Collaborative Decision Making in Complex Work Settings: A Process of Managing Interdependencies

Nallini Selvaraj

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CANDIDATE'S DECLARATION FORM

Name of candidate: **Nallini Selvaraj**
Student number: **2337173**

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ABSTRACT

There exists disparity between the conceptualization and occurrence of Collaborative Decision Making (CDM) in everyday work activities of complex work settings. Current notions in the field of Computer Supported Cooperative Work (CSCW) based on studies of decision making in groups typically portray CDM as an isolated event in which multiple personnel jointly undertake decision making. In the real world, however, decisions are made during work performance and interlaced with other processes and activities. Moreover, the complex work setting is a cooperative arrangement in which decision making is distributed. This research aims to alleviate the disparity by investigating how people in a complex working environment make decisions collaboratively. The original contribution to knowledge made by this thesis is the theory of CDM as a process of managing interdependencies.

Field-studies conducted in an airport to examine the way CDM is undertaken during Air Traffic Control operations inform theory development. The study takes a qualitative approach and is guided by Grounded Theory Methodology (GTM). The findings of this research indicate that undertaking decision making in the cooperative arrangement of complex work settings requires managing the distributions and interconnections inherent in this setup. In addition, participation and contribution of personnel in decision making is found to be structured by the dependencies between their activities. These findings form the central focus of the theory leading to the depiction of CDM as a process of managing interdependencies.

The theory presented in this thesis clarifies and extends existing views by explicating the differentiated process of CDM in the cooperative arrangement of a complex work setting. Based on this a new definition of CDM is formulated. In addition, a conceptual framework of ten parameters is derived to serve as a tool for analysing CDM taking place in a particular work setting. Application of this framework is demonstrated by analysing an aircraft accident report to draw insights about the occurrence of CDM in this setting.

This thesis is dedicated to my family

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PUBLICATIONS RELATED TO THIS THESIS

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N, Selvaraj. and B, Fields. (2010) *Developing a framework of Common Information Space (CIS): Grounded Theory analysis of airport CIS*. In Proceedings of the 16th International Conference on Collaboration and Technology (CRIWG'10). Eds. Kolfschoten, Herrmann and Lukosch. Springer-Verlag. Berlin: Heidelberg. pp. 281-296.

N, Selvaraj. and B, Fields. (2010) *Mediation role of boundary objects in articulating common information spaces*. Paper presented at: Workshop held in conjunction with the 9th International Conference on Designing Cooperative Systems (COOP 2010). 18 - 21 May 2010. Aix-en-Provence: France.

N, Selvaraj. and B, Fields. (2009) *A grounded theory approach towards conceptualizing CIS for heterogeneous work communities*. In Proceedings of the 23rd British HCI Group Annual Conference on People and Computers: Celebrating People and Technology (BCS-HCI '09). British Computer Society. Swindon: UK. Pp . 471-479.

N, Selvaraj. B, Fields. and P, Amaldi-Trillo. (2007) *Decisions and collaborative work: A different perspective*. In: Proceedings of the 14th European Conference on Cognitive Ergonomics (ECCE 2007). 28 - 31 August 2007. London: UK. p. 243-246.

N, Selvaraj. and B, Fields. (2006) *Collaborative Decision Making in Complex Safety Critical Systems: A Common Information Space Approach*. Paper presented at: 9th Human-Centered Technology Postgraduate Workshop (HCT). University of Sussex. 11 - 12 September 2006. Brighton: UK.

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LIST OF ABBREVIATIONS

AC	Arrivals Controller
AFDS	Aircraft Flight Display System
AFTN	Aeronautical Fixed Telecommunication Network
ATC	Air Traffic Control
ATIS	Air Traffic Information System
CDM	Collaborative Decision Making
CFMU	Central Flow Management Unit
CSCW	Computer Supported Cooperative Work
DC	Departure Controller
EFPS	Electronic Flight Progress strips
GC	Ground Controller
GP	Ground Planner
GT	Grounded Theory
GTM	Grounded Theory Methodology
LATCC	London Area Terminal Control Centre
LTCC	London Terminal Control Centre
MET	Met Office in UK
NATS	National Air Traffic Services
NDM	Naturalistic Decision Making
RC	Radar Controller
SID	Standard Instrument Departure
TC	Tower Controller

LIST OF DEFINITIONS

Activity	Actions performed to reach a particular state
Goal	A desired state
Organization	A number of individuals and work units united for a particular purpose.
Personnel	Employees of an organization
Process	A series of activities and actions taken to achieve a particular result
Task	An assigned piece of work to be finished within a certain time as part of one’s duties in an organization
Work Environment	Physical location and surrounding conditions in an organization where a task is performed
Work Setting	State or arrangement of the place in an organization where a is task performed
Work Unit	A collection of entities in an organization working together to accomplish a goal
Real World	Practical and actual circumstance as opposed to abstract one

CHAPTER 1

INTRODUCTION

1.1. SYNOPSIS

The basis of this thesis is that current conceptualizations of Collaborative Decision Making (CDM) in real world complex work settings are limited in their focus. There is a disparity between the existing and its occurrence in the cooperative work arrangement of the real world. Moreover, the fields of investigation typically address either the collaborative or decision making aspect of CDM. In particular, this is evident in Computer Supported Cooperative Work (CSCW) which places considerable focus on collaboration, while decision making is not a topic of direct study. Conversely, Naturalistic Decision Making (NDM), a field which explores decision making in real world settings, addresses CDM by focussing on individual cognitive processes and sociality is investigated in the light of overlapping cognitive constructs. Nevertheless, there is an ongoing realization of the embedded nature of decision making in everyday work activities which has not been incorporated in studies of CDM. Hence, the work undertaken in this research aims to address the gap by developing a theory of CDM based on empirical studies of real world complex work settings such as Air Traffic Control. This thesis contributes to a new perspective and theoretical understanding of the occurrence of CDM in the cooperative arrangement of complex work settings.

1.2. RESEARCH BACKGROUND

Complex work settings characteristic of modern organizations are depicted in the field of Computer Supported Cooperative Work (CSCW) to be ensembles of people, technology and environment (Schmidt 1991b; Schmidt and Bannon 1992; Schmidt and Simone 1998). In this setup, work performance is distributed amongst multiple individuals with different expertise and responsibilities. They can be co-located or distributed in space and time, and function in dynamic and unpredictable environmental conditions. Personnel act semi-autonomously based on their own understanding of the circumstances they confront but recognize that their work activities are interrelated with that of others (Boland et al. 1992). Work performance including decision making involves intricate relationships and rich interaction between entities in the ensemble (Carstensen and Schmidt 1998; Cilliers 1998; Hilburn 2004).

Decision making in complex work settings takes place in a collaborative setup. It is a collective endeavour requiring joint effort by multiple individuals and is generally referred to as Collaborative Decision Making (CDM). Based on the traditional perspective of decision making as a problem solving process, CDM is generally considered to be a kind of reasoning phenomenon whereby a collection of decision makers go through the solution space of a problem to find an optimal or 'satisficing' solution by using their expertise and resources (Durfee, Lesser and Corkill 1989). Alternatively, in recent years, CDM in the socially organized setup of complex work settings is treated as a process of reaching a decision that is agreed upon by more than one individual in order to attain common goal (Panzarasa, Jennings and Norman 2002; Seguy, Noyes and Clermont 2010; Kapucu and Garayev 2011).

CDM is typically explored through decision making undertaken in a 'group' or 'team'. Moreover, while personnel engage with both cognitive and social processes to undertake CDM, investigations focus on either the former or latter depending on whether the focus of the researching field is on cognitive or social aspects of work performance. Traditionally, decision making is considered to be the domain of cognitive science and collaboration that of social science. This disparity structures the focus of investigations of CDM.

Computer Supported Cooperative Work (CSCW) and Collaborative Decision Making (CDM)

The field of CSCW focuses on the social organization of work and hence concentrates on the social processes involved in CDM. Furthermore, since CSCW takes the traditional view of decision making as a cognitive process, it is not a direct subject of study. Instead, decision making is approached indirectly through the development of technological systems, known as Group Decision Support Systems (GDSS) and Collaborative Decision Support Systems (CDSS), based on investigations of decision making in groups and social processes such as communication, cooperation and coordination.

When CDM is undertaken in groups the focus is on how the group as a whole arrives at a decision which is accepted by all group members (Jones and Roelofsma 2000). It involves two processes namely: 'selection process' which consists of individual member's choice of decision, and 'consensus process' of exchanging their decision rationale and negotiating the choice of decision from the set of alternative solutions provided by group members (Herrera-Viedma, Herrera and Chiclana 2002). In such a conceptualization, CDM is aimed at consensus building through debating and negotiating choice from a set of alternatives, decision making is the goal and decision is the final-point in the process of CDM.

Research undertaken in CSCW to explore decision making in groups is generally conducted through laboratory studies (Bannon 1997; Mohammed and Dumville 2001). In the course of its evolution CSCW studies have steered towards emphasizing the importance of understanding work practices in real world settings. Whilst ‘workplace studies’ (Schmidt 1998a; Luff, Hindmarsh and Heath 2000) of collaboration are prevalent in CSCW, studies of CDM in real world work settings are relatively limited. In contrast, the field of Naturalistic Decision Making (NDM) specializes in studying decision making as it takes place in the actual work settings of the real world (Lipshitz et al. 2001; Klein 2008).

Naturalistic Decision Making (NDM) and Collaborative Decision Making (CDM)

NDM research focusses on human cognition and contextual features that define decision making in the real world. The field aims to elicit descriptions of cognitive strategies employed by decision makers during everyday work activities. Investigations in this field study CDM in teams and how it occurs in real world settings such as military command and control, firefighting, air traffic control and ambulance dispatch centres. CDM is defined in the field of NDM to be a process by which team members seek, exchange and synchronize information in order to decide on a course of action (Mcintyre and Salas 1995).

While taking stock of decision making research in NDM, Lipshitz, Klein et al. (2001) present the need for more empirical work to develop relevant theories in natural work settings. NDM has been proliferating towards a wider context through ‘macrocognition’ research which extends beyond cognitive aspects of individual decision making and endeavours to broadened the focus of the field to include collective work through inclusion of concepts such as ‘common ground’ and coordination (Klein et al. 2003; Schraagen et al. 2008). This undertaking is still in its formative stages and can benefit from stronger theoretical linkages with social theories (Vanharanta 2009). Knowing that CSCW addresses the social aspects of CDM, it is hypothesized for the purpose of this thesis that research from CSCW may address the gap in NDM. Also, this thesis looks to NDM research only to the extent of addressing the nature of work performance in natural work settings and literature from the field does not form the core focus.

1.3. RESEARCH MOTIVATION

The motivation for this thesis is derived from the disparity identified in the conceptualization of CDM based on studies of decision making in groups in CSCW and its occurrence in the cooperative work arrangement of real world complex settings. Whilst this thesis is based in the field of CSCW, findings from NDM research may be implicated in modifying current views on CDM. Related concerns that instigate this research work are as follows:

a) 'Choice-point' notion of CDM

Based on studies of group decision making, the typical view held is that CDM occurs at a 'choice-point'- an instance during work performance when the need for making a choice of action arises. Research in the field of CSCW focuses on this 'choice-point' and therefore takes the stance that decision making is the goal in CDM. However, NDM research demonstrates that this is not the case in the real world. Instead, in NDM the goal of undertaking CDM is task performance in prevailing circumstances (Orasanu 1990; Brehmer 1992; Jones and Roelofsma 2000; Gore et al. 2006). During everyday work activities decision making does not take place in isolation but is interlaced with other processes and work activities. Therefore, there is still a need to provide actual representation of decision making in the cooperative work arrangement of real world context.

b) CDM as a process of achieving common goals and consensual decision

Various definitions depict CDM to be a process of achieving a 'common goal' which is the decision on the course of action to be taken to solve a problem (Bui and Jarke 1984; Panzarasa, Jennings and Norman 2002; Kim et al. 2004; Seguy, Noyes and Clermont 2010; Kapucu and Garayev 2011). Such a view of CDM is contested by some CSCW researchers (Schmidt and Bannon 1991b; Sullivan et al. 1999; Cohen, Cash and Muller 2000). Their argument is that in the cooperative work arrangement of complex work settings goals of personnel participating in CDM can be of different scope and nature. Regardless of the above, CDM in real world settings is still considered a process of achieving 'common goals'.

