Figure 9.2. Circumplex of team roles

We further propose the roles can be categorised into groups of *neutral, active,* and *passive*. The blue segment on Figure 9.2 shows team roles with low *Social engagement* (passive), the red represents high *Social engagement* (active), whereas yellow means neutral participation (middle level).

Blue colour roles: *Passive Information Provider, Outsider, Passive Connector* and *Passive Collector.* We suggest calling them passive because they are low in *Social engagement*. People

that chose these roles prefer being passive in communication (especially *Outsider* and *Passive Collector*). However, these roles involve different combinations of *Personal agency/Communion*. *Passive Information Provider* is more task than social-oriented because the person provides information only if somebody asks. *Outsider* merely ignores communication. *Passive Collector* is a little more involved in social processes by active listening and taking notes, whereas *Passive Connector* has already a social task to complete (communicate with some person outside the group by emails).

Red colour roles: *Active Information Provider, Initiator, Facilitator* and *Active Connector*. The red colour on Figure 9.2 symbolises team roles with high communication activity (*Social engagement*). An *Active Information Provider* gives information to the other team members. They explain information, answers the questions, and help in problem-solving by providing missing details. Initiators are even more socially active, suggesting new ideas, shows new directions, always ready for the new discussion to start. In this way they may completely change communication flow in the group. However, they are still more oriented on the task (project) problem-solving, rather than on social, whereas *Facilitator* not only helps to develop project but also regulates communication processes in the team. This role is higher in *Communion* then Initiator.

Yellow colour roles: *Explorer, Representative, Arbitrator* and *Gatekeeper*. *Explorer* and *Representative* are high in *Personal agency*. These roles require quick task accomplishment, such as asking questions or answering a supervisor's question when addressing a whole group. Participants with *Representative* roles are more engaged in communication: if somebody asks a team about this part of job, they represent a team and provide a response on behalf of the entire group. In contrast, *Explorers* express only own opinions.

Finally, the roles of *Arbitrator* and *Gatekeeper* have goals to decrease conflict level in the team and to invite passive members of the engineering team to contribute into the discussion. These are roles are both high in *Communion*. *Arbitrator* is a little more social-engaged role because solving conflict may require high level of communication activity.

9.5. Conclusions

In this Chapter, typical behaviour patterns were analyses and a list of team roles was suggested. These team roles were arranged in a circular order so that they created a circumplex. This represented different aspects of behaviour patterns and how team roles can be correlated with each other using Communion/Personal agency and Social engagement axes. In addition, team role assignment in project teams was analysed from the perspectives of personality (social sensitivity) and team needs.

Implication for engineer managers and supervisors of student teams

The results of this work can be used by professionals in organisations and at university to build an effective team of engineers that can cope with complex project by solving problems and having productive discussions during the project meeting time. The following is suggested:

1. First, **sensitivity to team needs** should be considered by people who are trying to build an effective project team of engineers: at least one person with high sensitivity in each team could be beneficial for project development. Team members with high level of this parameters feel easier in conflict situations and they generally try to take a team role that correspond to team needs. This can be done by simple testing of potential team members, and by ongoing leadership of organisational culture.

2. Results of this study shows that another important factor is **participants' satisfaction** with team communication. People are happy with communication when chosen team roles are consistent with the individual objectives and personal preferences of participants. We suggest that team members could be given them an option to choose a team role according to their personality. For example, passive people may prefer to be *Passive Collectors* in project meeting rather than *Facilitators*, and they should have a choice to behave according to their preferences. Managers or supervisors of the team can do this by testing potential or existing team members and finding for them a right place in a group or right group. However, satisfaction also must be balanced against (a) the project needs, and (b) personal growth. If team members only ever take roles in which they are comfortable, then their personal development would seem precarious. The circumplex may help here, by identifying adjacent roles that may be easier for them to transition to.
3. **Leadership of teams,** which relates more to shaping people's behaviour rather than management of project objectives, is identified with the Yellow colour roles of *Explorer, Representative, Arbitrator,* and *Gatekeeper.* A key aspect of engineering team leadership appears to be the ability to solicit contributions from quieter members and facilitate but not dominate the discussion. At the next level in the organisation, leadership involves shaping the organisational culture to encourage behaviours that enhance team performance, and personal development of subordinates.
4. The circumplex of team roles could be used to analyse a balance of passive and active behavioural patterns in a team. It is a visual **representation of team communication activity and role distribution** in a group: what kind of communication behaviour is the most typical for the team, which role is missing, how active are team members in discussion project problems. According to our study results, high activity of team members does not guarantee project success. And even very passive communication teams still have chance to complete a project successfully. However, we assume that the chance for project success increases if a team has at least one active team member willing to discuss a problem and to coordinate others. If not, team members may find their meetings are less productive than they might be, and hence may need to spend more time in discussion.
5. Implications for supervisors and students: Prior to the student project starts they were familiarised with the team roles and circumplex and pass an anonymous test to identify which role they could potentially accept or avoid in order to be happy with the team communication. It is feasible to do at the first project meeting with the supervisor when students discuss future plans and distribute official roles in project development among team members. It is better to do before the project starts than after communication problems arise. The content could be taught in a previous year, so they were familiar with it.

Limitations

The research presented in this chapter has several limitations:

- Supervisors of student teams followed their official position duties and it was hard to identify their real preferences in communication.
- *Agreeableness* can be taken only as approximate measure of social sensitivity.

- Observations were conducted on students at their official meetings with supervisor or clients, whereas students may have other types of meetings between each other that were not observed.
- The division between main and secondary team roles should be considered a rough approximation as sometimes it was hard to see the difference.
- Gender, age, and other demographic factors were not considered in this part of study.

Future research questions

- Bigger sample and more statistical data could give additional information about correlations between personality and team roles.
- Factors that influence team communication such as the presence or absence of supervisor, location of the meeting, relationship between participants, and style of supervision need further study.
- Other personality traits (Extroversion, Conscientiousness, Openness to experience) could be correlated with the team role choice too. (While these factors were collected here, the volume of data was insufficient for statistical analysis).

Summary: The findings showed that participants have their own preferences of team roles and they are not fixed. People may accept a team role according to their choice if there is a gap in the role structure. The next chapter will describe the process of communication role changes (adjustment) in details.

Chapter 10. Communication adjustment

This chapter is an adaptation of the following paper:

> Nestsiarovich, K., Pons, D., & Becker, S. Communication Adjustment in Engineering Professional and Student Project Meetings. *Behavioral Sciences*, 2020, 10(7), p. 111.
>
> https://doi.org/10.3390/bs10070111

10.1. Introduction: Definition and classification of adjustment situations. Adjustment triggers

When a person adapts a team role, they do not automatically use the same communication style during the whole time of group communication. Team roles (behaviour patterns) are very changeable. They greatly depend on personal characteristics, team goals and other factors such as for example a new person in communication group, different meeting locations, and even different modes of behaviour by participants, as influenced by external factors.

The processes of changing a communication behaviour we can call an *adjustment*. We observed these adjustments happening at different levels of observation. The *micro-level* is where two interlocutors change their communication behavior very quickly in response to a situation of misunderstanding. The *mezzo-level* corresponds to the interactions between participants during a single meeting. The *macro-level* involves the longitudinal change of communication behaviours across multiple meetings. The levels also relate to the time scale over which people change their behaviours. We further propose, based on observations, that grounding occurs at the microlevel, regulation at the mezzo-level, and communication development at the macro-level.

The performance of an engineering team greatly depends on the behaviour of its individual members. To operate effectively participants should perform their role in the team in a manner that will move the project toward completion. In addition, the nature of the work is meaningful to people at a personal level, affecting motivation, and hence this too needs to be considered. Therefore, there is a need to better understand the roles that project team members adopt, and how those communication roles adjust as the project evolves. There is a general tendency in the communication literature to view communication as having two somewhat independent attributes to the interactions: task-oriented, and socio-emotional. However, the literature does not robustly show how this is contextualised to engineering activities.

This Chapter develops a model of the process whereby team members adjust their communication style and team roles to the behaviour of other people and to different communication settings. We show that this happen with three different dynamics: at the micro-level (grounding processes in conversation), the mezzo-level (emotional and rational regulation) and the macro-level (the dynamics for the duration of the project or team).

10.2. Approach

The data for this Chapter was collected during observations (second stage only) at two industrial organisations and at the University of Canterbury (New Zealand). Five student teams were observed during the whole academic year. That gave us information about how communication between participants changed over time. The researcher used the previously developed ID method of note-taking for observations.

The primary research questions for this part of study were 'How do people adapt to the changing of communication environment in the project team?', and 'Over the lifecycle of an engineering project, how do team roles and communication at project meetings change in time?' To answer the questions, we investigated two different project group types (i) engineering student teams at University of Canterbury, New Zealand, and (ii) engineers in professional practice (New Zealand) where interactions occur between people as they work on complex projects.

10.3 Social psychology literature on group development

Social psychology is rich in the discussion of small team communication and group development. Publications relevant to the present study include Bales [293], Tuckman [294], Gorse and Emmits [295, 296], Loosemore [277, 278] and others.

Bales [293] created 'the equilibrium model of group development' that explained the development of team over a period of time. They suggested that there should be a balance (equilibrium) between the task-oriented needs and the socio-emotional needs of the group. Effective teams that are high in cohesiveness and performance can maintain equilibrium between solving tasks and social problems inside the group [297]. However, this balance could be temporary because the team may meet different situations and move through different stages of progress: the 'orientation stage' (group members meet each other so task-oriented type of behaviour is dominant); the 'evaluation stage' when team members actively communicate with each other and exchange opinions; and the 'control stage' when team members try to influence the group communication. Socio-emotional behaviours increase as the team moves through these stages [298]. Group conflict may occur when a group cannot balance its relational and its task-based interactions [295].

However, other studies in organisational communication [299, 300] indicated that communication is less emotional inside the working environment than Bales proposed [301]. Gorse and Emmits [295, 296] found that interactions between team members in the construction area were task-based rather than social-based. Also, online communication has also been reported to have low levels of socio-emotional communication [302]. Hence the communication medium and environment may predefine the balance between behaviour patterns inside a team [295].

Bales' model considered only two different categories of team roles: task-oriented and socio-emotional. Communication team roles inside these two big groups were not identified. Another researcher [302] found that the differences in behaviour inside task-based categories were related to the work experience and type of work. It could be interesting to study what else may predefine the distribution of communication interactions inside project teams, and how engineering context influences the balance between task-oriented and socio-emotional interactions.

Another communication model was created by Tuckman [294] who proposed the following temporal phases of group development: forming, storming, norming, performing, and adjourning. Forming includes orientation, testing and dependence. At these stages, team members are mostly uninformed about project objectives, they behave independently, and they may be focused on themselves. Orientation is conducted through testing and identifying the boundaries of communication between people. Dependence arises as the establishment of relationships between the team leaders and the other team members. Mature members try to model appropriate behaviour. Generally, in this stage of development, the team communication aims to define the scope and the approach of future work [294]. In the Storming stage, resistance

to group influence and task requirements may appear, together with conflicts around interpersonal relationships. These problems may be overcome in the third stage, Norming. This is the finding of communication norms through the expression of personal opinions. Finally, the group reaches the fourth stage, Performing, where team roles become flexible and structural problems are solved. That means that the group is ready to deal with the tasks [294]. A fifth stage was added later by Tuckman and Jensen [303], and was called Adjourning which was characterized by the completion of the task and, finally, the team separation.

Brown [247] found that the frequency of communication depends on the phase of the task (and group development as they are correlated) and that this influences the team effectiveness. Teams that meet frequently and discuss the engagement of the participants at early stages, generally have better performance than those that do not [248].

In another work [304], the stages of group development were used to study how participants of different groups perceive team communication. Team composition did not correlate with stages of group development, and the perceptions of group interactions were similar among different teams.

A limitation of the above models of group development is that these models only consider group development over the period of the entire project development. They do not include communication change (adjustment) at other levels (during the meeting time or inside the conversation). Hence, there is a need to better understand see how behaviour patterns change within a shorter timeframe.

10.4. Results and findings

Factors that cause communication adjustment

There are many factors that may cause a change in communication behaviour of participants. To analyse them, we used information from the interview.

The list of interview questions is provided in the Appendix D. One of the questions explicitly relates to changes in individual behaviour: *'Do you feel that you changed your communication behaviour at different meetings? Which communication situations caused that?*' Responses from the five student teams and two engineering organisations are summarized below in Table 10.1. In doing so we identified several themes or categories of factors. The primary factor, inasmuch as it was identified by all groups (including supervisors), was Solving Progression issues. The next tier of factors that were common to both student and practicing engineers were: Adjustment to Audience; and Adopted/assigned roles. Factors that were only identified by practicing engineers were Engagement with Depth of discourse, and Type of meeting. Likewise factors only identified by student engineers were Defensive behaviour, Growth in personal confidence, and Mood responses.

Table 10.1. Communication adjustment factors for student engineers, academic supervisors, and engineers in commercial organisations.

Factors Affecting Changes in Communication Behaviour	Student Engineers	Academic Supervisors	Engineers in Commercial Organisations
Adjustment to audience	Presence of supervisor or client/boss.		'*Meetings with the software teams are different form the meetings that includes management*'.