Furthermore, based on studies of decision making in groups CSCW portrays CDM as a process of achieving consensus on decision to be made. In this case, all group members participate in the discussion and negotiation involved in arriving at their decision. Taking this into consideration the existing models (Karacapilidis and Papadias 2001; Yang et al. 2001; Herrera-Viedma, Herrera and Chiclana 2002; Panzarasa, Jennings and Norman 2002; Liu 2010) typically illustrate CDM as a sequential process of individuals identifying the need to solve a problem through collaboration, organizing themselves in a group, collectively reasoning and agreeing about action to be taken, and committing themselves to a given course of action. The model of CDM in Enterprise Architecture by Nakakawa, Bommel et al. (2010) is an exception as it is a non-sequential depiction. Nonetheless, all identified models (Karacapilidis and Papadias 2001; Yang et al. 2001; Herrera-Viedma, Herrera and Chiclana 2002; Panzarasa, Jennings and Norman 2002; Liu 2010) are founded on the stance of CDM as a process of forming consensus which culminates at decision as the end-point.

Moreover, in contrast, studies in NDM show that in real world settings not all members are involved in all aspects of team decision making. CDM undertaken during everyday work activities is not particularly aimed at achieving consensus of decision and is not a sequential process of collaborative activities steering towards a decision as the end point (Cannon-Bowers and Salas 2001; Hoffman and Yates 2005).

c) CDM as an activity of sharing information and mental models

In the cooperative work arrangement of complex work settings information required for decision making is distributed across people, artefacts and environment. Hence, it is contingent upon information sharing. Activities involved in undertaking CDM are therefore mainly addressed through this aspect. The focus of CSCW research is on providing communication channels to facilitate efficient decision making in groups in terms of accuracy and speed of information exchange. Similarly in NDM, CDM in teams is addressed through information sharing which serves the purpose of achieving 'shared situation awareness' (Endsley 2000; Endsley 2003) as well as 'shared mental models' (Converse, Cannon-Bowers and Salas 1991; Stout et al. 1999).

Nevertheless, Schmidt (1990; 1991b; 2011) contends that in the cooperative arrangement work is performed by heterogeneous ensemble of decision makers. They are semi-autonomous in their functioning in terms of goals, criteria, perspectives, heuristics, interests and motives. Work performance in this setup involves a number of extraneous activities. Thus, in this context CDM is differentiated from that portrayed through 'group decision making' research. In CSCW, generally, conceptualizations of CDM are limited in their scope of investigation. This merits the need to look at other related factors.

d) Shift in Perception towards Decision Making

Another motivation for this research is the ongoing shift in perception towards decisions and decision making. Currently, conceptualization of CDM is founded on the stance that decision making is a cognitive act that is an outcome of social interactions. This stance is derived from the 'dualistic view' of decision making as the activity of the cerebral and actions as that of the body (Brown 2005). However, there is a growing shift in perception which calls for a move from the 'dualistic view'. Taking an Ethnomethodological perspective (Brown 2005) questions this view held by the Rationalistic, Descriptive, and Naturalistic approaches. He argues that perceiving decision making as a purely cognitive process separates decisions from actions and this does not capture the rich ways in which people socially engage with the world during decision making. With regards to this cognitive activity, Brown (2005) contends that decision making should be seen as an activity being embedded in social interactions. The shift in perception steps away from the typical cognitive view and brings forth the need to place decisions and decision making within the ecology of social interactions taking place during work performance.

This thesis is motivated by the growing interest in recent years in the situated, embedded and embodied nature of decision making in work performance (Alby and Zucchermaglio 2006; Goel et al. 2012). Just as the traditional cognitive view towards decision making influenced the approach taken to CDM research in CSCW, it is proposed in this thesis that the shift in perception towards decision making as being embedded in social interactions also has resonance with it. This would lead CSCW research to explore the sociality of decision making and allow investigations to contribute to CDM research by directly addressing decision making. Additionally, CSCW may benefit from adopting the shift in perception towards decision making to explore CDM in real-world settings by moving away from the 'choice-point' perspective. There is a lack of research in

CSCW that explores the resonance this shift in perception towards CDM, which needs to be addressed.

1.4. AIM AND OBJECTIVES

This thesis addresses the limitations of current conceptualizations of the way CDM transpires in real world complex work settings. Particularly, in the field of CSCW there are insufficient studies of exploration and understanding of the occurrence of CDM in these specific settings. Also, there is an ongoing movement advocating the need to address the social processes in the theoretical aspect of decision making. CSCW research has yet to incorporate this shift in perception.

The purpose of this thesis is to provide a deeper understanding of the occurrence of CDM in the cooperative arrangement of complex work settings in the real world. In order to achieve this, the research considers decision to be a choice of action taking place to perform a task. This includes fulfilling the requirements of the task and solving problems arising in the process. Furthermore, it steps away from the typical cognitive stance towards decision making and adopts the view that decision making is embedded in everyday work activities. The aim of the thesis is to develop a theory of CDM founded on this stance. With the purpose of achieving this aim, the research work addresses the following question:

> ***How do people in a complex heterogeneous working environment make decisions collaboratively?***

To capture the essence of CDM in real world settings the objective of this research is to allow the theory to emerge from studies of its occurrence in natural work environments. This involves selecting a suitable research methodology to develop a novel understanding of what CDM comprises in complex work settings. Based on this the thesis will explain what brings people together in these settings to make decisions collaboratively, how it takes place in constantly changing conditions across distance and diversity, how intricate relationships between their work activities are managed, and what form CDM takes. The findings of this research will be used to develop an analytical framework to serve as a tool for exploring, understanding, and drawing insights about the way CDM is undertaken in a work setting.

1.5. CONTRIBUTION AND SIGNIFICANCE

This research makes the following contributions:

- The theory of CDM which presents a new perspective on its occurrence in the cooperative arrangement of complex work settings.
- A framework derived from the theory which can be employed to analyze the way CDM is undertaken in a particular work setting.

The main significance of this research is:

- It explains and clarifies current notions about undertaking CDM in the cooperative work arrangement of complex work settings.
- Demonstrates the integrated nature of decision making in social work activities.
- Provides a theoretical framework which is rich enough to appraise key elements of undertaking CDM in real world complex work settings.

1.6. THESIS STRUCTURE

Chapter 2 - "Research Background: Collaborative Decision Making in Complex Work Settings" - presents the context of this research and brings forth the limitations and drawbacks in current conceptualizations of CDM.

Relevant research areas are critically reviewed to establish the background, motivation, aims and associated question driving this research.

Chapter 3 - "Research Methodology" - discusses the methodological approach of this thesis and designed qualitative study. This provides the rationale for the choice of Grounded Theory Methodology (GTM) and explains the associated procedures employed to develop the theory of CDM. It also presents the rationale for choice of Air traffic Control (ATC) as the domain of study, airport as the setting for conducting field studies and entailing socio-technical system as the unit of analysis. An account of airport ATC operations and the nature of collaborative work and decision making in this setting is included. The findings of this research are presented over the next three chapters forming the core of the thesis.

Chapter 4 - "Theory of Collaborative Decision Making as a Process of Managing Interdependencies: A Synopsis" **-** presents an overview of the theory of CDM emerging from this research. It provides a map of high-level concepts comprising the theory. The conceptual framework is structured through the 'Six Cs theoretical coding' family in GTM and revolves around the 'core category' emerging from the analysis.

Chapter 5 - "Conditions Impacting Collaborative Decision Making in Complex Work Settings" **-** describes the conditions which emerged during the data analysis as influential factors in undertaking CDM in the cooperative work arrangement of complex work settings. These conditions include the Context and Cause components of the 'Six Cs'.

Chapter 6 - "Collaborative Decision Making as a Process of Managing Interdependencies" **-** introduces the theory of CDM as a process of 'managing interdependencies' emerging from this research. This includes the core category, and Covariance, Contingency and Consequence components of the 'Six Cs'.

Chapter 7 - "Discussion: Theory of Collaborative Decision Making" - presents a discussion of the theory of CDM and associated findings described in the previous three chapters. It is structured around a number of themes elicited from the literature reviewed in chapter 2, and the contribution and significance of the research work are drawn. Additionally, evaluation of the qualitative study undertaken here and Grounded Theory generated through this study is presented. The issues of researcher bias and ethics was handled are described.

Chapter 8 - "Application of the Theory of Collaborative Decision Making" - presents a framework of ten parameters elicited from the theory of CDM. It is employed as an analytical tool for characterizing the way CDM is undertaken in a work setting. The application of the framework is demonstrated by employing the parameters to analyze an aircraft accident report to draw insights and conceptualize the way CDM takes place in this setting.

Chapter 9 - "Conclusion" – summarizes, interprets and critically reflects the research findings and discusses the overall conclusion of the thesis. Subsequently, it delineates the significance of key findings, their implications in relevant areas, and limitations.

CHAPTER 2

RESEARCH BACKGROUND

2.1. INTRODUCTION

The previous chapter highlighted the gap in existing conceptualizations of Collaborative Decision Making (CDM) and its occurrence in real world complex work settings. The need for this research aimed at exploring and theorizing how CDM is undertaken during task performance in such settings was highlighted. Such an undertaking requires a multidisciplinary effort involving review of literature from multiple fields, which forms the theoretical structure of the thesis and is presented in this chapter.

This review commences with delineating the characteristics of complex work settings in the real world in which CDM is undertaken. Literature reviewed in the field of Computer Supported Cooperative Work (CSCW) revealed that decision making is not a direct subject of research in this field. Instead, it is indirectly addressed though social processes such as communication, coordination and cooperation involved in decision making. Nevertheless, considerable research on collaborative work performance in the conditions of complex work settings is provided in this field and is reviewed in this thesis.

Furthermore, to address the decision making aspect of CDM, this thesis explored literature from the field of Naturalistic Decision Making (NDM).

While, the focus of NDM research is on human cognition, the findings from studies conducted provide useful insights about the nature of decision making in the conditions of the real world. Another realm of research considered to inform this research is Decision Theory, which helps understand the theoretical change towards decision making taking place over the years. This led to identifying that existing conceptualizations of CDM are based on the traditional perspective of decision making and have not incorporated the recent notional changes.

The literature review not only describes existing notions of CDM in the respective disciplines of research, but also attempts to understand the connections between often considered disparate fields of study such as CSCW and NDM. The review includes studies of collective decision making undertaken in groups and teams based on which associated individual competencies and social requirements in undertaking CDM are delineated. A number of models of CDM are also reviewed and drawbacks identified. The chapter concludes with a discussion of the reviewed literature in the course of which the theoretical assumptions and motivation for this thesis is established.

2.2. Work Performance in Complex Work Settings

Complex work settings encompass multiple individuals, who may be collocated or distributed, functioning in dynamic environments, and supported by various artifacts to facilitate their work performance. Drawing on the characteristics presented by Carstensen & Schmidt (1999), Cilliers (1998), Hilburn (2004), Hollnagel (2012), Rosen et al. (2008), Schmidt (2002b), and Schmidt & Bannon (1992), a work setting is a complex system due to the following factors:

It is an open system that interacts with the environment and operates in conditions, which include time pressure, information uncertainty, dynamic information, and large amount of information.