			Official style of meetings or presentation was associate with more official behaviour than at team-only meetings where engineers feel more freedom. Different teams were also observed to have different styles of communication.
Adopted/assigned roles	Chairing a meeting		Engineers were more active in communication when they had much to say about the problem. '*I am an Initiator and Information Provider, when I am hosting a design proposal meeting for the work I am doing'*
Solving progression issues	The feeling that the group or an individual needed their active contribution ('At some meetings where there was a talking point that was getting stuck I tried to shift the conversation', 'When one of our team members was away, I filled the role of Information Provider').	Changes in their communication behaviour at meetings depended on students' project progress or client needs. For example, *'I became more assertive halfway through when the client had expressed a concern regarding team achieving goals', 'I changed communication style when there were unsolved problems or slow progress in the team'.*	'*In some meetings I am the prime driver, in others I am a low-level participant*'.
Engagement with depth of discourse			This refers to the professional level of communication ('*more professional level of communication is more challenging*'). Participants were more talkative when they felt confidence in the area of discussion: '*If I am the expert, I will do more information providing'*.
Type of meeting			Engineers felt that their communication behaviour depended greatly on the specific details of the particular situation such as the status and quantity of team members in that situation ('*many people give less chance and desire to talk*'), the type of meeting. *''Stand-up' tends to be*

			providing progress updates versus high level design which is more of a how should we do the meeting'.
Defensive behaviour	Less personal progress in project tasks, unprepared meetings, or relatively unknown topic lead to low desire to contribute in discussion (three students). Sensitivity to negative critique, and hence intended to be passive.		
Growth in personal confidence	*'Throughout the year I gained more confidence in the work I had completed'.*		
Mood responses	When participants felt tired, unwell, or were just in a bad mood, they were less likely to be active.		

As evidenced above, the participants of the project teams change their behaviour in response to different factors. This is a process of *communication adjustment*.

Given the longitudinal nature of the study, it was possible to observe these interactions dynamics across different timescales. Hence we propose, based on the observations, that the role adjustments may be categorized into three different timescales or levels: *micro-level* being the grounding processes within a conversation cycle; *mezzo-level* being emotional and rational regulation during a meeting; and *macro-level* being the role dynamics over the duration of the project.

Communication and behavioural pattern change at macro-level

At the macro-level, people adjust their behaviour through the changing of communication style and behaviour patterns (team roles) over a long period of time: in the case of the student teams over an academic year. Table 10.2 shows the change of communication activity of student teams over the project development time.

Table 10.2. Communication activity changes for students during the different stages of project development.

Team	Communication Changes with Project Development (from observation notes)
1	Students were not very active in the beginning of the project. As the project continued, their activity increased.
2	There was a difference in team behaviour in the beginning and at the end of the project study. In the beginning, students communicated more with supervisor than between each other. They asked a lot of questions and reported results. In the second semester, the situation changed: students became more active in team communication. In the interview responses, some students cited that this was due to having greater confidence.
3	According to the observations and interview data, all students in this team initially were very active in communication. Later some students decided that being active was difficult because of the supervisor's style (supervisor was a centre of communication and preferred to lead the discussion), so they adjusted their communication behaviour and showed less initiative, talked only when supervisor addressed some questions to them or asked a team. When this happened, student became active, trying to say as much as possible in the short period of time prior to the supervisor started talking again and dominating the conversation.
4	High communication activity in this group was stable during the whole academic year.
5	The team initially was very passive and then activated communication towards the end of semester. Students not only reported to supervisor actively, but also tried to talk with each other to solve problems.

The results in Table 10.2 show that the increase of communication activity happened with all teams. A more detailed examination of the changing team roles in student Team 2 was performed, based on interview data in the middle of the academic year and at the end. Students were asked 'What is your intuitive perception of your own communication style in this team?' Another question allowed them to identify all team roles that they thought described their own behaviour. The list of roles was from [305]. The results are shown in Table 10.3.

Table 10.3. Team role changes in Team 2 over the academic year.

Partici-pant	***Interview questions: 'What is your intuitive perception of your own communication style in this team?' 'Please tick all team roles (communication patterns) that you think describe your typical communication behaviour?'***	
	Answer in the First Semester	**Answer in the Second Semester**
2A	Initially subdued, however taking a larger influence in position over the time due to observing lack of direction or drive in team. Passiveness still preferred to an extent. *Explorer, Active Information Provider*	I think I try to bring the general thoughts and conversation to a more focused point at times. *Initiator, Explorer, Gatekeeper*
2B	Observe, comment key points, mostly passive. *Representative, Explorer, Gatekeeper*	Brief and to the point. *Representative, Gatekeeper, Active Information Provider, Passive collector (final meetings)*
2C	Seems somewhat relaxed but likes clarification and clear answers so can plan. Prefers being active to be well-informed - asks questions, comments, etc. *Representative, Explorer, Facilitator, Gatekeeper*	Honest and upfront, perhaps asking a lot of questions but not great at clarifying what I am asking. *Representative, Explorer, Passive Collector,*

2D	I tend to listen silently and talk only when needed. I focus on my work but check with team members frequently. *Passive collector, Representative*	I like to hear what everyone has to say and only talk when needed. I only take control of the conversation in which I am proficient. *Passive collector, Representative, Gatekeeper, Facilitator (elected)*
2E	Open, curious, suggestive. *Facilitator, Information Provider, Explorer*	Open conversation. Try to get to the bottom of things. *Facilitator, Explorer, Passive Collector*

Evidently the individual's intuitive perception of their own communication behaviour did not change over the academic year. Participants described their behaviour with different words, but their self-described main characteristic remained the same. In reality, according to the observation notes, there was some communication adjustment occurring. This indicated that the individual's perception of their own behaviour could be different from the observered actual behavioural patterns.

Thus, **participant 2A** took more active roles in the team communication as the project developed. They were 'taking a larger influence in position over the time due to observing lack of direction/drive in team'. This corresponds to roles of *Initiator* and *Gatekeeper*.

Participants 2B initially asked many questions, however over time they started to provide information rather than asking. At the end they also became very passive (*Passive Collector*) for some reason.

Participant 2C apparently did not notice communication behaviour changes at the meetings. Initially they were very active (first three meetings), trying to facilitate and regulate communication flow in the group. However, later they became more passive, presumably because of the high communication activity of other members.

Participant 2D was passive from the very beginning of the project and remained mostly passive. However, later they became more sensitive to others need, accepting the role of *Gatekeeper*. Probably this was because in the second semester this participant was frequently elected by group members to be a *Facilitator* (chairing the meeting).

Finally, **participant 2E** (supervisor) was more active in the beginning of the project (*Explorer* and *Information Provider*) by asking leading questions and providing necessary information. Later they became more passive (*Passive Collector*) letting the students initiate and solve minor problems by themselves.

In general, it seems there was a difference in team behaviour in the beginning and at the end of the project. In the beginning, the team reported to the supervisor rather than discuss problems between each other. By the end of the second semester, the situation changed: students became more actively participating in common discussions.

Components of communication setting

The results show that participants do not automatically use the same communication style during the whole time of project duration. Team roles appeared to be very changeable. Roles have been shown depend on parameters including personal characteristics, the team's goals, the addition of a new member group, and even on the meeting location [305].

Two components to the communication process are identified. The first is the initial setting of roles (adoption), and the second is the adjustment (changing of behavior patterns) that occurs during the project development. While the macro-level involves the longitudinal change of

behaviour across multiple meetings, changes in the participant's role behaviour are also anticipated at the mezzo- and micro-levels.

The findings suggest that at the micro-level two interlocutors change their behavior quickly in response to a situation (e.g., of misunderstanding). The mezzo-level corresponds to the interactions between participants during a single meeting. Hence, the communication dynamics relate to both the organisational scale and the time scale over which people change their behaviour.

We further propose, based on the observations, that grounding occurs at the micro-level and regulation at the mezzo-level.

Communication adjustment at the micro-Level

Miscommunication and non-understanding

Communication changes at the micro-level were observed to be associated with oral conversation during the project meetings and these changes were primarily associated with miscommunication, misunderstanding, and non-understanding. This is consistent with the literature.

Non-understanding occurs when person fails to interpret a message at all (not having any hypothesis or ideas) and is aware that it has happened. In contrast, during misunderstanding a participant believes that his or her interpretation is correct, but this may be far from what the speaker intended [80]. Misunderstanding should not be confused with misconception, which refers to errors in prior knowledge [82]. Generally non-understanding is recognised immediately while misunderstanding may not be identified until conversation is over (or never identified) [81]. Partial understanding refers to the understanding of some part of the full intention of the other person [81].

Micro-adjustment: conversational grounding in engineering communication

The micro-level communication adjustment is a reaction to a miscommunication event, whereby interlocutors attempt recovery by regulation or by correction of the communication behaviour. As Clark noted [83], a speaker cannot just deliver message and hope that a listener will understand it. At this level, the adjustment is a grounding process of communication. A typical grounding process involves people giving evidence of understanding or non-understanding [306]. This is evident in non-verbal behaviour such as facial expressions and gestures, or verbal behaviour such as posing clarifying questions and asking for information to be repeated. The interlocutor contributes to grounding by seeking information as to whether what they have said has been comprehended.

During the observations of this study, some micro adjustment processes were also observed. A typical situation we observed for engineering meetings was when a participant made a statement using technical terminology, and the interlocutor misunderstood this statement. We observed the common response was to give a wrong answer or ask a clarifying question along the lines of '*Sorry, I don't understand; please repeat*'. The first person then stated their matter again, using different words and without special terminology, so that they finally understood each other. We also observed that participants used non-verbal signals, particularly facial expressions and gestures, to show their misunderstanding or to explain something. Observational note-taking in this study used the interaction diagram (ID) method [201]. An example micro adjustment processes is represented in the interaction diagram of Figure 10.1.

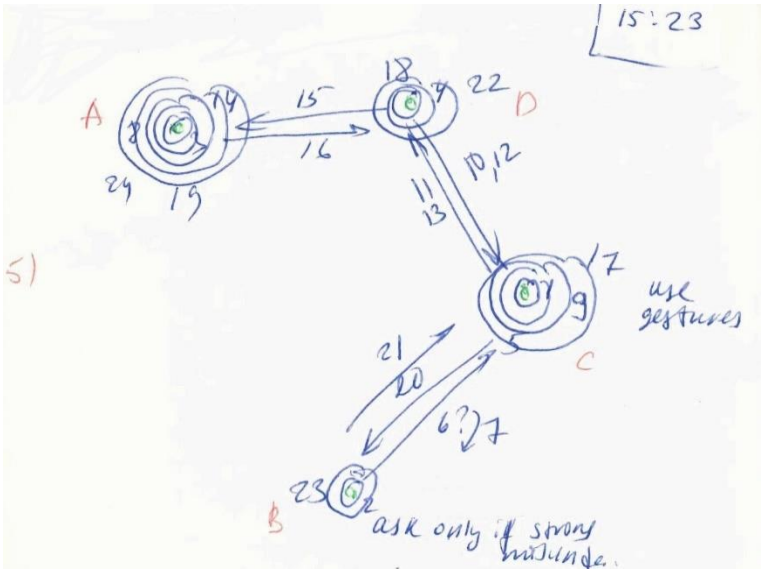


Figure 10.1. Example of grounding process in project meeting (participants B and C), represented as an interaction diagram.

In Figure 10.1, A, B, C, D are participants of the meeting that communicate between each other. Each interaction (turn-taking) was represented by an arrow and was assigned a sequence number. Question signs near the number mean questions were asked, arrows above this question sign represent that an answer was given. Circles represent a broadcast addressed to the whole group rather than to an individual (arrow). As Figure 2 shows, participants B and C misunderstood each other, asking questions and using gestures for explanations. This kind of miscommunication was the most common problem in observed engineering communication at the micro-level.

Another problem was when a participant had insufficient knowledge of a topic and had to ask additional questions to understand. Analysis of the responses to the interview questions showed that these two problems covered most of miscommunication events. By asking additional questions, people adapt to the new communication situation and their team roles may temporally change, from Information *Provider* to *Explorer*.

Communication adjustment at mezzo-level

The micro- and macro behaviour changes interact and occur in parallel during a meeting. Micro adjustments happen regularly, whereas macro regulations were observed less frequently.

Regulation at Mezzo-Level

At the mezzo-level, which corresponds to the entirety of a meeting, the adjustment was observed to have *rational* and *emotional* components. Both result in an adjustment to team role. We propose that the rational component consists of adapting to procedures and rules of a particular meeting or discussion. This is evident in Table 10.1 as *Solving Progression issues*, and *Engagement with Depth of discourse*.

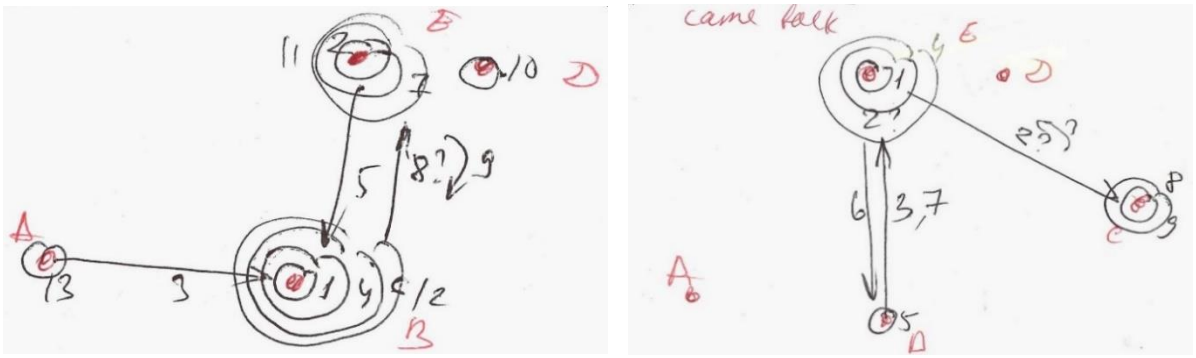
This is complemented by emotional regulation, where people respond affectively to internal or external stressors [307]. Situations that might elicit emotional responses could be when a person encounters a new environment or communication event, such as a different meeting location or a new member of the team.

The person feels stress, anxiety, or fear in the situation, which they attempt to control (hence the term ‘regulation’) by internal cognitive processing. This results in temporary mood behaviour

such as passivity, change in tone, or some neurotic behaviour. A complete emotional adjustment can lead to a return to a normal behaviour, i.e., a return to the team role that is typical for this person. Incomplete emotional adjustment may cause problems such as non-understanding misunderstanding. If regulation fails, then aggression may occur. Emotional adjustment may be accompanied by non-verbal signs [308].

The emotional regulation factors are visible in Table 10.1 as *Adjustment to Audience, Type of meeting, Defensive behaviour, Growth in personal confidence*, and *Mood responses*.

An example from our observations was a new team member who behaved very passively at the first meeting, when joining an already existing group. Newcomers need to determine the behavioural expectations of the team, and to feel comfortable in the new environment. Another important factor was the relationship between participants, particularly the presence or absence of a supervisor or manager in the meeting. Our data showed that without a supervisor, participants felt more freedom and their behaviour became more natural (in harmony with their character and personal communication preference). An example of such situation is given in Figures 10a,10b below. The team communication intensified without supervision, participant B took a temporary role of Team leader and transmitted information to other group members. Even participant D became more active. When the supervisor returned, the communication within the team was suppressed.



(**a**) (**b**)

Figure 10.2. (a) Supervisor is absent; (b) Supervisor (C) came back.

Generalising our observations, we conclude that a typical macro adjustment process involves two key factors. First, it is precipitated by some special situation, such as arrival or departure of a team member, the introduction of a new participant, etc. Second, adjustment involves rational and emotional regulation.

Adjustment by Changing a Team Role

Our third finding is that another form of adjustment at the mezzo-level is the adjustment of team role. This happened when one team member suddenly changed their team role (e.g., receives a telephone call) or left the meeting. As a result, the other team members adjusted their behaviour, changing to more active or passive roles, sometimes substituting a missing component.

Figures 10.3 and 10.4 shows an example of a team role adjustment that was typical for project student teams. In this example, P1 (participant 1) was a supervisor, participants P2–P5 were students, and P6 was a visitor (PhD student). Arrows mean active participation in problem discussing, dashed arrows represent provision of information to a group member.

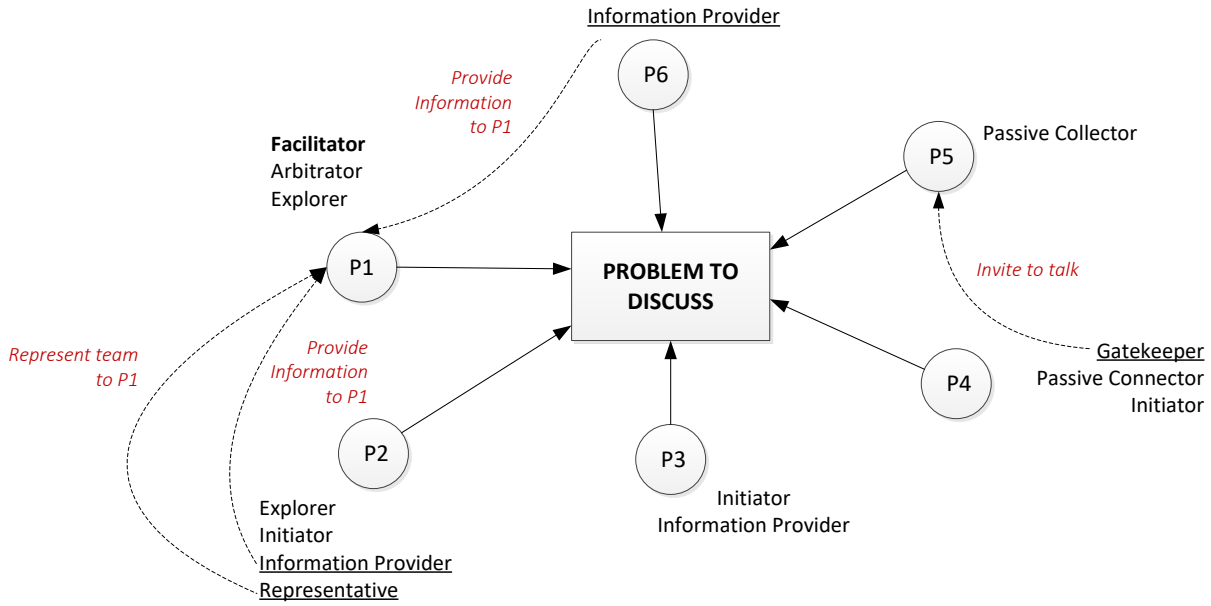


Figure 10.3. Team role adjustment: stage 1.

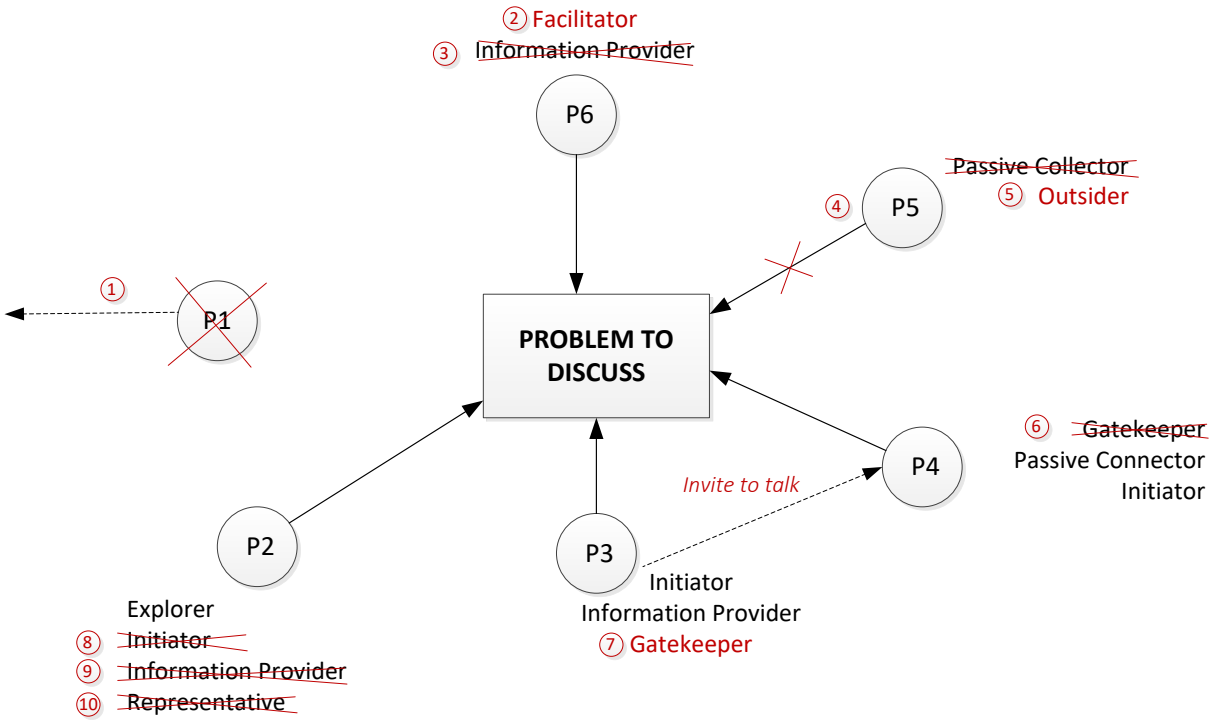


Figure 10.4. Team role adjustment: stage 2.

The team role changes happened very quickly. Red numbers on Figure 10.4 show the sequence of events (changing of team roles). A crossed circle shows departure of a member, crossed line indicate active behaviour turned into passive behaviour, crossed team role (and new roles in red) show changed roles.

Therefore, we propose two stages of team role assignment. First is a situation prior to the team role change, and the second is the changing of team roles (adjustment process). An example follows.

Stage 1: Precursors to role change

Stage 1 is an initial communication balance in the student team before supervisor P1 left the room. Initially P1 covered the role of *Facilitator*, *Arbitrator* and *Explorer*. Participants P2 and P6 provided the supervisor with necessary information (*Information Provider*). P2 also represented the whole team when supervisor asked a question to them (*Representative*). Student P3 was Initiator and *Information Provider* (provided information to other participants, not only to supervisor P1). P5 was a *Passive Collector*, and student P4 tried to involve P5 in more active communication from time to time (*Gatekeeper*). Also, P4 took the role of *Passive Connector* and Initiator.

Stage 2: Role adjustments occur

After a person with power (P1) left the meeting (event 1), the distribution of team roles changed significantly. Participant P6 took the role of Facilitator instead of the supervisor (event 2) and relinquished the role of *Information Provider* (event 3). *Passive Collector* P5 apparently lost interest in conversation and became *Outsider* (out of communication completely) (events 4 and 5). P4 then stopped attempts to involve P5 in conversation (Gatekeeper) and became more passive too (event 6). P3 took the role of Gatekeeper and invited P4 to talk (event 7). At the same time P4 continued with their other team roles — *Initiator* and *Information Provider*. Finally, student P2 lost their position as *Representative* and *Information Provider* because supervisor left the room and became less active in communication (events 8–10).

The team role assignments of this group resulted in markedly higher passivity by members after the balance of power in the meeting changed. Apparently, these team role macro adjustments contained both rational and emotional components. The *rational component* was evident in the creation of new communication procedures and rules to continue discussion without the supervisor. Multiple individual *emotional components* were evident, as members responded negatively to their peer taking the leadership role. Evidently participants did not want to continue communication without the supervisor but were unable to respond rationally. They instead used emotional mechanisms to change to less participatory roles, and hence curtailed the efficacy of the meeting. Altruistic responses were also evident, where individuals helped other members to adapt to the new situation or attempted to involve others in communication.

Possibly some of the negative consequences of this event might have been reduced had participant P6 built approval before taking the role of *Facilitator*, rather than simply capturing it.

The rational and emotional mechanisms for team role adjustment were also evident in other student groups, and in the commercial engineering project meetings.

10.5. Discussion

Model of communication adjustment at micro- and mezzo-levels

We propose the following model of the adjustment processes. We use the idea that miscommunication is divided into misunderstanding, non-understanding [80], and partial understanding [81]. We adapt the scheme of error handling from [79].

The model assumes a turn-based interaction. First, the speaker starts a new turn in conversation. The listener interprets the speaker's output, accepting or disagreeing with the speaker's ideas and attempting to correct contentious areas. If the participant (listener) is not a new member, the normal grounding process starts. The goal is to find common ground by asking questions or showing utterance of understanding. If the grounding is successful (both members show

acknowledgment, confidence and evidence of understanding), then a degree of understanding (full or partial) has been achieved. Otherwise, if participants are still unsure about mutual understanding, then the grounding process has failed. In which case the outcome is misunderstanding (distortion of information perception and misinterpretation), or even complete non-understanding. Role changes may occur whereby a participant may abandon the attempt to resolve the communication problem. This process is summarised in Figure 10.5.

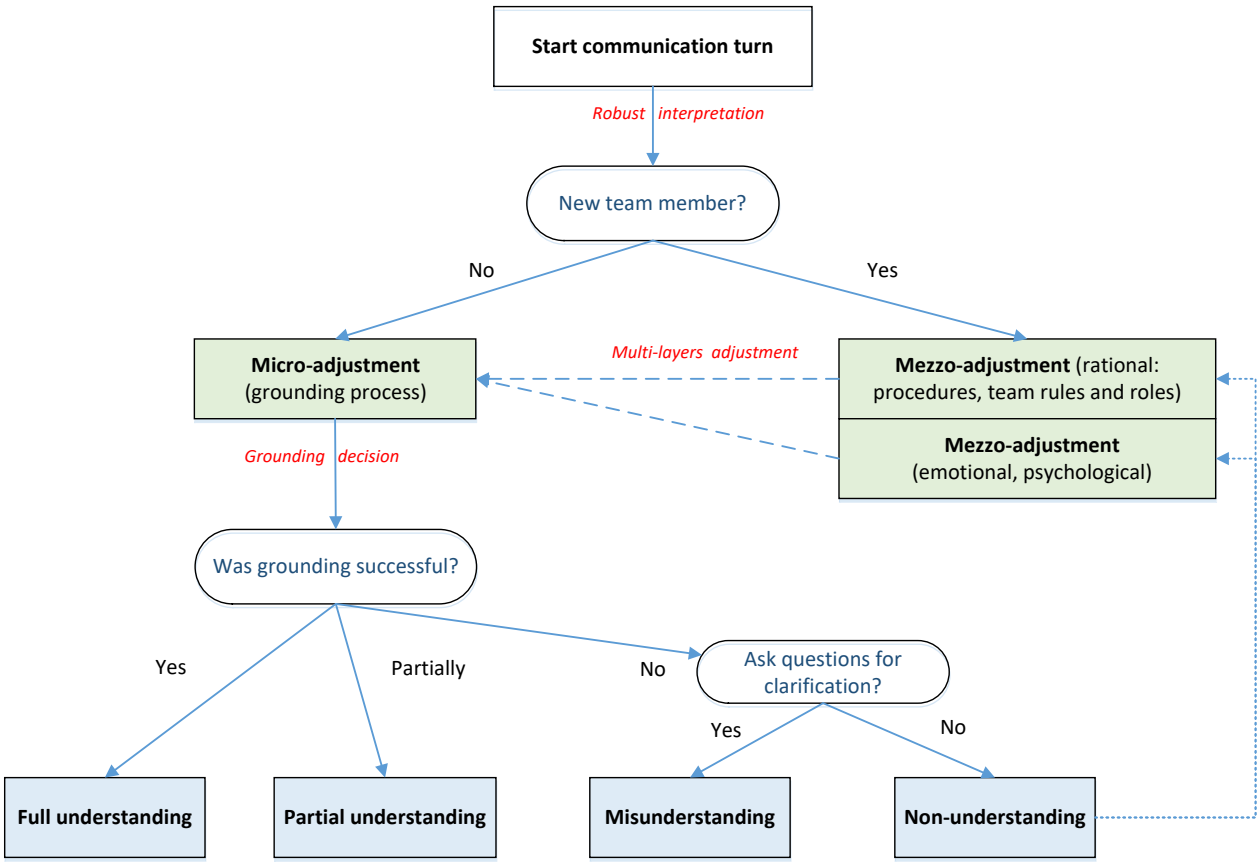


Figure 10.5. Model of adjustment processes at micro- and mezzo-level of team communication.