People are distributed in terms of spatiality, temporality, expertise, knowledge, and roles.

It evolves through time and the past is 'co-responsible' for current behaviour of the system.

It consists of a large number of components including human and technological artefacts.

There is rich interaction between components, which causes any element to influence and be influenced by others as well as sustain one another in some instances.

Interaction between components is dynamic and changes with time.

The components and environment can have a number of possible states.

Examples of settings that embody the characteristics of complexity delineated above include the safety critical work settings of Air Traffic Control (Bentley et al. 1992; Fairburn, Wright and Fields 1999), Emergency Management (Aldunate, Pena-Mora and Robinson 2005; Amy, Dahlbäck and Lundberg 2013), Nuclear Power Systems (Carvalhoa, dos Santosa and Vidalb 2005; Iversen et al. 2013), and Medical Operation Theatres (Christian et al. 2006; Dekker et al. 2013). The work settings not necessarily need to embody all the characteristics. In such complex domains of the real world, work performance invariably requires involvement of more than one individual. Undertaking work activities in these settings requires interplay between individual and collective activities, for example, as demonstrated in the studies of financial share trading taking place in a securities house (Heath, Luff and Sellen 1995) and London underground line control rooms (Heath and Luff 1992). This is because, in order to manage the complexity of work performance in real world settings, tasks are subdivided into multiple parts and distributed among a number of individuals. They then need to interact when the subtasks interact (Obradovich and Smith 2003). Managing the complexity and undertaking work performance in such settings therefore requires collaborative working.

2.2.1. Collaborative Work

Collaborative work is explored in a number of fields of research such as economics, politics, management studies, sociology and psychology to name a few. There exists a myriad of definitions of the term ‘collaboration’ each offering a different perspective. This can be attributed to the focus and perceptions offered by the different fields in which the definitions and interpretations are conceived. One definition that synthesizes descriptions of collaboration across multiple disciplines is presented by (Bedwell et al., 2012), which states collaboration as:

> *An evolving process whereby two or more social entities actively and reciprocally engage in joint activities aimed at achieving at least one shared goal.*

The underlying assumptions of this definition are drawn from a review of multidisciplinary literature and depicted as follows (Bedwell et al., 2012):

Collaboration is an evolving process	Collaboration is not a particular state but an active process in which people engage to achieve a desired outcome through interpersonal interactions and relationships that change over time.
Collaboration requires two or more social entities	Collaboration cannot occur without two or more entities because it involves interaction and working together.
Collaboration is reciprocal	It requires mutual engagement between involved entities and hence collaboration is reciprocal. However, equal participation from each entity is not required and would suffice as long as they sufficiently contribute towards reaching their joint aims.
Collaboration requires participation in joint activities	Collaboration requires participation in joint activities because of the interdependent effort required for work performance.
Collaboration is aimed at achieving a shared goal	The critical aspect of collaboration is considered to be ‘shared goal’ because it forms the key element separating collaboration from other forms of shared work.

While the above conceptualization presents a consolidated view of collaboration in a broad sense, the social organization of collaborative work performance in complex work settings is explored in this thesis through research undertaken in the field of CSCW, which is dedicated to investigating collective work performance and the role of technology in facilitating this (Grudin 1994; Pratt et al. 2004; Schmidt 2009; Schmidt and Bannon 2013). In the course of its evolution, research in CSCW has steered towards emphasizing the importance of exploring and understanding work practices in real world work settings. Influenced by important findings of Suchman, A. L. (1987), a number of ethnographic studies of collaborative work in real world work settings - known as 'workplace studies' - were undertaken (Plowman, Rogers and Ramage 1995; Heath, Knoblauch and Luff 2000; Blomberg and Karasti 2013; Fitzpatrick and Ellingsen 2013). These studies bring forth the nature of everyday work performance in complex work settings. Based on the findings of these studies, the general perception in CSCW is that complex work settings are 'cooperative ensembles' of people, artefacts and environment, and collaborative work performance takes place in a cooperative work arrangement.

2.2.2. Cooperative Work Arrangement

In complex work settings, individuals cannot manage the complexity and accomplish tasks on their own, at least quickly and efficiently as required, due to the limitations of their mechanical and information processing capabilities. Therefore, work activities involved in task performance are distributed among multiple individuals who then aggregate their skills and function cooperatively (Schmidt 1990, 2002b). This requires personnel to balance their actions with respect to that of others involved in task performance (Bardram 1998). In such a cooperative work arrangement, personnel function as an ensemble to augment capacity, combine techniques and integrate different heuristics and perspectives in the work setting in order to manage entailing complexity and undertake task performance (Schmidt 1990). Furthermore, when operating in the dynamic conditions of complex work settings personnel function jointly to manage the requirements of a particular situation after which they disperse to manage their individual work (Gaver 1991; Schmidt 1991b; Schmidt and Bannon 1992; Schmidt 1993; Schmidt and Rodden 1996).

The need to function collaboratively in a cooperative work arrangement is deemed to arise from mutual dependence in work performance brought forth by the interrelationships between work activities of individuals involved in undertaking tasks (Schmidt 1994a; Schmidt 2002b). They are mutually dependent *in the sense that one actor depends on the quality and timeliness of the work of the others and vice versa* (Schmidt and Bannon 1992). Hence, the cooperative work arrangement is an ensemble of personnel with interdependent activities. In order to manage this arrangement, a number of secondary activities such as coordinating, scheduling, aligning, and meshing of the distributed individual activities are required. Such activities are addressed in the field of CSCW as 'articulation work'.

2.2.3. Articulation Work

CSCW research to investigate 'articulation work' has been built on the foundation laid by Anselm Strauss (Strauss 1985; Strauss et al. 1985; Strauss 1988) and Kjeld Schmidt (Schmidt and Bannon 1992; Schmidt 1993; Schmidt 1994a; Schmidt and Simone 1996, 1998; Schmidt 2010). Articulation work is defined by Schmidt (Schmidt 2002b) as *'second-order' activities (or aspects of activities) through which the interdependent and yet distributed activities of the cooperative work arrangement, as deployed and configured, are continually coordinated and integrated*. According to this notion, work performance in the cooperative work arrangement of complex work settings needs to be articulated i.e. *who is doing what, where, when,* and *how* in order to accomplish tasks. As the complexity of relationships between these dimensions increase, so does the need for articulation work (Fjuk and Smordal 1997), which is particularly essential for managing the dynamic nature of complex work settings. Work performance in such settings is a situated activity (Suchman 1987) and articulation work helps to adapt to changes taking place in the work environment (Mi and Walt 1991). Based on this literature review articulation work is distinguished along the following three dimensions:

Planned and Situated Articulation: During task performance, planned articulation work takes place when formal actions are planned in advance to carry out entailing activities. However, complex work settings are dynamic environments in which situation of task performance is continually varying and can sometimes be unexpected. Hence, articulation work also takes place in an evolving manner through constant re-planning and re-scheduling of work activities based on the changing conditions in the work environment which is known as situated articulation (Suchman 1987; Strauss 1988; Kraut and Streeter 1995; Carstensen and Sorensen 1996; Grinter, Hersleb and Perry 1999; Bardram and Bossen 2005; Munkvold and Ellingsen 2007; Bardram and Hansen 2010; Iversen et al. 2013).

Indirect and Direct Articulation: When personnel involved in task performance indirectly coordinate their activities in an unpremeditated and inconspicuous manner it is known as indirect articulation (Simone and Schmidt 1993). This takes place by personnel inferring or anticipating the relation of one another's actions in task performance, (Kasbi and Montmollin 1991; Heath and Luff 1992; Schmidt 1994b, 1998b; Schmidt 2002a). They keep track of who is in the physical space, where they are, what they are doing, and when and how occurrences take place in the work environment thereby creating awareness during task performance (Schmidt 1998b; Gutwin and Greenberg 2002). Establishing awareness is considered to be one of the fundamental ways of supporting this kind of articulation work (Schmidt 1998b). A widely acknowledged definition of awareness is provided by (Dourish and Belotti 1992) as *an understanding of the activities of others, which provides a context for your own activities.* This is considered to facilitate fluent and seamless alignment of individual contributions in collaborative activity (Schmidt and Simone 2000). Also, since during work performance there is constant interplay between individual and collaborative activities (Gaver 1991; Dourish and Belotti 1992; Schmidt and Rodden 1996), awareness of other's status and activities during task performance helps in managing these transitions (Gutwin and Greenberg 2002).

Furthermore, just indirect articulation is inadequate for undertaking collaborative work in complex work settings (Schmidt 1994a). There is a need for direct articulation, which, in contrast, involves drawing attention of personnel to information or state of the environment considered relevant to their involvement in task performance. This is done for example, by positioning an object in a certain way, pointing to the object of interest, or by talking aloud. Such activities have been demonstrated in a number of studies of work practices in air traffic control (Harper, Hughes and Shapira 1989; Harper and Hughes 1992; Hughes, Randall and Shapira 1992). Both indirect and direct modalities of articulation work are 'meshed' seamlessly and dynamically during work performance (Heath and Luff 1992; Schmidt and Bannon 1992; Harper and Hughes 1993; Heath, Luff and Sellen 1995).

Moreover, in complex work settings, personnel are provided with various *mechanisms of interaction* such as plans and procedures (Suchman 1983; Suchman and Wynn 1984; Wynn 1991; Cartensen 1994), timetables (Heath and Luff 1992), schedules (Egger and Wagner 1993), forms, checklists (Degani and Wiener 1990), and classification schemes (Bowker and Star 1991; Andersen 1997) to support articulation work. These are considered as 'mechanisms' because they can be objectified in some physical form (artifact) that can be used to regulate and mediate this work. The artefacts used to facilitate coordination of distributed work activities has been labelled as 'coordination mechanisms' (Schmidt and Simone 1996).

The 'coordination mechanisms' are a combination of 'coordinative protocol' and 'coordination artefacts' (Simone, Diviniti and Schmidt 1995; Schmidt and Simone 1996). Whilst the 'coordinative protocols' are an integrated set of procedures and conventions which present affordances and constraints for articulating distributed work activities, the ‘coordination artefacts’ stipulate and mediate articulation work in the context of a set of conventions and procedures depicted by ‘coordinative protocols’ (Hertzum 1999; Lundberg and Sandahl 2000; Schmidt and Wagner 2002; Schmidt and Wagner 2004; Jones and Nemeth 2005). Representation of state change in the ‘coordinative artefacts’ facilitates coordination as it offers cues about other’s intentions and actions, status of entities in the cooperative ensemble, and challenges and problems faced during task performance (Schmidt and Wagner 2002; Bardram and Bossen 2005). These artifacts act as means through which information is represented, disseminated, shared, and transformed in the course of collaborative work activities during task performance (Tellioglu 2012).

Nevertheless, the complexities in real world work settings cannot be handled by just supporting information sharing or pooling it from multiple sources. Instead, collaborative work performance in complex work settings requires that information shared among members of the cooperative ensemble is interpreted correctly, and its relevance to one’s activity unfolded. This is because collaborating personnel are dispersed spatially and across different work units in the cooperative work arrangement. Consequently, they have different perspectives based on their expertise and role in task undertaken, and have only partial and provincial access to information. This leads to discrepancies in information interpretation across distributed individuals (Schmidt and Bannon 1992). Nevertheless, personnel are not required to have identical interpretation of shared information because they are involved in different aspects of task performance and only need to establish “common enough” understanding in order to be able to carry out their individual role in task performance (Schmidt and Bannon 1992).