This scheme combines grounding process with macro adjustments, such as emotional regulation and adapting to the rules and procedures of the meeting for the new member. These processes occur simultaneously. A new team member after passing the basic macro adjustment process becomes involved in conversation with its possible miscommunication events.

Any team member that fails to understand the team discussion may need to repeat the adjustment process again. This might involve seeking to better understand team goals and rules, obtain more topic-specific knowledge, solve any maladapted emotional regulation problems (e.g., changing attitudes to other participants or to own contributions to project completion).

Team role adjustment at macro-level of communication

The above model represents the role adjustment (or grounding) over short time frames, within conversation episodes or within meetings. However, adjustments also occur over the project timeframe, i.e., the macro-level. This is a type of metacommunication, whereby roles changed more slowly in response to changes in the technical nature of the work, change of team membership, or a maturation of the protagonist's own feelings towards other participants. For

example, some observed role adjustments enhanced cooperation and cohesion, while others thwarted perceived negative behaviours of others, and these responses were deliberate.

Consequently, the long-term development of the team, in terms of development of cohesive and constructive relationships, is an important factor for role adjustment at the macro-level. We did not specifically look for Tuckman's temporal demarcations, nor were they obvious in the data in the order they proposed, nonetheless our observations support the idea that the temporal development of teams involves role adjustments in response to task, social, and personal changes, and may be directed towards conflict or cooperation.

According to Bales' work on group development [293], there should be a balance between task-oriented and socio-emotional needs of a team. In our case, this could be understood as a balance between team roles that have direction toward task development (to get jobs done) and social development. It is generally accepted that the two dimensions are in conflict, or at least independent of each other, such that over-emphasis on task completion causes deterioration in group cohesiveness (and the inverse). While this balancing process is commonly anticipated in the literature, it has not been all that clear how it occurs in practice.

We saw evidence for how this balance mechanism occurred in the teams under observation. Participants dynamically adjusted their roles to compensate for what they perceived as shortcomings in the group's behaviour as a whole. These adjustments occurred very quickly—within minutes—and were primarily characterised by rational or emotional mechanisms, sometimes both. Furthermore, it was evident that participants had a limited range of roles they were able to access in these adjustment situations. There was a stability to the role taken by a member, such that the natural adjustment to a new role was only slightly different to the previous one. This observation implies that there is a progression or scale of roles, and hence it is natural to wonder how that might be arranged. The answer was previously reported by the present authors, based on the same data set [305]. The idea that emerges is of a circumplex of team roles, see Figure 9.2. The first axis represents the objective—the outcome the participant seeks for the group. The second represents the approach—what engagement style the participant uses. The circumplex shows that adjacent roles are the most accessible locations for role adjustment, and that opposite segments are contrary to each other on the attributes represented by the axes.

To analyse the balance between roles, a team role profile can be created. See Figure 10.6 for an example for some of the teams. We refer to this as the *collective role profile.*

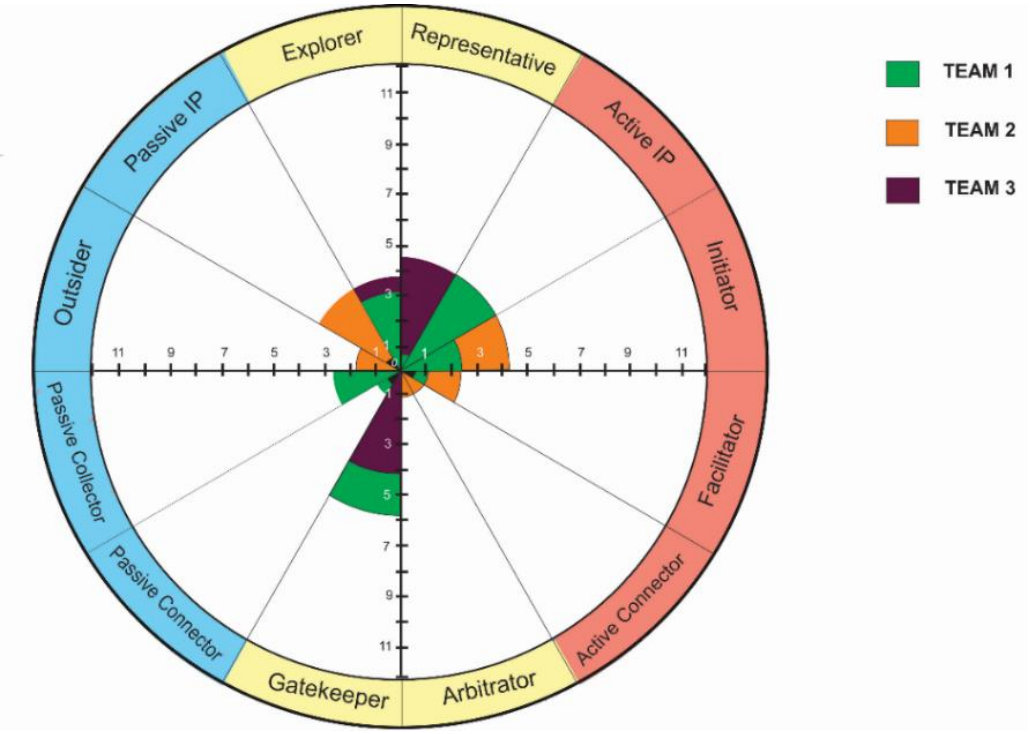


Figure 10.6. Example of collective role profiles for several teams.

Numbers on the axes represent how many times this behaviour pattern (team role) was used by team members. This may be done through observation using the ID method of note-taking, or interview answers. As evident in the above figure, the teams put the task-oriented roles to greater use than the communion ones, with a tendency to rely on the Gatekeeper role to provide the communion balance.

In our study case with the student teams (Table 10.3), the collective role profiles did not change to great extent over the duration of observation. Changes tended to be minor. For example, Students 2B and 2C became more passive, passing their active social position (roles of Initiator and *Gatekeeper*) to students 2A and 2D. Supervisor 2E moved from *Explorer* (active task-oriented role) to the more passive role of *Passive Connector* giving opportunity for students to initiate and solve problems by themselves.

It is also important to notice that the taxonomy of team roles describe casual behaviour of project team members, i.e. according to their personal preferences, rather than behaviour being defined by official positions. Therefore, keeping a balance between social and task-oriented roles may be hard to regulate for a person with power (supervisor or manager).

Our observations showed that when the project needed a change in the collective role profile, the adjustment was limited to adjacent team roles. It appears that the roles taken by participants were preferred styles of collective interaction, and like personality traits, somewhat fixed though malleable. Hence, we recommend that when a participant needs to move to a more active or passive sector of circumplex, they first try to accept the adjacent team role. For example, a very passive student with the role of *Outsider* could try to be a little more active at the meeting taking role of *Passive Collector* or *Passive Information Provider (Passive IP),* thus slowly moving out of their zone of comfort. It appears this may be a promising area of future research, with the potential for significant improvements in human development and mentoring.

10.6. Implications for practitioners

Managers in leadership roles may wish to consider ways of encouraging behaviour that develop team performance and decrease the chance of conflicts or misunderstanding.

At the **macro-level,** managers could consider creating a trustful environment for the team members so they can feel comfortable communicating in their team roles. Our results show that events that precipitate adverse emotional responses cause members to adjust their roles towards reducing the expression of own ideas.

Managers might consider managing the team role distribution among participants. People are naturally more comfortable with some roles rather than others [305], but their preferences are not fixed. The present part of study showed that participants will change roles, and quickly too, as gaps occur in the role structure. From this we infer that people's adoption of roles is significantly affected by the non-availability of their preferred roles (perhaps due to other more forceful people taking those roles), and altruistically by their assessment of roles that need filling. Consequently, managers might do more to help develop younger or new team members by giving them tasks that explicitly require greater communication activity. The opposite is likely to also apply—some team members may have taken roles out of duty, and actually be more comfortable with more passive roles. In this way, the process of communication adjustment could be facilitated by the manager so that member felt more confident about their contributions to the successful completion of the project.

At the **mezzo-level**, during an individual meeting, it may be beneficial for meeting chairs to more deliberately manage the rational and emotional regulation mechanisms, especially for newcomers. Minimising the anxiety and stress on new team members is recommended, to give them time to adapt to the procedures and rules of the project meeting. Also, meeting chairs may need to actively manage the negative emotional responses of team members, which they might do by being sensitive to the signals thereof and finding ways to bring affected members back to more constructive roles.

At the **micro-level** the implications are that individual team members should seek to reduce miscommunication, e.g., through careful use of common terminology, and the deliberate establishment of that lexicon for new team members.

The project management standards, such as the PMBOK [20] adopt a closed loop model of managerial processes for planning, executing and controlling processes. The present work suggests that it is necessary for the project manager to take a more adaptive role to the management of human resources.

Members of the project team have technical roles based on their discipline-specific knowledge and skills—this is well recognised in project management theory. What is less recognised is that each of those team members also has a team role. Project managers need to manage these roles too.

From a project management perspective, the results of our study show that the team communication effects that most adversely affect project success are the silent role changes towards disengagement that occur from emotional regulation. It cannot be assumed that team members' responses will always be rational. Therefore, managing the style of communications within the team (the way members treat each other) and the team roles that people adopt (or are forced into) becomes a key part of the project manager's responsibility.

10.7. Implications for students and engineering educators

We advise that university educator try to get final year project meetings as close to the engineering organisation communication environment as possible. In particular:

- Student project meetings could be more structural (less freedom), with strict agenda.
- Formal team roles could be distributed among participants prior the first project meeting starts and regular reassigned. That could be done after initial testing and/or student group discussion.
- Each student should be given opportunity to run the meeting (become a Team Leader).
- Introduction of a procedure to deal with miscommunication could be beneficial for both supervisor and student participants. Some student may be chosen by team members as an Arbitrator.
- Students that feel uncomfortable in any active team role may be suggested to choose an adjacent role (in circumplex) so they gradually learn to be more active and go outside of zone of comfort.
- Supervisors of student teams are advised to give full freedom in communication to students and try to have minimal involvement in the student discussions. However, project timeframe should be always considered.
- Supervisors could invite people with different work skills and from different age group to join the project meeting (e.g. PhD students, student from different background).
- Gatekeeper should be assigned in each student group as this role is important. This will help students to develop social sensitivity which is one of the main factors of team communication success.

10.8. Conclusions

This Chapter identified the changing of communication behaviour and informal team roles that people adopt in engineering projects, also how the adjustment process operates. Since people are key to successful project management, this provides a deeper and more contextualized understanding of the resource management aspect of project management. In particular, this work moves the field forward from a relatively simplistic sender-receiver model of communication. Instead team members were observed to make constant adjustment of communication style and team roles. Project communication is not just a mechanical process of information exchange, but it includes interpretations of messages (grounding), emotional and rational regulation and also changing of behaviour patterns (team roles) throughout the project.

It was observed that participants of engineering project meetings adjusted their communication style to the behaviour of other people and to different communication settings. We suggest this within three different dynamics: dynamics of micro-level (grounding processes in conversation), mezzo-level (emotional and rational regulation) and macro-level (over a period of time). Misunderstanding is attributed to partial adjustment at one of the levels. Factors predefining communication behaviour change at the macro-level were identified, and a model of communication adjustment at the mezzo-level and at the micro-level is presented.

Chapter 11. Development of a framework

11.1. Model 1: factors predefining engineering project communication

According to our observations, engineering communication in a broad sense consists of communication at meetings. This communication may occur in official meetings with a person in a leadership role such as a supervisor or manager, or it may occur a non-official context, without any participants in positions of leadership without any communication related to job questions outside of meetings (see Figure 11.1). In the last case, engineers ask questions to each other or try to solve current problems that are not generally overly complicated and not required a team meeting.

Communication with clients and people outside of organisations could be considered to be a separate task because of special features of such processes. Clients are not a part of the organisation and therefore may have their own rules and procedures for communication. Clients are also people who order project jobs and any personal meeting or message exchange with him is of high importance for project team. It is generally regulated by the organisational rules and performed by engineers with high levels of experience. Communication with clients can take various forms, such as meetings with many people, or non-official discussion without a meeting. For this purpose, engineers may use various devices: telephone calls, emails, presentations, and video conferences.

Engineering communication depends on many factors that may be divided into two big categories: permanent and temporal. Temporal factors predefine communication only at current meetings, whereas permanent factors have high stability and influence communication in a large time scale.

Temporal factors: This can include the current task and stage of a project, the location and duration of the conversation, composition and quantity of people in the group, communication setting and location inside meeting place, also personal factors like mood sometimes may predefine behaviour of team members and therefore, influence the results of communication (see Chapter 7 and Chapter 10).

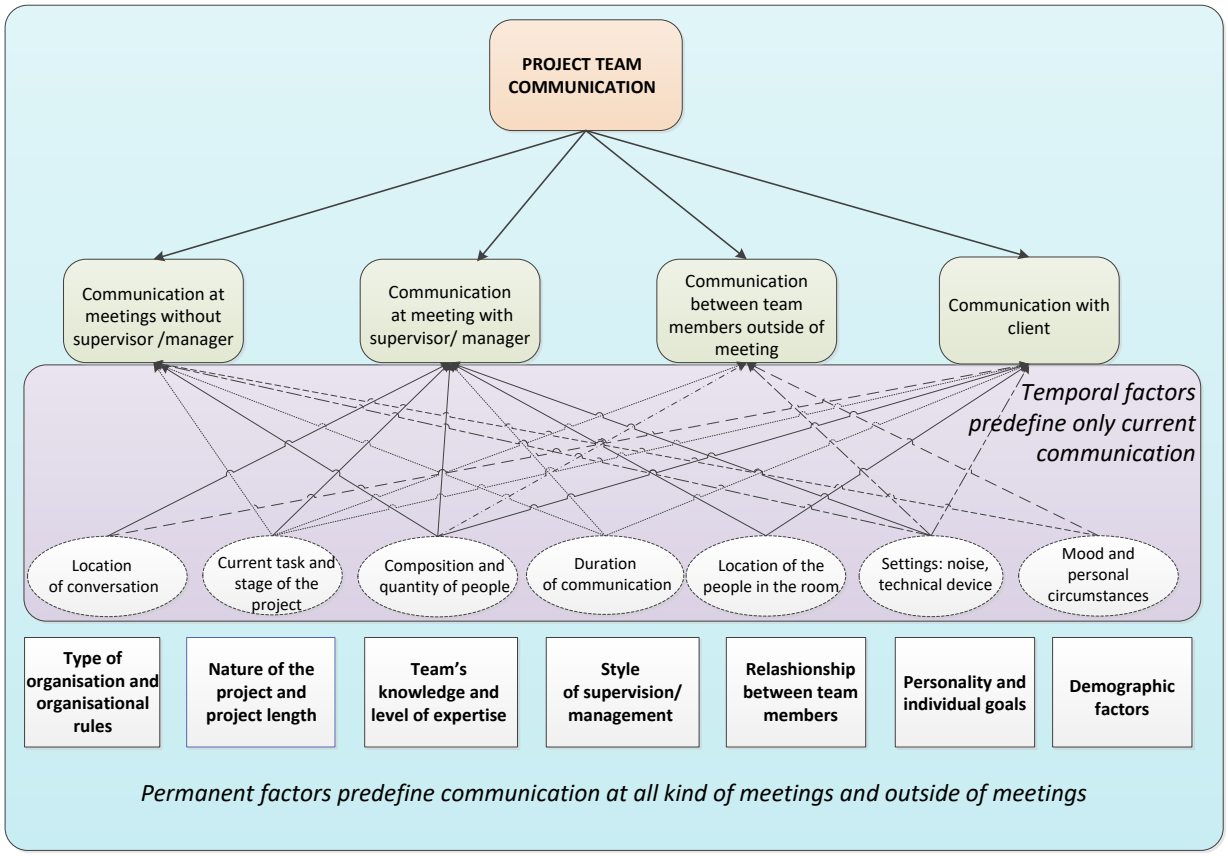


Figure 11.1. Factors predefining engineering project communication

The lines in Figure 11.1 show which type of communication is greatly influenced by a temporal factor. Minor correlations were not taken into considerations. Solid lines mean that data was taken from observation results in student groups and engineering teams or from interviews, whereas dashed lines illustrates possible importance (our assumptions where there was not enough data for support these hypotheses).

According to our data, the location of meetings is important for the communication with an official power person such as a supervisor or a manager of the project team (see Chapter 7.3). It could be also important in communication with a client in a personal meeting. The location of communication between team members outside of the meetings or at meetings without a supervisor or manager could be considered as less significant.

It is possible to assume that current task and the stage of the project are equally important for all types of engineering communication. Composition of the group and the quantity of people at the meeting may also change the style of communication (Chapter 7.3). The duration of communication is apparently important for any kind of project meetings.

According to the interview data, the location of the people in the room has the least power to predefine team communication. However, this may happen in some circumstances at the meetings with a supervisor or manager, and with clients. Finally, mood and emotional factors may be influential for some categories of people (Chapter 7.4 and Chapter 10.3).

Permanent factors: type of organisation and organisational rules, nature of the project and project length, team's knowledge and the level of expertise, style of supervision or management, relationships between team members, personality and individual goals, and demographic factors.

The interview answers of participants show that type of organisation (university, consultancy firm or industrial organisation) and organisational rules may predefine communication in the project teams: people feel restricted by the expectations placed on them by the work situation (Chapter 7.4). Also important is a nature of project and project length. As we observed in organisation 1, a short project requires quick task-performing and clear job and duties distribution. Communication in such project teams is more concentrated. On the other side, observations in organisation 2 (Chapter 7.4) shows that long-term engineering projects may include initial setting meetings, final review meetings, many presentations and could be less focused and intense (it depends on the project nature). The team's knowledge and level of expertise is obviously important for every project team. Communication with low knowledge of the theme will be less productive and project will go on very slowly.

A supervisor's style at university and style of management in organisation also have great influence on team communication as it predefines communication procedures and communication environment in the group (Chapter 7.3). There are other factors that may change communication routine and people's behaviour in the team such as relationship between project team members, demographic factors (see Chapter 4), personality and individual goals – how and why people choose their team roles. The model of such a choice is presented below.

11.2. Model 2: team role adoption and distribution

Role assignment: conscious and unconscious choice

From a psychological perspective, our conscious choice comes in the context of personal preferences, our needs (goal), and values [309, 310]. We can adopt this to the engineering project discussions: a choice of team role is predefined by participant's communication preferences, individual objectives (what participant needs to say in this project meeting) and values. Values in this context mean everything that is believed to be important for a team communication, such as a participant's attitude to team needs. Some people with high sensitivity may choose a team role because understand that team needs this kind of behaviour in this moment.

To develop this idea, we suggest that team roles appear in social group as a result of two main assignment processes: team role adoption and team role distribution.

Team role adoption is a personal conscious choice of communication behaviour. It arises from personal preferences, individual objectives and values (sensitivity to team needs). Other factors such as location and personal relationships may also influence the choice of team role, but in a short perspective. In a long perspective (the whole academic year), we assumed that temporal factors could be ignored.

Team role distribution can be defined as a joint allocation of roles based on what the team has to accomplish. Team preferences may not be aligned with personal preferences. In contrast to team role adoption, this is unconscious process of choosing roles.

Role adoption is a personal choice, whereas role distribution is a team choice that involves self-organisation processes in a group of people. Role adoption and role distribution are two opposite processes developing simultaneously. That is consistent with the literature: dual process theory [311] suggests that personal decisions arise from interplay between two cognitive processes: subconscious (intuitive) systems and conscious (rational) systems. This interplay also may exist in team assignment processes and is shown on Figure 11.2 by blue arrow.

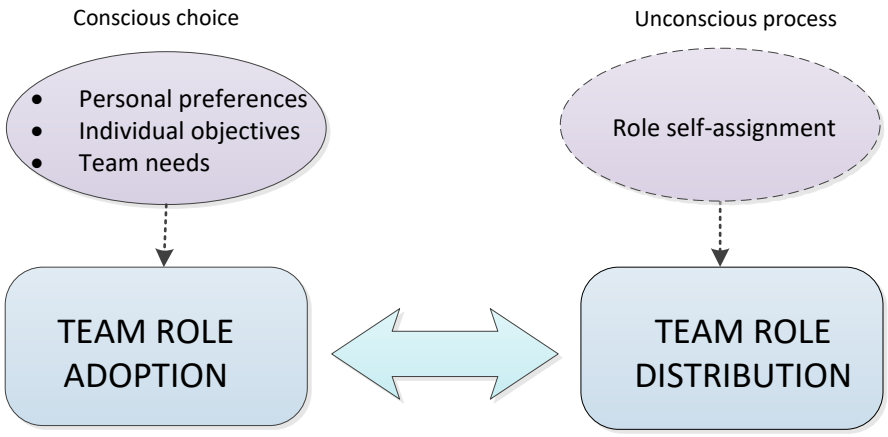


Figure 11.2. Model of team role assignment

The components of team role adoption may have different weights for each individual. Some participants incline to adopt the role that other members or the whole team may need in this moment. Others are more self-sufficient and follow own communication preference consciously. There can be also participants who change their communication style in accordance with individual goals even if they do not like to be in this role. For example, a student chose the role of *Facilitator* because the team needed one, even though they would personally have preferred a more passive role).

Self-organisation processes in project teams

There is enough evidence from previous studies of other authors about existence of self-organisation processes in social groups [66, 67, 312]. We assume that these self-organisation processes in project team includes self-assignment of team roles inside one group. A person may behave in different way in different circumstances and may not realise this.

According to [313], information production occurs a self-organisation system. As a social system, a project team may therefore produce information too.

Social systems create two types of information: individual and social [313]. Individual information is very changeable. It consists of personal attitudes, individual values, norms and preferable style of behaviour. Social information is more stable and more complex. It comprises *Culture*, *Economy* and *Politics*. The cultural part includes group ideas, social norms and values. In our case, this can be information about project team discussions – what is the goal and main idea of the project? What is the most important thing that is expected from team? Economy is a production and distribution of material resources. From engineering project perspective, we may understand this as what teams produce: final project results. Finally, according to [313], politics refers to the taken decision. A decision about organising team communication, for example, will concern who will be a Team leader, reflecting how leading position and roles change.

Therefore, a *Political part* includes information about behaviour and team role choice. A new information appears in the social system and leads to the role distribution according to the team's need. This is supported by our study results (observation and interview data). Only one of five teams preferred prior agreement before each meeting. They discussed who should be a Team Leader, who would be responsible for artefacts, etc. Other teams had spontaneous type of communication and role distribution. Participants did not discuss own style of behaviour and communication roles in the group and generally distributed only job duties. However, in these teams there were always presence of *Facilitator*, *Representator* and *Outsider*. Hence, we may suggest that whereas participants are aware of some part of social information (such as project

output or norms of behaviour), another part is unconscious for them. For example, a Team Leader position may be opened to everybody willing to be active if teams did not make prior arrangement.

The team role changing (adjustment) can be conscious or unconscious depending on circumstances. A good example from observation is when a team with only one active member tried to replace their role when this person was sick or absent. Then another person became active and took the role of missing team member. When asked later about this behaviour changing in interview, participants could not explain this and not even realised this. Therefore, some processes of role assignment are unconscious and may be explained by self-organisation processes in the project team.

Chapter 12. Conclusions

12.1. Outcomes – original contributions

The work makes the following original contributions:

1. A novel **observational method** called the *interaction* diagram was developed that provides a graphical representation of the interaction flow during meetings. It has the benefits of offering a procedure to quickly analyse communication situations, identify group roles, and compare group activity at different meetings. It does this without the being as disruptive as video or audio recording, though this also means that it does not retain verbatim information. The new method is especially strong when the objective is to observe the *interactions* of people, rather than provide a transcript. The method was compared against the process of formal minute-taking, which confirmed that the two methods provide very different perspectives of the same meeting.

2. A new set of **12 team roles** was identified for participants of project meetings. These were based on the literature, and further modified by observation. The list of roles is: *Facilitator, Active Connector, Arbitrator, Gatekeeper, Passive Collector, Passive Connector, Outsider, Passive Information Provider, Explorer, Representative, Active Information Provider and Initiator.*

The novel contribution here is that this team role inventory is designed specifically for participants of engineering project meetings.

3. Observations of team behaviour lead to a new insight into the process of **team role assignment**, and the creation of new theoretical constructs. The suggested team roles were arranged in circular order to create a **Team role circumplex**. While circumplexes exist elsewhere in psychology and human development, there is no prior work in the area of engineering team roles. Key features of the new circumplex are the identification of two axes: *Personal Agency/ Communion* and *Social engagement/ Social Disengagement*. Hence by this theory, the process of team role assignment is an **interplay between two parallel events**: conscious personal choice (role adoption) and unconscious as a part of self-organisation processes in social system (role distribution).

4. Communication at project meetings **at university and in commercial engineering firms** was compared and several distinctions in communication patterns were identified. The official position mostly predefined communication in industrial organisations, whereas at university participants seemed to have more freedom to choose their communication style. Furthermore, communication in organisations was more structured than at university where the schedule of meeting was more flexible. The way to deal with miscommunication was also different: there were special procedures that regulate such situations in commercial engineering organisations whereas at university participants changed their behaviour or room layout according to the situation. Furthermore, many common features were found, such as importance of team size, communication settings, similar types of meetings, and attitude to boundary objects.

5. **Factors predefining project team communication** (temporal and permanent) were determined and analysed. These factors included communication setting of the meeting, team size, location inside the meeting place, nature of the project and project length, style of supervision, personality, and demographic factors.

Parallel discussions may appear when team size exceeds six members. Furthermore, we found that location inside the meeting room and position near the person with power may be important for some team members.