One concept frequently invoked in relation to this aspect is ‘common ground’ arising from Clark’s theory of communication (Clark 1996). Establishing ‘common ground’ is the process of personnel involved in joint activities coordinating their respective understandings of knowledge, beliefs, assumptions related to work performance through communication. This requires coordination of ‘content’ (*shared understanding of the subject and focus of work*) and ‘process’ (*shared understanding of the rules, procedure, timing and manner in which interaction will be conducted*) (Clark and Brennan 1991). Formation of such mutual understanding is an important aspect of collaborative work because coordination of work activities required for collaborative functioning depends on the predictability of other’s actions (Klein et al. 2005; Nova, Sangin and Dillenbourg 2008). The more ‘common ground’ collaborating personnel have, the easier it is for them to communicate, which in turn facilitates coordination and cooperation (Oslon and Oslon 2002). A determinant factor for establishing the ‘common ground’ required for collaborative work performance is spatial distance between collaborating personnel and this leads to the following classification of articulation work.

Local and Global Articulation: When articulation work takes place within a single unit, it is known as ‘local articulation’. Within a single unit, related personnel are collocated with possibilities for direct face-to-face interaction, immediate visibility and access to information and other’s actions, and seamlessly mesh work activities (Robertson 1997; Kraut et al. 2002; Oslon and Oslon 2002). Whereas, when it takes place across physical distance and different work units it is addressed as ‘global articulation’. The local and global nature of this work is studied in various domains such as occupationally segregated terrains, emergency situations, scarce-resource settings and performance-intensive settings (Clement and Wagner 1995; Faergemann, Schilder-Knudsen and Carstensen 2005). The findings of these studies reveal that global articulation is more demanding and dependent on formalized interaction between units. Everyday informal social interactions becomes less frequent in this case (Nova 2003; Nova 2005). Interaction across physical distance and work units is mainly mediated through information representation and dissemination artifacts (Dourish et al. 1996). Hence, global articulation is constrained by limited means of communication, entails predominantly formalized communication, and involves standardized mechanisms of interaction (Carstensen and Schmidt 1998; Boden, Nett and Wulf 2008).

Having examined the collaborative nature of work performance in this review, the following section discusses the nature of decision making in complex work settings.

2.2.4. Decision Making

Decision making in real world work settings is the focus of Naturalistic Decision Making (NDM) research. In this field, conditions in which decision making takes place in the real world have been described as follows (Orasanu and Connolly 1993):

- Ill-structured problems because causes and potential courses of action may not be easily identified.
- Conditions are uncertain and dynamic as situations are constantly changing.
- Entails multiple goals which may be ill-defined, in conflict or shift over time.
- Decision making is not an isolated event but occurs during work performance and hence is affected by preceding activities and decisions.
- Decision making process requires involvement of multiple individuals who can have shared or different views of the situation in which it is undertaken.

These conditions of complex work settings are also addressed in CSCW although the focus is on collaborative work. CSCW research typically does not study decision making directly as it is considered to be the realm of cognitive science. Instead, it is approached indirectly through the social processes involved in decision making such as communication, cooperation and coordination. Nevertheless, few characteristics of decision making in complex work settings are brought forth. The following discussion reviews literature from both NDM and CSCW studies to characterise the nature of decision making in real world complex work settings.

From CSCW perspective, decision making involved in task performance is considered to be distributed across different personnel in the cooperative work arrangement of complex work settings. According to (Schmidt 1994a), *the very fact that multiple actors are involved in doing the work introduces an element of distributed decision making*. The expertise, responsibility, and knowledge-base for decision making is separated and distributed among multiple individuals, and each individual is responsible for part of the decision making required for task performance (Wellens 1993; Soubie and Zarate' 2005; Salas et al. 2007). However, they are semi-autonomous as the interrelations and mutual dependencies between their work activities require joint effort. Therefore, decision making in such an arrangement of work performance requires personnel to cooperate and coordinate their activities (Schmidt 1991a; Boland et al. 1992; Wellens 1993; Schmidt 1994b; Jankowski et al. 1997).

In complex work settings, decision making is directed towards a goal arising from a task to be performed. This is demonstrated by Brehmer (1992) through studies of Firefighters' perception towards decision making during work performance and who quotes Klien's (Klein et al. 1993) personal communication with him - *When asked about their decisions at the site of the fire, the fire chief said: 'We do not make decisions, we fight fires*!'. Hence, in real world settings, decision making is part of an ongoing process of task performance. Furthermore, in the real world, decision making is dynamic as it takes place in an evolving environment. The requirements to be fulfilled and possibilities for doing this may change. Therefore, the context of decision making is not entirely predictable. In addition, a series of decisions are required for fulfilling requirements and can be interrelated.

Hence, decision making requires feedback from previous decisions (Brehmer 1992; Campanella et al. 2012). An illustration of dynamic decision making is provided through the work of the controllers allocating airspace in Air Traffic Control (ATC) setting as follows (Gonzalez 2005):

> *ATC, for example, requires controllers to make multiple decisions regarding how to allocate space to best accommodate multiple airplanes. The fact that the assignment of a landing lane to an incoming airplane precludes the use of that lane by other airplanes arriving in the near future reflects the interdependency of decisions that characterizes DDM[1] tasks. Furthermore, environmental parameters such as arrivals, departures, and weather are exogenous during ATC—i.e., they are beyond the influence of the controller. Finally, incoming airplanes need to be assigned to a landing lane at the correct moment in real-time. Thus ATC provides a realistic example of real-time DDM.*

The characteristics of 'dynamic decision making' in complex work settings are presented as follows (Brehmer 1992):

A goal cannot be reached with a single decision. A series of decisions are needed because earlier decisions affect current decisions. So decisions are not independent.

Decision makers need to not only consider how current decisions would solve the problem at hand, but also how it would affect the ability to cope with decision problems arising later on.

State of the work environment changes during decision making both autonomously and in consequence to decisions made by people. Hence, decisions are made in real-time and correct decisions have to be made in the correct order and at the correct moment in time.

Similar to ATC, 'firefighting' is an example of decision making taking place in an evolving environment in which decision making is not only dynamic but also adaptive. This is presented by Pohl (2008) as follows:

> *….a change in wind direction during a major brushfire may have a profound impact on the entire nature of the relief operation. Apart from precipitating an immediate re-evaluation of the firefighting strategy, it may require the relocation of firefighters and their equipment, the re-planning of evacuation routes, and possibly even the relocation of distribution centers.*

[1] Dynamic Decision Making

The effect of change in wind direction - single contextual factor - affects the entire plan of the firefighting operation and the decision making process. It leads to re-evaluation of the firefighting strategy and re-planning evacuation routes, and also requires firefighters and their equipment to be relocated (Pohl 2006). Hence, decisions change with the evolution of decision making situation and have to be made in real-time (Boland et al. 1992; Brehmer 1992; Kerstholt and Raaijmakers 1997; Ariely and Zakay 2001; Cook, Gerrish and Clarke 2001). This effects decision making in various ways (Brehmer 1992; Mosier and Fischer 2010). For example, it imposes time pressure which affects the process and quality of decision making as it impacts the inference and reasoning strategies of decision makers (Ehrhart and Bigbee 1999). Also, decisions have to be made as and when the requirement arises in real-time (Stankovic 1996). This provides decision makers with little control over when decisions will be made (Brehmer 2000). Therefore, decisions have to be made not only about what actions to take but also when. In the words of Zachary et al. (1998)

> *Making the right decision too late is as bad (or worse!) than making the wrong decision in a timely manner.*

Furthermore, in complex work settings there are many related issues and variables which have a bearing on each other and the situations in which decisions are made (Pohl 2006). Consequentially, issues arising during task performance cannot be considered in isolation while making decisions. Another aspect of the situated nature of decision making stems from the fact that personnel in the cooperative work arrangement of complex work settings function as part of a work unit such as a group or team. Hence, it is also situated in the purpose, aims and context of the work unit.

Typically, decision making is portrayed as a problem solving process. This includes information gathering and interpretation to ascertain relevant facts relating to the problem, identifying alternative tasks that can be performed, evaluating and choosing between alternatives, implementing the task, and determining if it achieves the expected result (Herbert and Associates 1986; Goncalves and Antunes 2000). A number of different theoretical perspectives have been developed to account for this process of decision making, which can be broadly classified into three types as Rationalistic Decision Making, Descriptive Decision Making, and Naturalistic Decision Making (NDM).

In the Rationalistic paradigm of decision making, a rational choice is made among alternatives to select the one that produces maximum utility. To make a decision, a person is assumed to enumerate the possible courses of action, evaluate each course to assess its value according to some criterion, and then to select the action judged to be optimal according to the set criterion (Doyle 1992; Doyle and Thomason 1999). The Descriptive Decision Making paradigm alternatively reflects the limited cognitive capacities of human beings and presents the notion of 'bounded rationality'. This is based on organizational studies according to which, the decision makers 'satisfices' by considering possible options sequentially until one is found that is adequate though not necessarily optimal (Simon 1978). However, in this case, the decision of 'good enough' result is made in advance, and information and options are searched for until the 'good-enough' result can be obtained (Brown 2005).

The realization that the analytical process of decision making that holds up optimality conceptualized through studies undertaken in laboratory conditions does not reflect real operational contexts characterized by the conditions discussed previously in this section resulted in the emergence of NDM research. Investigations in this field study decision making 'in the wild' and focus on the cognitive strategies of individuals rather than predicting which of the alternatives to implement. The expertise of the decision maker and the context in which it takes place play a significant role in the conceptualization of decision making.

When decision making is viewed from these three approaches, it is considered to be a cognitive process. However, this perspective changed, particularly with the emergence of theories such as Distributed Cognition (Hutchins and Klausen 1993; Hutchins 1995), Situated Cognition (Shattuck and Miller 2006; Busemeyer, Jessup and Dimperio 2009), and Embodied Cognition (Wilson 2002). These theories have contributed to addressing a wider unit of analysis in the exploration of the process of decision making through the inclusion of contextual and social factors. While considerable research addressing the contextual factors of decision making is undertaken in NDM, investigations which include social factors is limited and need for more research is necessitated (Panzarasa, Jennings and Norman 2002; Alby and Zucchermaglio 2006; Vanharanta 2009).

This thesis addresses the limitation by focussing on the sociality of decision making in complex work settings. In order to achieve this, the research examines the nature of decision making in collaborative work performance.

2.3. Collaborative Decision Making in Complex Work Settings

As stated above, in complex work settings, a number of individuals function semi-autonomously and are required during task performance to undertake work activities including decision making collaboratively. Collaborative Decision Making (CDM) has been considered to be the archetype of decision making in such settings consisting of work distribution among multiple individuals who need to jointly undertake tasks that are beyond individual capabilities (Panzarasa, Jennings and Norman 2002).

2.3.1. Defining Collaborative Decision Making

Various definitions of CDM have been formulated in different fields. For example, Bui & Jarke (1984), based on decision making in groups, present the following definition:

> *A decision situation in which there are two or more persons, each of which are characterized by their own perceptions, attitudes, motivations, and personalities, who recognize the existence of a common problem and attempt to reach a collective decision.*

Elements of this definition are found in the way CDM is defined by others in different fields of research. In NDM, Orasanu, Judith. & Salas (1993) define CDM as *the process of reaching a decision undertaken by interdependent individuals to achieve a common goal*, while Christensen & Larson (1993) consider CDM to occur *whenever two or more individuals contribute their diverse knowledge and expertise to the decision making process*. In the field of Logic and Computation, CDM has been defined by Panzarasa et al. (2002) as a process of reaching a decision that is agreed upon by more than one individual in order to reach a common goal. Another definition by Kim et al. (2004) presents CDM as *decision making in a distributed environment through mutual collaboration of the* participants. More recent definitions include CDM as *the realisation of a set of activities by a group of actors working together and sharing a common objective and resources, an activity leading to a decision* (Seguy, Noyes and Clermont 2010), and as a combination and utilization of resources and management tools by several entities to achieve a common goal by (Kapucu and Garayev 2011) based on investigation of Emergency and Disaster Management. Irrespective of the field in which CDM is defined, it is treated as a process of reaching a decision that is agreed upon by more than one individual in order to reach a common goal.