Gender differences in communication preferences of engineers in New Zealand organisations were analysed statistically. Results showed that the most frequent factors for miscommunication for males were language barriers and the absence of trust within the team, whereas females were more sensitive to personal characteristics and technical problems. Females appeared to assume that the communication barriers arise in the production control area and negotiating with customers and stakeholders; males assumed that it was in strategic planning. However, both genders agreed that the workshop is always a problematic area of engineering communication. In the case of misunderstanding, engineers generally identified the need to first ask for clarification from the source of information, and then males tended to want to ask superiors or search on the Internet, whereas females preferred to talk to colleagues.

6. We propose that **Social sensitivity** is key feature of team behaviours. This refers to empathy (personal ability) that helps a person to understand feelings of others in a group. It was assumed that the *Agreeableness* attribute of the Big Five personality trait is a proxy measure for social sensitivity. The other variable well-known in the literature is personal *satisfaction* of team members. This has elsewhere been identified as a factor in determining the roles that people take.

We proposed that these two factors interact in a simple model. We identified that, depending on the levels of *Social sensitivity* and *satisfaction,* there are approximately four levels of outcome for a team. The best is *Team coherence*, followed by *Reluctant cohesiveness, Parallel compensation*, and *Behavioural divergence*.

7. **Several parameters of communication at project meetings** were suggested and analysed for different engineering teams. This was done by quantifying frequencies of qualitive data (observations). These parameters provided additional information about project engineering meetings that cannot be received qualitatively: frequency of artefact use, communication activity or inactivity of the team and addressing/ transmitting ratio of interactions.

8. Finally, models of **communication adjustment** at different levels were developed. It was observed that participants of engineering project meetings adjusted their communication style to the behaviour of other people or to different communication settings. We suppose that this happens at three different levels: micro-level (grounding processes in conversation), mezzo-level (emotional and rational regulation) and macro-level (over a big period of time). These three levels of adjustment may predefine chosen communication style of a participant in project meeting. Misunderstanding is attributed to partial adjustment at one of the levels.

12.2. Implications

Observational studies using the ID method

The **ID method** was designed primarily for researchers who need to observe group interactions between team members in an engineering organisation or university without an audio or video recording. However, it can be used as a supplement to official minute-taking. It will add the name and sequence of interaction and can help to estimate the contribution of each person to the reached decision, communication activity of the whole meeting group and how well each topic was discussed.

Other possible applications include: the qualitative part of the ID method might be used for team formation or team recruiting, while the quantitative part might be used for appraisal and performance review. However, we note that quantitative analysis is time-consuming and may be better for research purposes rather than commercial application.

Building team performance

The results of **team role assignment** can be used by professionals in organisations and at university to build an effective team of engineers that can cope with complex project by solving problems and having productive discussions during the project meeting time. We suggest the following:

1. First, sensitivity to team needs could be considered by people who are trying to build an effective project team of engineers: at least one person with high sensitivity in each team could be beneficial for project development. Team members with high levels of sensitivity cope better with conflict situations and generally try to take a team role that correspond to team needs. This can be done by simple testing of potential team members, and by ongoing leadership of organisational culture.

2. Results of this study shows that another important factor is participants' satisfaction with team communication. People are happy with communication when chosen team roles are consistent with the individual objectives and personal preferences of participants. We suggest that team members could be given them an option to choose a team role according to their personality. For example, passive people may prefer to be *Passive Collectors* in project meeting rather than *Facilitators*, and they should have a choice to behave according to their preferences. Managers or supervisors of the team can do this by testing potential or existing team members and finding for them a right place in a group or right group. However, satisfaction also must be balanced against (a) the project needs, and (b) personal growth. If team members only ever take roles in which they are comfortable, then their personal development would seem precarious. The circumplex may help here, by identifying adjacent roles that may be easier for them to transition to.

3. Leadership of teams, which relates more to shaping people's behaviour rather than management of project objectives, is identified with the Yellow colour roles of *Explorer*, *Representative*, *Arbitrator* and *Gatekeeper*. A key aspect of engineering team leadership appears to be the ability to solicit contributions from quieter members and facilitate but not dominate the discussion. At the next level in the organisation, leadership involves shaping the organisational culture to encourage behaviour that enhance team performance, and personal development of subordinates.

Application of the circumplex

Building of **circumplex team profiles** could be used by engineering managers and supervisor to have a clear presentation of team role distribution at project meetings. Although, missing role may not necessarily indicate the communication problem without existing team needs in it, information about communication behaviour patterns in the team could be valuable for managers/ supervisors. A simple observation could help them with this.

Assessing team interactions

Suggested **parameters of communication flow** could give observers additional information about different type of interactions at team meetings, such as addressing and transmitting, the frequency of artefact use, and group activities of communication. This can be used by managers at organisations or supervisors at university to make quick validations of communication activity in a project team.

Making space for different gender-based styles of communication

In addition, there are some practical implications for **exploratory gender study**. Managers could consider the gender factor in creating a good work environment for people. Thus, males may

benefit from team trust, truthful information, superiors who they can respect, and effective work processes that achieve rapid results. Females may be more relationship-oriented and appreciate the opportunity for informal communication with colleagues and surroundings that provide emotional support. Females appear to prefer to keep some distance from superiors and have more formal interactions through meetings or phone conversation, rather than talking informally. Video conferences with superiors are perceived negatively by both genders, particularly by males.

In the mixed team, the enhancement of roles by gender preferences may be considered. For example, males may prefer presentation tasks, managing the situation, and strategic planning. Females, meanwhile, may prefer negotiation roles, production control processes, protocols, project plan preparation, and project reviews.

12.3. Limitations of the work

The developed **ID method** is limited to observation of small- or medium-sized groups (maximum about eight people) because of the manual nature of the recording. It is difficult to record the simultaneous non-verbal behaviour of multiple members, or if members constantly move about in the meeting. In addition, this method involves the researcher's judgements about what level of detail to choose – for example, any interactions or only verbal ones – how to define an artefact, personal interpretations of situations – for example, differentiating transmitting from addressing – and data presentation (how to represent new events). These limitations are similar to transcription [204]. The 'observer effect' [205] still exists because of the presence of the researcher. Another limitation is that the method does not provide a written verbatim transcription.

The method has not been directly compared to video recording. It would be interesting to determine whether some interactions might be missed, that might be detectable from video recording. It is to be expected that the observer might miss interactions during busy discussion periods, or in meetings with many active participants. Our initial observation from experience is that not keeping up with the interactions adversely affects the quantitative analysis but is not so damaging to the qualitative analysis. Other action communication situations as crew environments, or construction and operational activities, may require full video recording.

There are also some limitations on developed **team role assignment** models:

- Supervisors of student teams followed their official position duties and it was hard to identify their real preferences in communication.
- Agreeableness can be taken only as approximate measure of social sensitivity.
- Observations were conducted on students at their official meetings with supervisor or clients, whereas students may have other types of meetings between each other that were not observed.
- The division between main and secondary team roles should be considered a rough approximation as sometimes it was hard to see the difference.
- Gender, age, and other demographic factors were not considered in this study.

The main limitation of the **exploratory study (gender)** is the small sample size. Another limitation is a geographical spread. The survey was conducted with engineers working only in New Zealand. It could be interesting to see communication differences between cultures. In addition, age was not taken into consideration. The respondents were asked about years of work experience, whereas age group is somewhat different from experience. Future research may help to clarify this question.

12.4. Suggested future research questions

1. Future research topics for **observation method development** could develop the method further. These topics include non-verbal interactions (developing a way to show non-verbal interactions in parallel with verbal ones); artefact abbreviations (creating a list of possible artefacts and their abbreviations), and interactions in meeting rooms (improving methods to show interactions of many participants). In addition, it could be interesting to use multiple researchers for objectivity and measure the 'observer effect' [205].

To achieve this, it may be necessary to conduct observations with two or three researchers and to compare extracted qualitative data. Furthermore, a comparison between video recording of engineering meeting and ID note-taking could give additional information for method development: how to capture non-verbal interactions.

2. Regarding **team role assignment**, bigger samples and more statistical data could give additional information about correlations between personality and team roles. Also, factors that influence team communication such as presence or absence of supervisor, location of the meeting, relationship between participants, style of supervision need further study. Other personality traits, such as *Extroversion, Conscientiousness,* and *Openness to experience* could be correlated with the team role choice too. (While these factors were collected here, the volume of data was insufficient for statistical analysis).

To achieve this, it may be necessary to find say 20 teams of participants in engineering organisations or at university and conduct qualitative research: observe them, interview and check personality traits using BIG Five or another test. Furthermore, a quantitative study could supplement the qualitative research by using survey tools to ask people about their communication preferences, thus finding statistical correlations between different variables.

3. Possible future research questions for **gender study** could be exploration of the extent to which language and cultural barriers might have gender-specific effects in causing of misunderstanding. Also, there may be value in exploring the gender specific philosophical aspects of trust in team situations. There may be different mechanisms involved for the genders. It is possible also that males are more concerned about abstract aspects such as a strong team, where people can trust each other and explain their ideas clearly and possess full and exact work information. In contrast females may need the physical presence of people and a good relationship environment for effective communication.

To achieve this, it may be necessary to conduct a survey with bigger sample (N=113 in the present study but was not enough) and to compare teams with different cultural background or engineering teams from different countries. It may be possible to conduct a qualitative study observing engineering teams that would further clarify the questions about trust and different styles of behaviour in gender groups.

4. Finally, the observational part of the present study tentatively identified that there might be other **factors influencing team communication** that were not anticipated in the literature. Examples of these are 'Sitting versus standing at the project meetings', 'How technical device might influence team role assignment', and 'Comparison of communication in noisy and calm environments'.

To achieve this, it may be necessary to conduct more observation and interviews of engineering teams in different settings and type of meetings. A comparison of Stand-ups versus sitting review meetings might be undertaken or comparing meetings in production areas with those in office locations.

12.5. Conclusion

Although team communication plays a vital role in modern engineering society, there is a paucity of work that examines how team roles emerge as a response to the communicative processes between participants. This research explored different aspects of engineering communication at project meetings using qualitative methods comprising observations, questionnaires and structured interviews, and quantitative methods for extracting additional information.

For research purposes, a method of observation on project teams without audio or video recording was developed. The resulting interaction diagram method can represent multiple interactions between participants in a time-pressured situation in time sequence, and it provides a means to quantify the number and type of personal communication interactions.

We studied two types of project teams: student project teams at university (N=10) and teams of engineers at industrial organisations (N=2). Qualitative methods were used to gain basic information about participants' behaviour. Some qualitative information was quantified, so we suggested several parameters of communication flow that gave us additional information about team activity and using of artefacts at meetings. Furthermore, communication methods in project teams at university and organisations were compared. As a result, several distinctions in communication patterns were identified. Many common features were also found, such as the importance of team size, communication settings, and similar types of meetings.

The specific focus of this thesis was made on the team role assignment in the engineering context. We identified how participants of engineering project meetings acquire communication behavioural patterns, which roles they chose, and how this choice was correlated with participants' preferences, social sensitivity, and team needs. We also showed how these roles change over the time and how participants adjust their behaviour in accordance to communication situation. Several models were built in the field of team roles assignment. First, team role-taking was presented a result of two simultaneous processes: self organisation processes (role distribution) and personal choice of communication behaviour in the team (role adoption). Then, a circumplex of team roles was built to represent different aspects of these behaviour patterns and how team roles can be correlated with each other, using *Communion/ Personal agency and Social engagement* axes.

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Appendix A: Exploratory quantitative survey: questionnaire

A. Demographic questions

1. Please, identify your gender. Please, choose **only one** of the following:
- ○ Male
- ○ Female
- ○ Other

2. What is your current employment status? Please, choose only one of the following:
- ○ Full-time salaried
- ○ Not working but seeking work
- ○ Part-time salaried
- ○ Not working, not seeking work
- ○ Self-employed / sole practitioner
- ○ Retired
- ○ Short term or temporary or hourly contract

3. Are you currently employed in an engineering practice or management role (working in engineering), or do you apply your engineering education and experience to a non-engineering role (working with engineering)? Please, choose only one of the following:
- ○ In engineering
- ○ With engineering
- ○ Others

4. What is the level of your highest engineering qualification?
Please, choose **only one** of the following:
- ○ Diploma
- ○ Bachelor's degree
- ○ Postgraduate certificate/Diploma
- ○ Masters
- ○ Doctorate
- ○ Others (Please specify the details under comments region)

5. How many years of relevant experience do you have since graduating with your engineering qualification?
Please, choose only one of the following
- ○ 0
- ○ 1
- ○ 2
- ○ 3
- ○ 4-5
- ○ 6-10
- ○ 11-15
- ○ 16-20
- ○ 21-25
- ○ 25+

6. Which ONE of the following most closely describes your main area of practice? Please, choose only one of the following:
- ○ Aeronautical
- ○ Building Services
- ○ Biotechnology/Food

- Business
- Civil
- Chemical
- Electrical/Electronics/Power
- Environmental
- Fire
- Geotechnical
- Industrial /Manufacturing/Production
- Information/Telecommunications/Computer Systems/Software/ICT
- Mechanical
- Mechatronics
- Mining
- Oil/Gas/Petrochemicals/Energy
- Structural
- Transportation/Highway Engineering
- Waste/Water
- Nuclear
- Others (Please specify under comments region)

(Note: Aligned with IPENZ practice college fields - with minor variations)

7. Employment field: which ONE of the following most closely describes the organisation that employs you?
Please, choose **only one** of the following:

- Communications
- Construction
- Consultancy
- Education
- Government/Regulatory
- Local/Regional Government
- Manufacturing
- Primary industry (e.g. agriculture, forestry, fishing, mining)
- Production/extraction/processing
- Research & Development
- Transport
- Utilities (Electricity, Gas, Water)
- Others (please specify under comments region)

8. Employment sector: is the organisation that employs you a private or public sector organisation?

- Private Sector
- Public Sector

9. What is the size of your organisation in which you are employed? Please, choose only one of the following:

- 1-5 employees
- 6-19 employees
- 20-100 employees
- 100+ employees

10. In what country are you based? Please write your answer here _____

11. What is your current role? Please, choose only one of the following:

- Engineering student
- Engineering Graduate Progression (applies technical knowledge and skills under supervision)
- Independent Engineering Practice (takes responsibility for own engineering decisions)
- Engineering Team Leader (applies technical knowledge and skills through supervising others of less or same competence)

○ Engineering Technical Manager (supervises work of others who may have wider or greater technical skills or knowledge)
○ Engineering General Manager (manages activities of any nature but uses engineering mind-set)
○ Others (please specify under comments region)

12. To what extent does your current role involve engineering management? Please, choose only one of the following:
○ Not at all
○ Small extent
○ Moderate extent
○ Great extent
○ Very great extent
○ I don't know this.