Nonetheless, in CSCW, Bannon and Schmidt strongly argue that the cooperative work arrangement of complex work settings involves multiple goals of various personnel that can be of different scope and nature (Bannon and Schmidt 1989). Collective decision making in such settings is a process different from what is typically considered in ‘group decision making’ (Bannon and Schmidt 1989; Boland et al. 1992; Bannon 1997). This is attributed to the difference in characteristics of ‘group work’ and ‘cooperative work’. In real world complex work settings, decision making is less group (involvement of small, stable, homogeneous and harmonious ensemble of people) and more cooperative (entailing large ensembles distributed physically in time and space, semi-autonomous in control; which are transient formations emerging to handle a particular situation after which they dissolve; and patterns of interaction changes with requirements and constraints of the situation) (Bannon 1997). Therefore, CDM in such settings is argued to be more than achieving ‘common goals’ but studies elucidating this view are limited.

2.3.2. Forms of Interaction in Collaborative Decision Making

Participation in CDM takes place through four cumulative forms of “social interaction” - communication, cooperation, coordination, and collaboration (Jankowski et al. 1997) (Figure 2- 1).

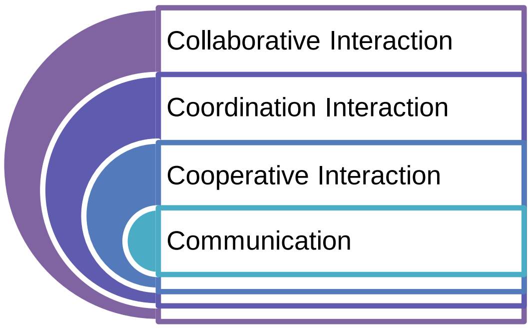


Figure 2- 1 : Forms of Social Interaction in CDM (Jankowski, et al. 1997)

Communication is the basic level of participation in CDM which takes place to exchange information and ideas. Cooperative interaction is at the next level which is built on the ideas developed through communication. Participants functioning cooperatively make a contribution to exchange during interaction. However, each participant can also take the results of the interaction away with them and act on the results as they see fit, with no further interaction required. This is followed by coordinated interaction in which participants cooperate and sequence their activities for mutual gain. At the highest level is collaborative interaction which takes place when participants work on the same task (sub-task) either simultaneously or near simultaneous manner with a shared understanding of a situation (Jankowski et al. 1997).

Collaboration through these forms of social interaction has been recognized as an effective strategy in decision making in complex work settings because it is considered to improve the quantity and quality of the information used to make decisions (Perry and Moffat 2004) and increases information processing capacity of decision makers (Hutchins and Kendall 2009; Kane, Toussaint and Luz 2013). In addition, it enhances creativity and diversity in decision making (Cook, Gerrish and Clarke 2001), and enables personnel to attain a greater sense of appropriate action and behaviour required for decision making (Orasanu and Salas 1993; Jankowski et al. 1997; Kapucu and Garayev 2011). Furthermore, Schmidt, Kjeld (1990; 1994a) argue that the multiple decision making strategies brought forth by different individuals and their contribution to task performance is subject to critical evaluation during CDM, which leads to making more robust and balanced decisions.

2.3.3. Individual Competencies and Social 'Sharedness' in Undertaking Collaborative Decision Making

In the cooperative arrangement of complex work settings, decision making entails involvement of multiple individuals and requires integration of their different viewpoints, objectives and strategies (Yang et al. 2001). This necessitates negotiation of possible course of action (Cook, Gerrish and Clarke 2001) and establishment of common understanding between involved personnel (Filip 2008). The operational processes in complex work settings are interrelated and personnel's work activities are influenced by each other's input, output, and decisions during task performance (Jankovic

2006). Besides, uncertain conditions brought about by the dynamic nature of work environment in these settings also contributes to making CDM a complex process (McClennan et al. 2006). Managing such complexities and successfully undertaking CDM has certain requirements at both individual and social level.

Individual Competencies

With respect to individuals, Eriksson (2009) identifies three aspects and associated competencies required for participating in CDM. The aspects include ability to frame decision situations, manage decision-making procedures and support the CDM system through methods. The first aspect, *framing*, is the capability of individuals to identify expertise and domain knowledge required in decision situations, identify group's "wants" in relation to overall strategies in the organization, and the constraints and possibilities of decision situations. This is facilitated by the means provided by the organization to determine what individuals can and cannot do in a decision situation. The second aspect, *procedures*, refer to an individual's role in the organization and associated behavior during decision making. Clearly defined roles dictate their behavior and help to comprehend their contribution to CDM. Behavior is also influenced by the preference of actors which are values held by them individually and in relation to overall values of the organization. The third aspect, *methods*, entails the rules, techniques and infrastructure needed for managing the CDM process. Rules are embedded in the organizational culture while techniques help to understand relationships in the organization, the dynamics of the decision situation, and infrastructure in the work setting. Furthermore, it helps structure, responsibilities, authority, relevant information, and decision issues of individuals. While, this framework helps understand individual competencies required to ensure effective and efficient CDM, the entailing social requirements of CDM are discussed next through the notion of 'social sharedness'.

Social ‘Sharedness’

In order to successfully undertake CDM in complex work settings, personnel need to function collectively as a group or team (Sundstrom, DeMeuse and Furtell 1990). This can be explored through information, ideas, and cognitive processes shared between members in a group or a team, which is addressed as ‘social sharedness’ (Kameda, Tindale and Davis 2002; Tindale, Kameda and Hinsz 2003). The argument presented by Kameda et al. (2002) is that things shared among group members influence the decision making process largely. Based on this, they advocate the use of the notion of ‘social sharedness’ to understand collective decision making, which is adopted in this thesis to address the social requirements for undertaking CDM. The review of literature in the fields of CSCW and NDM revealed three overlapping concepts of ‘sharedness’. They are sharing information, sharing awareness and shared understanding. CSCW and NDM studies investigate these aspects through ‘group decision making’ and ‘team decision making’ research respectively with the former focusing on the social processes and the later on the cognitive processes.

In recent years, groups are conceptualised as information processors (Hinsz and Tindale 1997). Much attention has been laid on group members making decisions collaboratively by sharing information, leading to the premise that group members made better decisions by pooling information (Stasser and Titus 1985; Kerr and Tindale 2004). Importance of sharing information in ‘group decision making’ was brought forth by various research undertakings (Larson, Foster-Fishman and Keys 1994). However, it was found that decisions made by groups rested on shared information while knowledge unique to individual members was overlooked (Stasser and Titus 1985; Larson et al. 1998) which resulted in missed opportunities for making informed decisions (Hermann, Rummel and Spada 2001). Failure to pool unshared information is more devastating when individuals are mutually dependent on each other for knowledge required to perform tasks (Johnson and Johnson 1992), which is the case in the cooperative arrangement of complex work settings as discussed earlier.

This brings forth the importance of effective communication in CDM which is influenced by the structure of decision task including group member's awareness of the end state to be achieved for successful task completion, comprehension of means to achieve the state, and an understanding of barriers hindering group's effort in achieving the required state (Hirokawa 1990). In the case of CDM in groups, members need to communicate about the goals to be achieved, the alternatives to be considered, its evaluation, and the choice to be made (Malone and Crowston 1990). Also, in real world complex work settings, communication and decision making take place in uncertain and constantly changing conditions. Therefore, valid and timely information sharing is critical (Kapucu and VanWart 2006).

Another aspect of 'social sharedness' essential for group decision making is establishing shared understanding of important information. This is because even though group members have shared goals, they have differing assumptions, viewpoints, interpretations, and decision preferences which are based on underlying individual assumptions and objectives. Such cognitive diversity may cause miscommunication and requires effort to be expended by group members to resolve differences in conceptualizing problems and establishing consensus by collective representation of decision issues. This however, depends on the affordances provided by the work environment, level of interdependence among group members, naure of task being performed, and when in the work process members need to function as a collective (Mohammed and Ringseis 2001).

Much research undertaken to explore CDM in groups in CSCW focuses on small interpersonal groups working on fixed tasks and clearly shared goals. Findings from such studies are insufficient to understand decision making as it actually occurs in the complex conditions of organizational settings (Bannon 1997). However, research undertaken in the field of NDM through studies of ‘team decision making’ explores and conceptualizes decision making undertaken in the process of task performance in real world settings (Koslowski and lgen 2006). Studies in NDM provide a closer representation of conditions of decision making in the real world. Based on this, the notion of shared understanding is extended further than that of information as depicted in the field of CSCW.

The premise in NDM is that decision making in complex work settings requires team members to possess common knowledge of operational environment, equipment, standard procedures and practices, and strategies to support joint decision making. In addition, it requires common understanding of individual role responsibilities, objectives, and plans (Rouse, Cannon-Bowers and Salas 1992; Cannon-Bowers and Salas 2001; Salas, Sims and Burke 2005; Salas, Cooke and Rosen 2008; Mosier and Fischer 2010). It is considered that by sharing this knowledge team members are able to make similar interpretations of cues in the work environment, make compatible decisions and take appropriate actions (Klimosky and Mohammed 1994; Cooke et al. 2000; Cannon-Bowers and Salas 2001; Mohammed and Dumville 2001). Furthermore, members will be able to develop good understanding of the task and other team member’s behavior (Converse, Cannon-Bowers and Salas 1991; Rouse, Cannon-Bowers and Salas 1992; Orasanu and Connolly 1993; Orasanu and Salas 1993), help members to proactively provide required information to others in the team and meet each other’s differing information needs (Yen et al. 2003). Based on the established common understanding team members can plan, communicate, coordinate activities, and adapt to the situation appropriately (Stout, Cannon-Bowers and Salas 1990; Cooke et al. 2000; Mosier and Fischer 2010).

Another dimension of ‘social sharedness’ required for undertaking CDM is in terms of sharing awareness. In the dynamic environment of complex work settings constant state changes takes place automatically and as a consequence of actions of decisions makers (Brehmer 1992). Hence, it is necessary to continuously keep track of the changes in the environment in order to make effective decisions (Cook, Gerrish and Clarke 2001; McClennan et al. 2006). This assessment of the environment results in what is called Situation Awareness (SA) (Elliott 2005). For example, studies demonstrates how situation recognition dictates the choice of actions to be executed in teams (Klein 1997), and how SA and decision making influence each other (Smith and Hancock 1995). Moreover, SA is contended to be the primary basis for decision making (Endsley 1995). Individuals establish SA by observing and integrating information from the work environment, comprehension of which is enhanced by pre-existing knowledge.

In the cooperative arrangement of complex work settings, collective work performance is dependent on the SA shared between team members (Endsley 2003; Garbis and Artman 2006). This is because in these settings activities of team members are interdependent and SA of an individual affects activities of others. Shared SA is achieved by monitoring the work environment, communicating required information to other team members, and coordinating their activities (Bolman 1979; Schwartz 1990; Salas et al. 1995; Entin and Entin 2000). Based on a synthesis of literature Salmon et al (2007) conclude that team SA includes awareness about individual roles and goals, other team member's activities, roles and responsibilities, and overall team goal and performance. It is established through team processes such as communication, coordination, and collaboration. This view is corroborated by other researchers (Furuta and Shu 2004; Gorman, Cooke and Winner 2006; Kolbe and Boos 2009).

2.3.4. Collaborative Decision Making across Distance and Diversity

In this research, the focus is on personnel belonging to different heterogeneous work units, who are spatially distributed and function collaboratively to undertake decision making during task performance. This entails personnel functioning as a cooperative ensemble, communicating synchronously and asynchronously, and coordinating work activities. Therefore, literature was reviewed to comprehend the effect of spatial distribution and heterogeneity of work units on CDM and is presented below.

Effect of Spatial Distribution of Work Units on CDM

Physical distribution affects CDM mainly with respect to communication, establishing collective understanding, awareness, and coordination required for the joint activity (Armstrong and Cole 2002; Fiore et al. 2003). The reason for this is that spatial distance reduces opportunities for rich interaction and direct communication (Herbsleb and Mockus 2003). Based on their investigations on decision making in teams, Cook et al. (2001) reveal that the timeliness of communication is facilitated by shared geographical location which is one of the catalysts for decision making across teams.

Communication across physical distance is typically mediated through technology which assists both synchronous and asynchronous communication. Much research on decision making in groups has focussed on electronic communication systems known as Group Decision Support System (GDSS). These systems mediating group decision making were found to improve the quality of decision making but concomitantly increased the time taken to reach decisions by group members (McLeod 1992). Besides GDSS, other technologies such as email, teleconferencing, video conferencing, and CCTV are used to mediate communication across distributed work units (Andres 2002). Although such technology is beneficial in terms of speed of information transfer and its accessibility, there are some drawbacks. It impairs efficiency by increasing the time taken to perform tasks and reduces the transmission of social context cues such as eye contact, facial expressions, and gestures which regulate interaction, information exchange, and monitoring feedback (Straus and McGrath

1994). Nonetheless, mediating communication through video conferencing and CCTV provide opportunities for transmitting social context cues.

Another aspect of CDM which is affected by the spatial distribution of work units is establishing shared awareness and common understanding. This is considered to be particularly important in the case of geographically distributed work units in order to coordinate and establish appropriate understanding because of lack of shared context provided by the collocated setup (Carpenter et al. 2008). Awareness and understanding shared across work units facilitate anticipation of each other's actions and information requirements to make decisions (Converse, Cannon-Bowers and Salas 1991). Furthermore, making decisions jointly in dispersed work settings requires high level of coordination. Based on their 'mutual awareness' decision makers can reason about own situation and others, share information with each other during the joint activity, and coordinate decision making (Garbis and Artman 2006; Yen et al. 2006). However, physical distribution decreases awareness because the distributed decision makers do not share the common field of work that provides cues and reference points for establishing common orientation (Mark 2002).

CDM across distributed work units requires integrating work activities of decisions makers. The entailing coordination is dependent on communication (Carmel and Agarwal 2001) because it is particularly vital for obtaining information required for making decisions (Smith-Jentsch et al. 2001). Moreover, the physical distance can cause misalignment in coordinating work activities across work units as the frequency of communication is reduced. This is also due to less opportunities for informal communication which help establish 'peripheral awareness' required for determining who is doing what and when during task performance (Carmel and Agarwal 2001). Hence, communication is particularly vital for establishing mutual understanding required for undertaking CDM (Clark and Brennan 1991). The restrictions posed by physical distance in the dissemination of social context cues available make the establishment of required shared understanding difficult. Another factor affecting this is the heterogeneous nature of work units.

Effect of Heterogeneity of Work Units on CDM

Heterogeneity between decision makers in complex work settings arises in terms of their expertise, role and responsibility in the work process, strategies employed, work practices, access to information, and physical location in the work process when they are required to be involved in the decision making (Reddy, Dourish and Pratt 2001). While such diversity improves performance and strategic decision making during CDM due to differing viewpoints, expertise and information processing capabilities of different individuals, it also gives rise to drawbacks such as increased coordination costs, competing goals, biases, conflicting priorities, miscommunication, and misinterpretation (Thomas 1999; Chatman and Flynn 2001; Kozlowski and Bell 2003). The differences between decision makers in heterogeneous work units affect mutual understanding of situation required for undertaking joint activity. For example, although pilots and air traffic controllers work towards the common goal of safe and efficient air navigation, the differences between their roles, responsibilities, training, and experience can create differences in operational sub-goals and lead to conflict (Bearman et al. 2010).

In order to avoid conflict, shared understanding has to be established between decision makers across the different work units involved in task performance. However, because of the heterogeneity, establishing common understanding of information shared through these artefacts across different work units is challenging (Cramton 2001). While much research in CSCW has focused on how shared understanding is achieved in collocated settings (Suchman 1983; Heath and Luff 1991; Ackerman and Halverson 1998; Hughes, Randall and Shapiro 1999; Herbsleb et al. 2000), research undertaken in the area of Common Information Space (CIS) has shifted the focus from studying establishment of common understanding in co-located settings to geographically distributed settings such as waste water plants, air traffic control settings, and oil and gas industry. Based on their work on airport ATC operations Fields, Amaldi, & Tassi (2004) suggest that although information is shared across the distributed heterogeneous work units, their meaning and interpretations are not.

Coordinating decision making across the heterogeneous work units requires decision makers to establish common enough understanding of shared information. This is enabled by maintaining CIS across the different work units in which the information representation and dissemination artefacts have characteristics of 'boundary objects' (Reddy, Dourish and Pratt 2001). These artefacts are malleable enough to fit local practices and stable enough to maintain consistency of information transferred across different work units. Hence, they act as 'coordination mechanisms' (Berg and Bowker 1997; Reddy, Dourish and Pratt 2001). Articulating work across heterogeneous work units through CIS and such 'coordination mechanisms' help determine who does what, where and when during CDM (Fjuk and Smordal 1997).

2.3.5. Sequential and Non-Sequential Models of Collaborative Decision Making Process

Involvement of more than one individual changes the dynamics of the decision making process. Multi-person decision making includes individuals identifying potential for collaboration, organizing themselves in a group, collectively reasoning, negotiating, and agreeing about appropriate goals and the course of action, and committing themselves to a given course of action (Karacapilidis and Papadias 2001; Yang et al. 2001; Herrera-Viedma, Herrera and Chiclana 2002; Panzarasa, Jennings and Norman 2002; Liu 2010). This process has been captured in the formal model of CDM undertaken in a group by Panzarasa et al. (2002) which has four stages (Figure 2- 2).

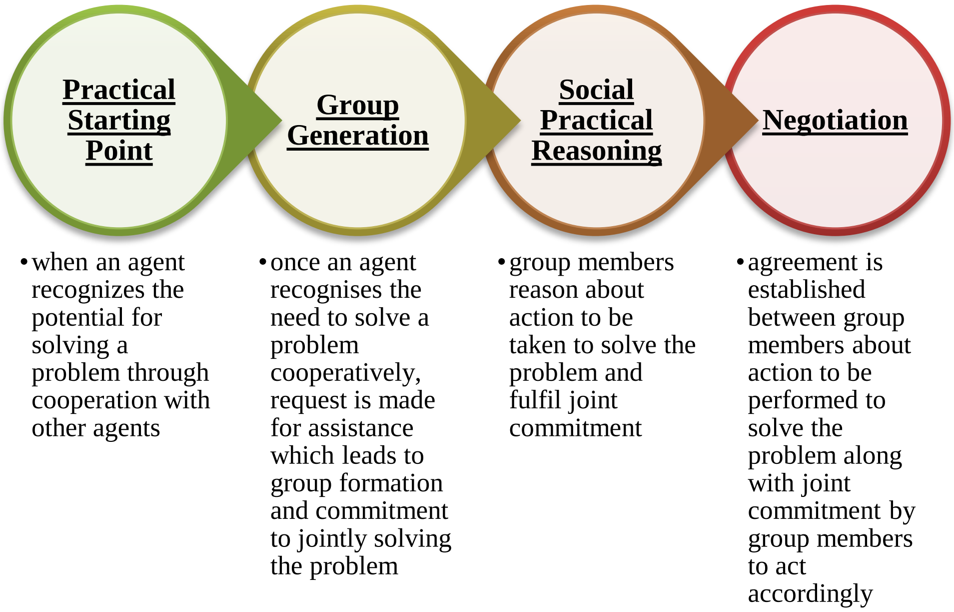


Figure 2- 2 : Formal Model of Collaborative Decision Making Depicted by Panzarasa et al. (2002)

However, this model describes CDM in an idealized world. One of its shortcomings is the sequential form which does not reflect the process in real world scenarios where decision makers move back and forth between the stages. Also, the model depicts the end-point of the CDM process as agreement on the course of action to be taken and not the decision made. This is in contrast to other approaches where the conclusion is the decision on choice of actions (Panzarasa, Jennings and Norman 2002).

Nevertheless, the model illustrates that while undertaking decision making as a collaborative endeavour *decisions are the product of a variety of social actions and interactions* (Panzarasa, Jennings and Norman 2002). Corroborating this view, Ellingsen & Mathisen (2011) declare that *decision-making groups communicate and share information, ideally, developing a shared understanding of the operation, working in a coordinated fashion to achieve the goals*. Adler, Baets, & Konig (2011) take similar perspective and consider efficient decision making in a collaborative endeavour to depend on both information exchange and synchronization.

A theoretical framework of CDM (Figure 2- 3) with a focus on consensus forming is presented by Kapucu and Garayev (2011). This is based on analysis of the Emergency Management Assistance Compact (EMAC) system's response to disasters such as Hurricanes Katrina and Rita in 2005 (Kapucu, Augustin and Garayev 2009; Kapucu and Garayev 2011). This framework integrates four factors (system, environment, capacity, and actors) which affect CDM during emergency situations. These factors affect the way requirements arising in emergency situations are perceived by organizations and the way they perform operations and functions. The factors are considered to create a collaborative environment that would produce a common decision which is based on consensus achieved between actors involved in CDM. However, this framework only presents the factors affecting CDM and does not depict its process.

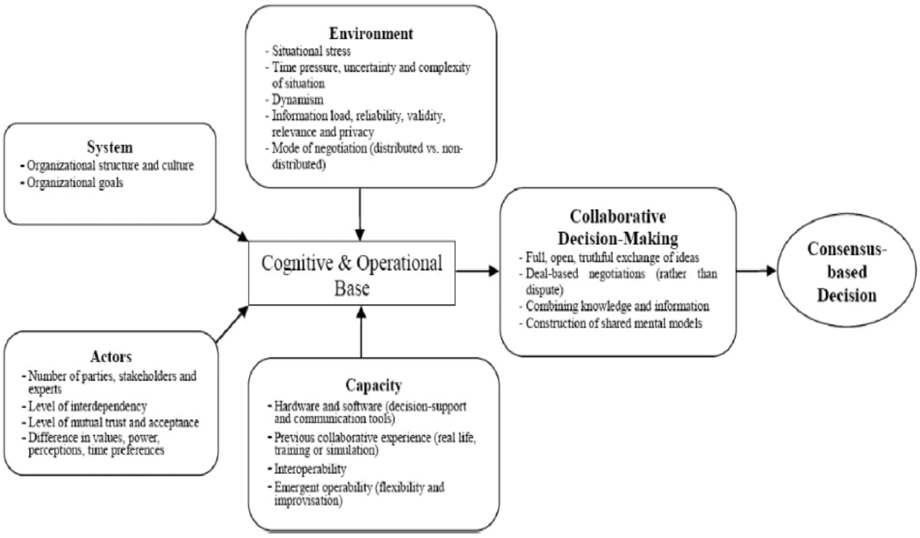


Figure 2- 3 : Theoretical Framework of Collaborative Decision-Making in Emergencies Depicted by Kapucu and Garayev (2011)

Another model which addresses the factors affecting CDM is that of Team, Systems, and Environment" (ITSE) Framework (Figure 2- 4). Through this Boiney (2004) makes explicit that *team decision making and other collaborative behavior cannot be characterized in isolation, but rather* *occur with the support (or hindrance) of tools and as influenced by important tasks, goals, and constraints in the decision-making environment.* This framework is based on complex interactions and interdependencies among people, systems, and environment characterising complex dynamic military domains and presents the view that *team decision making* is embedded at the intersection of these three components.