B. Personal Communication at work

13. Please, estimate the percentage of working time that you use everyday
Please write your answer(s) here:
- For reading and writing emails or electronic messages
- For interacting with other people on a face to face basis
- For talking over the phone
- For working with documentation
- For pure technical work

Please, write in your estimate from 0% to 100% _____

14. Please estimate approximately the number of communication contacts with people during your working day (in person, by phone and electronically)
Please write your answer(s) here

15. How do you receive most of new information necessary for your work?
Please choose **all** that apply:
- Meetings
- Electronic communication (email, video conference, skype, chats, google drive etc.)
- Job instructions, documents
- Verbal guidance of semiors
- Conversation with colleagues
- Phone
- Text messages
- Other

16. How often do you feel that you and your colleagues don't understand each other?
Please choose **only one** of the following:
- Never
- Sometimes
- Very often
- Always
- I don’t know

17. How often do you feel that you and your superiors/subordinates don't understand each other?
Please choose **only one** of the following:
- Never
- Sometimes
- Very often
- Always
- I don’t know or not applicable

18. In your experience, how important are the following factors in causing personal misunderstanding in the workplace? Please choose the appropriate response for each item:

	Unimportant	Somewhat unimportant	Neutral	Somewhat important	Very important	Don't know or Not applicable
Cultural diversity	○	○	○	○	○	○
Language barriers	○	○	○	○	○	○
Different gender	○	○	○	○	○	○
Different age group	○	○	○	○	○	○
Different education background	○	○	○	○	○	○
Ethics and low communication skills of some colleague	○	○	○	○	○	○
Physical separation	○	○	○	○	○	○
Technical problems with transmission of information	○	○	○	○	○	○
Delay in message delivery	○	○	○	○	○	○
Lack of information	○	○	○	○	○	○
Excess of unnecessary information	○	○	○	○	○	○
Ambiguous information	○	○	○	○	○	○
False information	○	○	○	○	○	○
Personal characteristics	○	○	○	○	○	○
Problems in work organisation	○	○	○	○	○	○
Low job motivation	○	○	○	○	○	○
No trust inside team	○	○	○	○	○	○
Too many people in one department	○	○	○	○	○	○
Wrong distribution of duties	○	○	○	○	○	○
Others (please specify under comments region in 2.6B)	○	○	○	○	○	○
Other:						

19. Do you feel barriers in communication become greater as the project increase in size and complexity?
Please choose **only one** of the following:

- ○ Never
- ○ Sometimes
- ○ Very often
- ○ Always
- ○ I don’t know

20. Which communication means do you prefer in 'relationship building' with your superiors?
Please choose the appropriate response for each item:

	Unimportant	Somewhat unimportant	Neutral	Somewhat important	Very important	Don't know or Not applicable
Formal meetings	○	○	○	○	○	○
Informal meetings	○	○	○	○	○	○
Video-conferences	○	○	○	○	○	○
Phone	○	○	○	○	○	○
Email	○	○	○	○	○	○
Text messages	○	○	○	○	○	○
Chats, Blogs	○	○	○	○	○	○

Others	○	○	○	○	○	○

21. Which communication means do you prefer in 'relationship building' with your subordinates? Please choose the appropriate response for each item:

	Unimportant	**Somewhat unimportant**	**Neutral**	**Somewhat important**	**Very important**	**Don't know or Not applicable**
Formal meetings	○	○	○	○	○	○
Informal meetings	○	○	○	○	○	○
Video-conferences	○	○	○	○	○	○
Phone	○	○	○	○	○	○
Email	○	○	○	○	○	○
Text messages	○	○	○	○	○	○
Chats, blogs	○	○	○	○	○	○
Others	○	○	○	○	○	○

22. Whom will you contact first in case of lack of information or misunderstanding?
Please choose **all** that apply:

- ○ Ask clarification from the source of information
- ○ Ask colleagues
- ○ Ask superiors
- ○ Ask somebody whose opinion is important for you even if he/she is not professional
- ○ Search information on internet or in knowledge base
- ○ Read books or journals
- ○ Don't search and ask, trust your own experience and knowledge
- ○ Other_____

23. Which common communication skills are most useful for your job?
Please choose **all** that apply:

- ○ Listening ability
- ○ Resolving conflicts
- ○ Persuading a person
- ○ Negotiating to achieve agreements between parts
- ○ Summarising and recapping
- ○ Questioning
- ○ Read and write technical documentation
- ○ Presentation skills

24. How often does misunderstanding occur in the various phases of a project?
Please choose the appropriate response for each item:

	Always	**Most often**	**Occasionally**	**Seldom**	**Rarely**	**Never**
Before the project commences	○	○	○	○	○	○
During the project	○	○	○	○	○	○
After the project	○	○	○	○	○	○

C. Communication in organisation

25. Which of the following domains are problematic for communication in your organisation?
Please choose all that apply:

- ○ Workshops (Current work problems)
- ○ Manager's offices (Strategic plans)
- ○ Meetings with stakeholders
- ○ Project management (Meetings and discussion of projects)
- ○ Production Control
- ○ Designer's office (design discussions)
- ○ Marketing and sales discussion
- ○ Negotiations with sellers of raw materials
- ○ Interactions with customers

- Personnel department (contracts, employees benifits and rights)
- Industrial saftey and conditions of work
- Other

26. In your opinion, to what extent does communication misunderstanding influence the organisation's productivity?
Please choose **only one** of the following:
- No influence
- 20% sometimes
- 50% in half cases
- 75% great influence in most cases

27. Do you feel that problems in communication provoke conflicts in your department?
Please choose **only one** of the following:
- Never
- Sometimes
- Often
- Always
- I dont know

28. What proportion of information generated by OTHER PEOPLE do you understand? Please write in estimate from 0% to 100% for different groups.
- Colleagues
- Superiors
- Subordinates

29. What proportion of information generated by YOU do you think other people actually understand? Please write your answer(s) here
- Colleagues
- Superiors
- Subordinates

Please write in your estimates from 0% to 100%

30. To what extent does your organisation encourage free-flow of information?
Please choose **only one** of the following:
- Never
- Sometimes
- Very often
- Always
- I dont know

31. What can you suggest to improve the communication level of your organisation?

_____

_____

D. Communication between engineering departments

32. What percentage of communication you receive has the following attributes?
Please write your answer(s) here:
- Lack of vital information/badly specified information
- Just right amount of information required for performing the task
- Too much detailing

(The percentage should add up to 100%)

33. When do you prefer to receive feedback from other departments?
- Before the project commences
- During the project
- After the project
- Only when my input is needed

- Never
- Other:

34. Which communication style do you prefer? Please choose all that apply:
- Communicate early provisional but potentially unreliable information
- Communicate complete and comprehensive information
- Other

35. How often do you have to redo your work, because of lack of prior information regarding the capabilities of other inter-dependent teams? Please choose only one of the following:
- Never
- 1 out of 5 times
- 2 out of 5 times
- 3 out of 5 times
- 4 out of 5 times
- 5 out of 5 times

36. How often do you have project reviews with interdependent teams?
- Daily basis
- Weekly basis
- Monthly basis
- Never
- Other:

37. What impact does project review have on performance?
- Reduces misunderstanding and therefore improves the performance
- Leads to increased procedures and results in delay of important technical work
- Reduces misunderstanding but results in wasting time that could be used for technical work, hence no impact
- Reduces the amount of work that has to be redone but increases the procedures, hence minimal impact
- Other

38. How do predefined communication structures/protocols/rules, impact the performance?
- Creates clarity and allows proper flow of information which is useful
- Does not allow for flexibility, which results in loss of information
- Has no effect
- Other

Appendix B. Initial questionnaire for participants in the qualitative study

Questions for students only

1. Please identify your gender_____
2. What engineering discipline do you study? _____
3. What is the level of your highest qualification? _____
4. To what extent do you know other team members:
    - I do not know anybody
    - I can recognise several members of this group
    - I know one-two members of this group very well and recognise others
    - I know several members of this group very well and recognise others
    - I know all team members very well

Questions for participants in industrial organisations

1. Please identify your gender_____
2. What is your age group? (18-25, 26-37, 38-48, 49-59, 60-65, over 65)
3. What is the level of your highest engineering qualification? _____
4. What is the area of your current engineering expertise? _____
5. How many years of relevant experience do you have since graduated with your engineering qualification? _____
6. What is your current position in this organisation? _____
7. To what extent do you know other team members:
    - I do not know anybody
    - I can recognize several members of this group
    - I know one-two members of this group very well and recognize others
    - I know several members of this group very well and recognize others
    - I know all team members very well

Appendix C. Big Five taxonomy test

Online version of test taken from https://openpsychometrics.org/tests/IPIP-BFFM/)

		Very Inaccurate	*Moderately Inaccurate*	*Neither Accurate nor Inaccurate*	*Moderately Accurate*	*Very Accurate*	
1.	Am the life of the party.	O	O	O	O	O	(1+)
2.	Feel little concern for others.	O	O	O	O	O	(2-)
3.	Am always prepared.	O	O	O	O	O	(3+)
4.	Get stressed out easily.	O	O	O	O	O	(4-)
5.	Have a rich vocabulary.	O	O	O	O	O	(5+)
6.	Don't talk a lot.	O	O	O	O	O	(1-)
7.	Am interested in people.	O	O	O	O	O	(2+)
8.	Leave my belongings around.	O	O	O	O	O	(3-)
9.	Am relaxed most of the time.	O	O	O	O	O	(4+)
10.	Have difficulty understanding abstract ideas.	O	O	O	O	O	(5-)
11.	Feel comfortable around people.	O	O	O	O	O	(1+)
12.	Insult people.	O	O	O	O	O	(2-)
13.	Pay attention to details.	O	O	O	O	O	(3+)
14.	Worry about things.	O	O	O	O	O	(4-)
15.	Have a vivid imagination.	O	O	O	O	O	(5+)
16.	Keep in the background.	O	O	O	O	O	(1-)
17.	Sympathize with others' feelings.	O	O	O	O	O	(2+)
18.	Make a mess of things.	O	O	O	O	O	(3-)
19.	Seldom feel blue.	O	O	O	O	O	(4+)
20.	Am not interested in abstract ideas.	O	O	O	O	O	(5-)
21.	Start conversations.	O	O	O	O	O	(1+)
22.	Am not interested in other people's problems.	O	O	O	O	O	(2-)
23.	Get chores done right away.	O	O	O	O	O	(3+)
24.	Am easily disturbed.	O	O	O	O	O	(4-)
25.	Have excellent ideas.	O	O	O	O	O	(5+)
26.	Have little to say.	O	O	O	O	O	(1-)
27.	Have a soft heart.	O	O	O	O	O	(2+)
28.	Often forget to put things back in their proper place.	O	O	O	O	O	(3-)
29.	Get upset easily.	O	O	O	O	O	(4-)
30.	Do not have a good imagination.	O	O	O	O	O	(5-)
31.	Talk to a lot of different people at parties.	O	O	O	O	O	(1+)

32.	Am not really interested in others.	O	O	O	O	O	(2-)
33.	Like order.	O	O	O	O	O	(3+)
34.	Change my mood a lot.	O	O	O	O	O	(4-)
35.	Am quick to understand things.	O	O	O	O	O	(5+)
36.	Don't like to draw attention to myself.	O	O	O	O	O	(1-)
37.	Take time out for others.	O	O	O	O	O	(2+)
38.	Shirk my duties.	O	O	O	O	O	(3-)
39.	Have frequent mood swings.	O	O	O	O	O	(4-)
40.	Use difficult words.	O	O	O	O	O	(5+)
41.	Don't mind being the center of attention.	O	O	O	O	O	(1+)
42.	Feel others' emotions.	O	O	O	O	O	(2+)
43.	Follow a schedule.	O	O	O	O	O	(3+)
44.	Get irritated easily.	O	O	O	O	O	(4-)
45.	Spend time reflecting on things.	O	O	O	O	O	(5+)
46.	Am quiet around strangers.	O	O	O	O	O	(1-)
47.	Make people feel at ease.	O	O	O	O	O	(2+)
48.	Am exacting in my work.	O	O	O	O	O	(3+)
49.	Often feel blue.	O	O	O	O	O	(4-)
50.	Am full of ideas.	O	O	O	O	O	(5+)

Appendix D. Interview

Interview questions for participants in university

1. How comfortable did you feel in this team communication? *(please use scale from 0 –10)* What did you like? What was wrong?