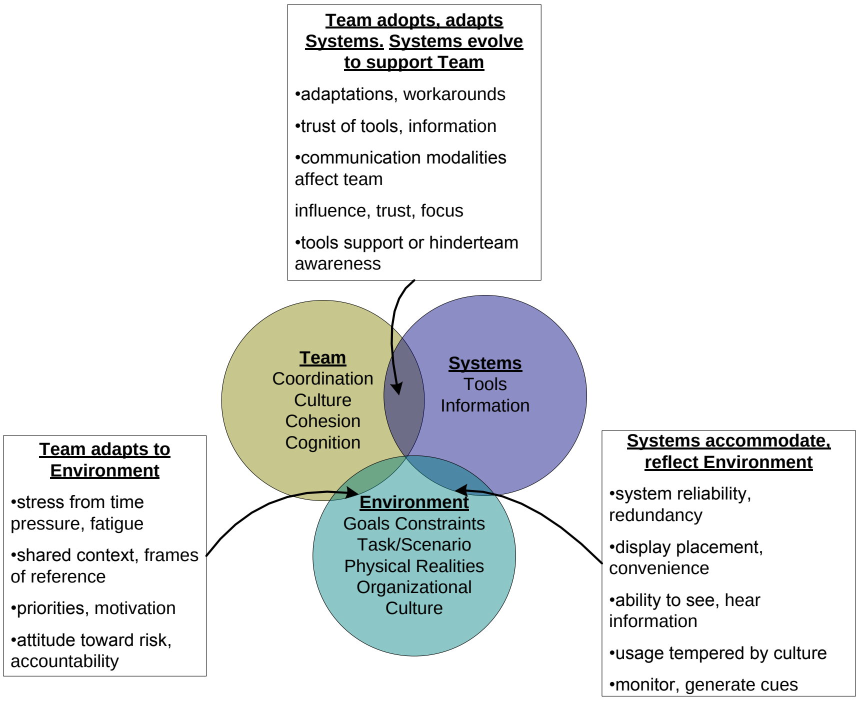


Figure 2- 4 : ITSE Framework of Team Decision Making Depicted by Boiney (2004)

Boiney (2004) also declares that while undertaking studies on *team decision making*, all three components of the framework need to be taken into consideration which includes: *issues relating to the team of human operators and their means of coordinating and reaching decisions, characteristics of the systems being used in support of collaboration and decision making, and characteristics of the environment likely to influence the application of technologies and the performance of the team.* Indeed, *team decision making* and collaborative behaviour do not take place in isolation through just one of the components, rather it is achieved through complex interactions and interdependencies between people, systems, and environment.

The process of CDM has been captured in other research undertakings. For example, according to Karacapilidis & Papadias (2001), CDM can be addressed through argumentative discourse and collaboration among those involved. From this perspective, they state that CDM occurs when *consensus emerges through a process of collaboratively considering alternative understandings of the problem, competing interests, priorities, and constraints*. A more recent study which demonstrates CDM through argumentative discourse is that of Winman & Rystedt (2012). While both research undertakings focus on technological support for CDM, Winman & Rystedt (2012) investigate the CDM process as it takes place synchronously in a co-located setting (meeting room) through face-to-face interaction between multiple medical professionals. Whereas, Karacapilidis & Papadias (2001) illustrate CDM mediated through a Collaborative Decision Support System (CDSS) for distributed asynchronous collaboration.

Based on studies of inter-professional teams in a hospital ward making joint decisions, Winman & Rystedt (2012) depict the process of CDM as involving two main phases - *briefing* and *decision making* (Figure 2- 5). *Briefing* takes place to develop a general overview of the situation by presenting relevant information to team members while *decision making* process involves discussion with the goal of achieving a mutual agreement to address the situation.

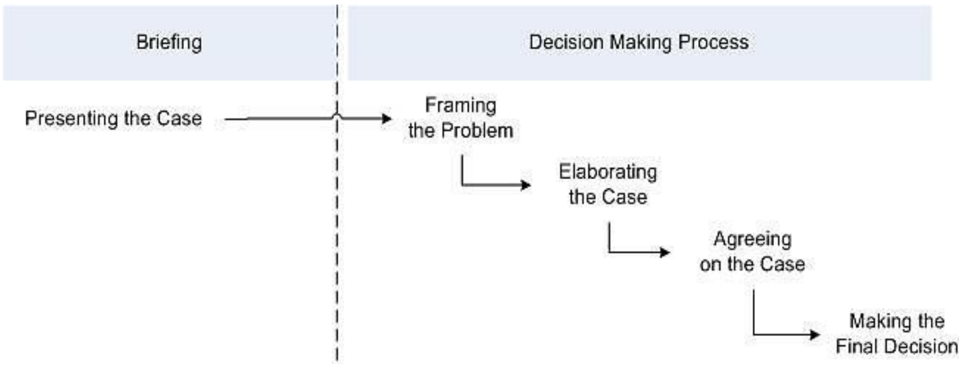


Figure 2- 5 : Phases in CDM of Multiple Medical Professionals Depicted by Winman and Rystedt (2012)

The process of CDM (Figure 2- 6) commences with *briefing* which is the preparatory phase. During this phase, required information is gathered from multiple sources of professional knowledge domains and presented in a manner that is relevant and comprehensible to the different members involved in CDM. In the hospital ward, a nurse undertakes the briefing and presents the case. During the briefing process information is filtered and reorganized according to the requirements of those involved. This is necessary as the briefing phase is just a point for defining the case and to proceed to the decision making phase. It is not intended to be a complete description of the situation. Also, the briefing needs to fit in with the time schedule, making the process of CDM time-bound.

The next phase in the CDM process is *framing the problem.* This involves preliminary reconstruction of the patient case through selection and transformation of information from the brief. It takes place by team members interacting with each other and discussing information presented during briefing. This is followed by *elaborating the case* stage where information shared during *framing the problem* is used for discovering current state of events and *issues concerning how to respond to present and future responsibilities* as well as clarifying nature of problems and possible course of actions (Winman and Rystedt 2012). This also involves raising various questions with respect to the overall goal, contradictory both views and information, and reformulating conclusions. The next stage is *agreeing* *on the case* in which consensual conclusion of how to understand and frame the case and how to proceed with solving the problem takes place. Several arguments arise during this process and have substantial impact on the final decision which is based on both administrative and professional considerations.

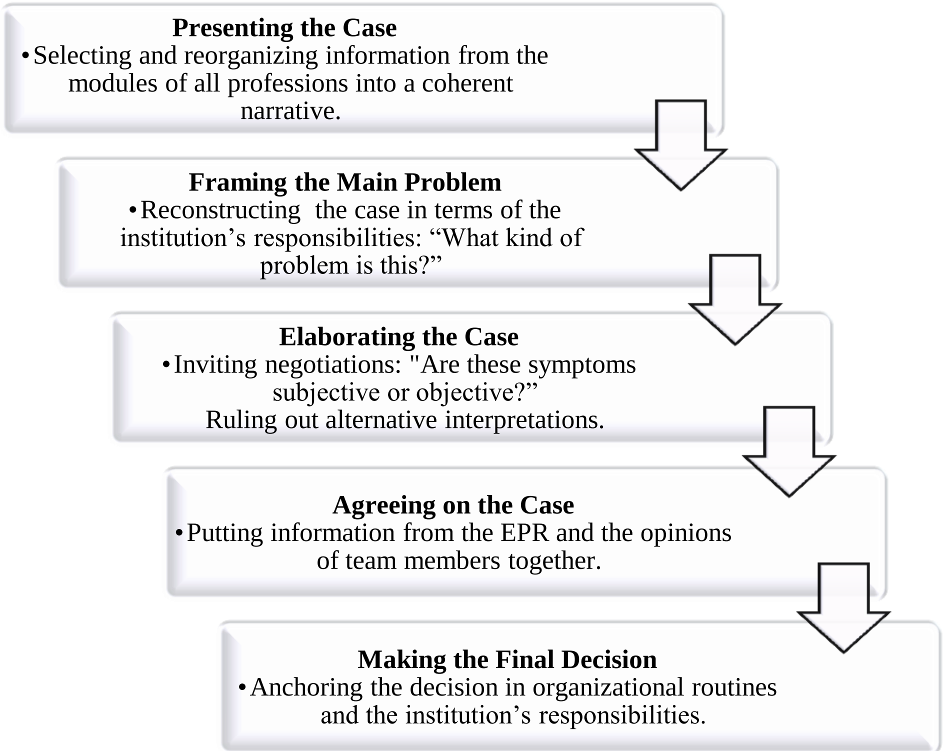


Figure 2- 6 : Process of Collaboration Decision Making Depicted by Winman and Rystedt (2012)

Winman & Rystedt (2012) present how decisions are made dynamically through the way information obtained from a global Electronic Patient Record (EPR) system is filtered, restructured, assigned locally relevant meaning, and recast into pre-embodied patters during the interactions taking place in the process of making decisions as a collective. This model represents personnel from different teams gathering to engage in the CDM process with the explicit aim of arriving at a decision.

The above conceptualizations of CDM (Karacapilidis and Papadias 2001; Kapucu and Garayev 2011; Winman and Rystedt 2012) perceive decision making as the end point. This is similar to the conceptualizations of *group* *decision making* in which members assemble together with the aim of arriving at a decision and the decision made is the end point. Hence, the models of CDM arising out of these investigations are sequential in nature.

In contrast, in the field of Business Management, Nakakawa, Bommel, & Proper (2010) presents a non-sequential model of CDM process based on studies of Enterprise Architecture development. The entailing concepts, relations and sequences for explaining this model is depicted in Figure 2- 7. from which it can be inferred that it does not represent CDM as a sequential process aimed at arriving at a decision. Nakakawa, Bommel, & Proper (2010) take into consideration that a collection of joint decisions are made in the course of architecture creation and it is a negotiation process among different units. Also, in this case, enterprise development is the focus and not decision making as presented in other studies informing the conceptualization of CDM discussed previously in which the multiple individuals convened with the aim of arriving at a single consensual decision.