_____
_____
_____

2. **[students only]** Please estimate your contribution to the project? *(please use scale from 0 -10)*

_____

3. To what extent did you feel that miscommunication occurs in your meetings? *[never, sometimes, most times, always].* What do you think were the typical causes for this?

_____
_____

4. How productive do you think was your team in problem-solving? *(please use scale from 0 -10)*

_____

According to you, what were the barriers for team productivity and successful problem-solving? And what were the strong aspects of communication in your team?

_____
_____
_____

5. What is your intuitive perception of your own communication style in this team?

_____
_____

6. Please tick <u>all team roles</u> (communication patterns) that you think describe your typical communication behaviour?

- *Initiator (Initiate process)* - Active participation, propose new ideas and tasks, new directions of work.
- *Passive collector (Collect information)* - Passive data collecting, non-verbal signs of agreement or just short yes/no answer, low verbal participation in team discussion, attentive listening, and keeping ideas inside.
- *Explorer (Ask questions)* - High verbal participation, active data collecting: ask general questions, ask for different facts, ideas or opinions, and explore facts. Ask to clarify or specify ideas, define the term, and give an example.
- *Information provider* - Provide detailed and excessive information: take an active part in the conversation, but mostly talk than listen
- *Facilitator (Summarize, control discussion)* - Define the task or group problem; suggest a method or process for accomplishing the task; provide a structure for the meeting, control the discussion processes. Bring together related ideas, restate suggestions after the group has discussed them, offer a decision or conclusion for the group to accept or reject. Get the group back to the track
- *Arbitrator (Solve disagreement*) - Encourage the group to find agreement whenever miscommunication arises, or group cannot come to the common division.

- *Representative (Express, answer)* - Verbalize group's feelings, hidden problems, questions or ideas that others were afraid to express, provide an answer to the question that referred to all group.
- *Gatekeeper* (*Fill gaps, sensitive to others)* - Help to keep communication channels open, fill gaps in conversation, ask a person for his/her opinion, be sensitive to the non-verbal signals indicating that people want to participate.
- *Connector* (*Connect)* - Connect the team with people outside the group
- *Outsider* - Stay in the room but do not participate in project discussion (think about something else)

7. Do you feel that you changed your communication behaviour at different meetings? Which communication situations caused that?

_____
_____

8. To what extent do you feel that other people's discussions prevented you from making a contribution at meetings?

_____
_____

9. **[students only]** If you happened to be elected Team Leader at some meeting, did you feel comfortable in this role? If not, why not?

_____
_____

10.**[students only]** Do you feel more comfortable at meetings to address your ideas to other students rather than to supervisor and client? Why is that?

_____
_____

11.If you need to say something, which situation is more natural for you: to talk with a particular person or to transmit ideas to the whole team?

_____
_____

12.What is your preferable style of communication at meeting: slow but accurate discussion, middle intensity of communication, or communication at high speed with quick exchanging of ideas? According to you, which meeting style is the most helpful in problem-solving?

_____
_____

Which style of communication 'students- supervisor' at project discussions do you prefer? (extensive freedom, less freedom, total control). Do you think it predefines the results of project performance? Why?_____
_____
_____

13.Did you feel that location of the meeting and your position inside the room predefines your communication style? What position was the most comfortable for you?

_____
_____

14.Sometimes people in meetings make use of physical objects like drawings, papers, computer screens, physical models, whiteboard drawing, etc. To what extent did you find it helpful when people presented these types of objects? *[never, sometimes, most times, always]*. Why do you think so? Are there situations where these objects were distracting or caused miscommunication?

_____
_____
_____

Interview questions for participants in industrial organisations

1. How comfortable do you feel in this team communication? *(please use scale from 0 –10)*_____

What do you like?

_____
_____

What is wrong?

_____
_____

2. How productive do you think is your team in problem-solving? *(please use scale from 0 -10)*

_____

According to you, what are the barriers for team productivity and successful problem-solving? And what were the strong aspects of communication in your team?

_____
_____
_____
_____

3. To what extent do you feel that miscommunication occurs in your meetings? *[never, sometimes, most times, always].* What do you think are the typical causes for this?

_____
_____
_____

4. What is your intuitive perception of your own communication style in this team?

_____
_____

Please tick <u>all team roles</u> (communication patterns) that you think describe your typical communication behaviour?

- *Initiator (Initiate process)* - Active participation, propose new ideas and tasks, new directions of work.
- *Passive collector (Collect information)* - Passive data collecting, non-verbal signs of agreement or just short yes/no answer, low verbal participation in team discussion, attentive listening, and keeping ideas inside.
- *Explorer (Ask questions)* - High verbal participation, active data collecting: ask general questions, ask for different facts, ideas or opinions, and explore facts. Ask to clarify or specify ideas, define the term, and give an example.
- *Information provider* - Provide detailed and excessive information: take an active part in the conversation, but mostly talk than listen
- *Facilitator (Summarize, control discussion)* - Define the task or group problem; suggest a method or process for accomplishing the task; provide a structure for the meeting, control the discussion processes. Bring together related ideas, restate suggestions after the group has discussed them, offer a decision or conclusion for the group to accept or reject. Get the group back to the track

- *Arbitrator (Solve disagreement*) - Encourage the group to find agreement whenever miscommunication arises, or group cannot come to the common division.
- *Representative (Express, answer)* - Verbalize group's feelings, hidden problems, questions or ideas that others were afraid to express, provide an answer to the question that referred to all group.
- *Gatekeeper* (*Fill gaps, sensitive to others)* - Help to keep communication channels open, fill gaps in conversation, ask a person for his/her opinion, be sensitive to the non-verbal signals indicating that people want to participate.
- *Connector* (*Connect)* - Connect the team with people outside the group
- *Outsider* - Stay in the room but do not participate in project discussion (think about something else)

5. Do you feel that you change your communication behaviour at different meetings? Which communication situations caused that?

_____
_____

6. To what extent do you feel that other people's discussions prevented you from making a contribution at meetings?

_____
_____

7. What is your preferable style of communication at meeting: slow but accurate discussion, middle intensity of communication, or communication at high speed with quick exchanging of ideas? According to you, which meeting style is the most helpful in problem-solving?

_____
_____

8. Do you feel that location of the meeting and your position inside the room predefines your communication style? What position was the most comfortable for you?

_____
_____

9. Sometimes people in meetings make use of physical objects like drawings, papers, computer screens, physical models, whiteboard drawing, etc. To what extent do you find it helpful when people present these types of objects? *[never, sometimes, most times, always]*. Why do you think so? Are there situations where these objects were distracting or caused miscommunication?

_____
_____
_____

10. Do you have any comments on the difference between project meetings during your university studies, compared to the workplace? For example, did you find yourself comfortable when you first came to the organisation and took part in the project discussions? What are your feelings about this? Do you think that university students need to be better prepared for the communication in organisations?

_____
_____

Appendix E. Ethic approvals

Exploratory quantitative study

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

HUMAN ETHICS COMMITTEE

Secretary, Lynda Griffioen
Email: human-ethics@canterbury.ac.nz

Ref: HEC 2015/47/LR-PS

31 August 2015

Kristina Nestsiarovich, Anurag Bagalkot and Vinod Balasubramanian
Department of Mechanical Engineering
UNIVERSITY OF CANTERBURY

Dear Kristina, Anurag and Vinod

Thank you for forwarding to the Human Ethics Committee a copy of the low risk application you have recently made for your research proposal "Communication in engineering".

I am pleased to advise that this application has been reviewed and I confirm support of the Department's approval for this project.

Please note that this approval is subject to the incorporation of the amendments you have provided in your email of 27 August 2015.

With best wishes for your project.

Yours sincerely

Lindsey MacDonald
Chair, Human Ethics Committee

HUMAN ETHICS COMMITTEE

Secretary, Rebecca Robinson
Telephone: +64 03 369 4588, Extn 94588
Email: human-ethics@canterbury.ac.nz

Ref: HEC 2017/03/LR-PS

3 March 2017

Kristina Nestsiarovich
Mechanical Engineering
UNIVERSITY OF CANTERBURY

Dear Kristina

Thank you for submitting your low risk application to the Human Ethics Committee for the research proposal titled "Communication in Engineering: Investigation on Students' Communication".

I am pleased to advise that this application has been reviewed and approved.

Please note that this approval is subject to the incorporation of the amendments you have provided in your emails of 10th and 27th February 2017.

With best wishes for your project.

Yours sincerely

R. Robinson

pp.
Associate Professor Jane Maidment
Chair, Human Ethics Committee

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

HUMAN ETHICS COMMITTEE

Secretary, Rebecca Robinson
Telephone: +64 03 369 4588, Extn 94588
Email: human-ethics@canterbury.ac.nz

Ref: HEC 2017/70/LR-PS

2 February 2018

Kristina Nestsiarovich
Mechanical Engineering
UNIVERSITY OF CANTERBURY

Dear Kristina

Thank you for submitting your low risk application to the Human Ethics Committee for the research proposal titled "Communication in Engineering: Observation on Students and in Organisation".

I am pleased to advise that this application has been reviewed and approved.

Please note that this approval is subject to the incorporation of the amendments you have provided in your emails of 1st and 29th January 2018.

With best wishes for your project.

Yours sincerely

R. Robinson

pp.

Professor Jane Maidment
Chair, Human Ethics Committee

Appendix F. Publications

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
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Deputy Vice-Chancellor's Office

Postgraduate Research Office

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This form is to accompany the submission of any thesis that contains research reported in co-authored work that has been published, accepted for publication, or submitted for publication. A copy of this form should be included for each co-authored work that is included in the thesis. Completed forms should be included at the front (after the thesis abstract) of each copy of the thesis submitted for examination and library deposit.

Please indicate the chapter/section/pages of this thesis that are extracted from co-authored work and provide details of the publication or submission from the extract comes:

Nestsiarovich, K.; Pons, D. Interaction diagrams: Development of a method for observing group interactions. Behavioral Sciences, 2019, 9 (1), p. 5.

This paper was partially adapted and featured in Chapters 5, 8 and 9

Please detail the nature and extent (%) of contribution by the candidate:

This paper was initially conceptualised by Kristina Nestsiarovich and Dirk Pons, and then further refined in use by Kristina Nestsiarovich. The data collection was undertaken by Kristina Nestsiarovich, as was the data analysis. Project management of the research was done by Kristina Nestsiarovich. Supervision was provided by Dirk Pons. The original draft was written by Kristina Nestsiarovich, and all authors contributed to subsequent editing and review.

Kristina Nestsiarovich**: 75%** Dr Dirk Pons**: 25%**

Certification by Co-authors:

If there is more than one co-author then a single co-author can sign on behalf of all

The undersigned certifies that:

- The above statement correctly reflects the nature and extent of the Doctoral candidate's contribution to this co-authored work
- In cases where the candidate was the lead author of the co-authored work he or she wrote the text

Name: **Kristina Nestsiarovich** Signature: Date: **31.01.2020**

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Please indicate the chapter/section/pages of this thesis that are extracted from co-authored work and provide details of the publication or submission from the extract comes:

Nestsiarovich, K.; Pons, D. Team Role Adoption and Distribution in Engineering Project Meetings. Behavioral Sciences 2020, 10 (2), p. 57.

This paper was adapted in Chapter 9.

Please detail the nature and extent (%) of contribution by the candidate:

This paper was initially conceptualised by Kristina Nestsiarovich and Dirk Pons, and then further refined in use by Kristina Nestsiarovich. The data collection was undertaken by Kristina Nestsiarovich, as was the data analysis. Project management of the research was done by Kristina Nestsiarovich. Supervision was provided by Dirk Pons. The original draft was written by Kristina Nestsiarovich, and all authors contributed to subsequent editing and review.

Kristina Nestsiarovich: **75%** Dr Dirk Pons: **25%**

Certification by Co-authors:

If there is more than one co-author then a single co-author can sign on behalf of all

The undersigned certifies that:

- The above statement correctly reflects the nature and extent of the Doctoral candidate's contribution to this co-authored work
- In cases where the candidate was the lead author of the co-authored work he or she wrote the text

Name: **Kristina Nestsiarovich** Signature: Date: **31.01.2020**

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Please indicate the chapter/section/pages of this thesis that are extracted from co-authored work and provide details of the publication or submission from the extract comes:

Nestsiarovich, K.; Pons, D.; Becker, S. Communication Adjustment in Engineering Project Meetings. Behavioral Sciences, 2020, 10 (7), p. 111.

This paper was adapted in Chapter 10.

Please detail the nature and extent (%) of contribution by the candidate:

This paper was initially conceptualised by Kristina Nestsiarovich and Dirk Pons, and then further refined in use by Kristina Nestsiarovich. The data collection was undertaken by Kristina Nestsiarovich, as was the data analysis. Dr Sid Becker helped in organisation of data collection. Project management of the research was done by Kristina Nestsiarovich. Supervision was provided by Dirk Pons. The original draft was written by Kristina Nestsiarovich, and all authors contributed to subsequent editing and review.

Kristina Nestsiarovich: **70%** Dr Dirk Pons: **20%** Dr Sid Becker **10%**

Certification by Co-authors:

If there is more than one co-author then a single co-author can sign on behalf of all

The undersigned certifies that:

- The above statement correctly reflects the nature and extent of the Doctoral candidate's contribution to this co-authored work
- In cases where the candidate was the lead author of the co-authored work he or she wrote the text

Name: **Kristina Nestsiarovich** Signature: Date: **08.07.2020**