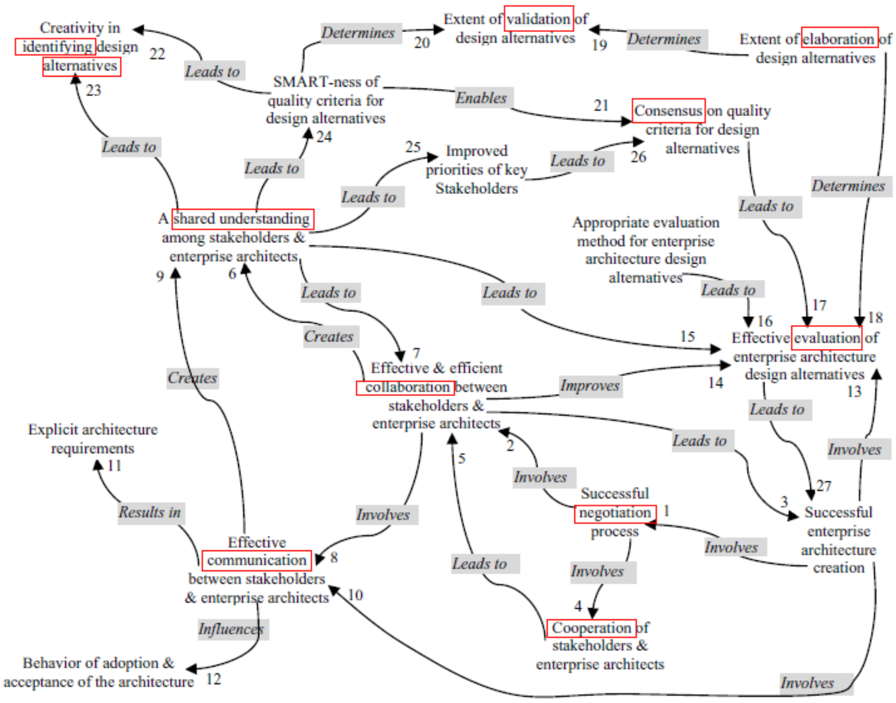


Figure 2- 7 : Theory of CDM in Enterprise Architecture Depicted by Nakakawa, et al. (2010)[2]

2.4. Discussion and Thesis Motivation

The literature reviewed in this chapter establishes current understanding and conceptualization of Collaborative Decision Making (CDM). The inference from this is that, typically, CDM is viewed as a process of reaching a common goal which is also addressed as shared goal. However, researchers in CSCW such as Schmidt & Bannon (1991a) criticize this notion and contend that the cooperative process of decision making involves interaction between goals of multiple individuals which can be of different scope and nature. Similarly, others (Sullivan et al. 1999; Cohen, Cash and Muller 2000) contend that collaboration can take place to achieve adverse goals. Nevertheless, this argument can be countered with the knowledge that in

[2] The main concepts relevant to discussions in this thesis have been highlighted in red boxes. Nakakawa, et al.(2010) use arrows to represent sequence of relations between concepts and the numbers are used to identify the relationships.

real world work settings, the complexity involved in undertaking tasks requires work to be distributed and shared between different individuals, they are all working towards achieving the same overall goal of successfully accomplishing the task. So in that sense, individuals involved in CDM are working towards the ‘shared goal’.

Furthermore, the inference from the literature reviewed in CSCW on collaborative work in complex work settings is that decision making in complex work settings takes place in a cooperative ensemble of humans, artifacts and the environment. The need to function in such an arrangement arises due to the mutual dependence of task activities. The argument put forth by researchers in this field is that if dependencies did not exist in the cooperative ensemble to instigate the requirements for integrating individual activities, then the need for collaborative functioning during task performance will not arise. Yet, there is a dearth of studies addressing this notion in relation to CDM.

In this research the focus is on CDM across distributed heterogeneous work units. Hence, the literature was reviewed to identify the effect of physical distribution and heterogeneity of work units on CDM. Physical distribution affects CDM mainly in terms of communication and coordination. It enables fewer opportunities for direct communication and exchange of socially relevant cues which in turn constricts establishment of mutual understanding required for CDM. Limited communication permitted by physical distribution and the ensuing separation makes difficult the establishment of shared understanding across distributed decision maker. Heterogeneity of work units, in contrast, affects CDM both positively and negatively. While this enables improved performance during decision making, it also leads to competing goals, biases, conflicting priorities, miscommunication, and misinterpretation. Hence, establishing required common understanding during CDM between decision makers belonging to heterogeneous work units is challenging.

The literature also reviewed models that capture the process of CDM in real world settings which confirmed dearth of research in this area. Out of the identified models, two frameworks, the ITSE framework of team decision making by Boiney (2004) and the theoretical framework of collaborative decision making by Kapucu and Garayev (2011) depict factors affecting CDM. Three models capturing the process of CDM were identified out of which two were sequential models (Panzarasa, Jennings and Norman 2002; Winman and Rystedt 2012) and one a non-sequential model (Nakakawa, Bommel and Proper 2010). The drawback with the sequential models is that they do not reflect the real world decision making process in which decision makers move back and forth between the depicted phases during decision making. Furthermore, the depictions of CDM (Panzarasa, Jennings and Norman 2002; Kapucu and Garayev 2011; Winman and Rystedt 2012) present it as a process of forming consensus and arriving at consensual decision as the end point in the process of CDM. Whereas, Nakakawa et al. (2010) present CDM as a process of conflict resolution involving evaluation of alternative course of actions and acknowledge that in real world settings a collection of joint decisions are made during task performance. The scarcity of theories of CDM and in particular the dearth of investigations of the collective form of decision making in CSCW is one of the motivations of this research study.

This research is further motivated from the shift in perception towards decision making. In particular, Brown (2005) taking an ethnomethodological perspective, questions the dualistic notion of decisions taken by rationalistic, descriptive, and naturalistic approaches which consider ‘decision’ as an activity taking place within an individual’s minds and one that is separate from actions or the work of bodies. Brown argues that although there is a growing realization in investigations of decision making to consider a wider unit of analysis which is beyond individual mental process, the models of human decision making behavior are still simplistic and do not capture the rich ways in which people engage with the world during decision making. Furthermore, Brown puts forth the argument that *decisions are not made in the head, but are instead social objects which are used in relationships with others*, and perceiving decisions as purely cognitive process separates decisions from cognition, and cognition from activity. By doing this, decisions are divided from each other and from actions which result from decisions.

Based on the literature reviewed, a decision is considered for the purpose of this thesis to be a choice of action made to accomplish a task goal. The literature indicates that making a decision in complex work settings requires an understanding of the requirements of the task as well as that of personnel involved in undertaking the task, and unfolding its relevance to the choice of action. This involves assimilating and integrating information from multiple sources and coordinating actions with related personnel. A decision therefore is viewed to emerge through social actions and interactions involved in undertaking the task.

Moreover, Hoffman & Yates (2005) argue that most investigations of decision making be it from rationalistic, descriptive, or naturalistic approach assume that an individual encounters a 'decision point' and a choice has to be made. Hoffman & Yates (2005) state that the typical notion of 'decision' is that of final-stage, final-point or final-action that brings a series of events to 'point-like conclusion' and as a *mental event occurring at a singular point in time*. They argue that it is more than the final point and that the process of deciding is not about only arriving at a single decision. Instead, it entails a host of work activities that are interactive and parallel. Furthermore, decision making during task performance entails a number of component decisions each of which could be unpacked.

Similarly, Brown (2005) contends that decisions should be perceived as *how people use decisions to organize their activity* and not necessarily as just choice points that entail cognitive work in order to make a selection. Brown considers decisions to be 'social objects' which can be used to structure collaboration. So instead of regarding decisions to be embedded in the mind of individuals, they are seen as devices that can help to coordinate activities in a work process. Decisions can act as mechanisms to implement many features of collaborative work such as coordinating social interaction, accounting for activities, structuring communication, coordinating the right resources for performing the task, and predicting future events. While Brown concedes that an important aspect of decision making involves thinking, calculation, expressing preferences and evaluation, he declares that this is combined with social interactions that take place during the process of making decisions. Hence, decisions are embedded in the social interactions. Alby and Zucchermaglio (2006) also take an ethnomethodological approach and further our understanding on decision making in a natural work setting through the following findings: decisions are embedded in social practices, work practices shape decisions, and decisions are distributed processes.

Hence, it can be inferred that paralled to the traditional view of decisions and decision making being a mental process, currently it is perceived as something that is embedded and embodied in social interactions. Such a perception towards decisions and decision making is still in the making and early developmental stages. For example, although research in NDM emphasis the importance of situational parameters and individual expertise in decision making, and the proliferation of research in NDM towards 'macrocognition' which includes social aspects such as coordination (Schraagen et al. 2008), decision making is still viewed as a cognitive process. Even when researching CDM in teams, the focus is on sharing individual cognitive constructs.

In addition, although investigations of CDM in groups focus on the social aspects such as group dynamics, information sharing and forming consensus, it takes the view of decision as the endpoint in the process.

However, during the actual work performance, a series of interrelated decisions are made and decision making is an ongoing process. Of late, there is growing realisation that in actual work practices of the real world complex work settings, there is another facet of decision making which is not explicitly and clearly identifiable as decision making, and is embedded within work practices and social interactions (Alby and Zucchermaglio 2006). More research is required to develop this viewpoint which is yet to be explored, particularly in CSCW. The need for developing conceptualizations of CDM that reflect this shift in perception forms another motivation for this research study.

2.5. SUMMARY

The literature review presented in this chapter has covered studies and concepts from a number of research disciplines. The purpose of the review of has been twofold: first to provide a background for understanding the nature of work performance in the complex settings of the real world and how existing conceptualizations depict CDM in such settings. Secondly, it is intended to raise the limitations and gaps in existing notions of CDM to be addressed in this research through which contributions can be made towards clarifying and extending prevailing knowledge.

Founded in the field of CSCW, this research investigates CDM undertaken by distributed decision makers belonging to heterogeneous work units in a complex work setting. The aim of this research is to develop a theory of CDM which addresses the recent shift towards perceiving decision making as situated, embedded, and embodied in social interactions. Hence, the conceptualization of CDM is derived from studies of real world complex work settings and is not structured by the reviewed theoretical frameworks. Moreover, the argument put forth in this thesis is that investigations of CDM need to move away from the typical cognitive and 'choice-point' perception towards decision making in order to reflect the way it actually occurs during task performance in real world work settings. This research has attempted to steer the field of CSCW towards such a direction by considering key alternative assumptions based on the current shift in perception towards decision making**.** In particular, these include a) decision making is not purely an individual cognitive process, but integrated with social processes, and b) decision making is not a 'choice point' event, but situated, embedded and embodied in work activities involved in task performance. Based on these aims and assumptions the question driving this research is

> ***How do people in a complex heterogeneous working environment make decisions collaboratively?***

The following chapter describes the choice of appropriate research methodology to facilitate this undertaking.

CHAPTER 3

RESEARCH METHODOLOGY

3.1. INTRODUCTION

The aim of this research is to explore, conceptualize and develop a theory of Collaborative Decision Making (CDM) taking place in complex real world work settings. The previous chapter discussed existing works related to this research, presented an overview of work performance in the conditions of such settings, and identified discrepancies in the current conceptualizations of CDM. This chapter explains the methodological procedures as well as the data collection and analysis techniques employed to undertake the study. Specifically, it presents the rationale for choice of interpretive approach and Grounded Theory Methodology (GTM) for carrying out the research and developing the theory of CDM. Field studies undertaken in the airport setting of Air Traffic Control (ATC) operations are described.

3.2. SELECTION OF QUALITATIVE RESEARCH

An important aspect of any research, whether testing existing theory or developing a new one, is the approach taken in arriving at the final product. The choice of methodology hence is an integral part of the research process as it provides a suitable framework and influences the corresponding study design, data collection and analysis methods, and how the results or findings are presented (Myers, 1997; Schwandt, 2001).

For the purpose of this research it is assumed that social reality does not exist independently of individual actions. Instead, reality is subjective and becomes meaningful to people because of their actions and interactions (Erickson 1993; Harrison and Dourish 1996; Dourish 2004; Brown 2005). The way people perceive the social world depends on the features of its setting (context) and the way they engage themselves with that setting (practice) (Nova 2003). In order to comprehend the socially constructed reality, work activities are studied 'in situ' by exploring everyday work practices, as illustrated by the seminal works of various investigators (Suchman 1987; Lave and Wenger 1991; Malone and Crowston 1994; Hutchins 1995; Schmidt and Simone 1996).

The goal of this thesis is not to quantify the behavior of personnel during CDM but to gain in-depth understanding of the way they undertake it during task performance and conceptualize it. Additionally, this research does not aim to test prior theories or hypothesis through objective accounts of CDM but is aimed at generating a new theory through subjective understanding of work performance in a specific context. Therefore, qualitative methodology was chosen (Lincoln & Guba, 1985; M. O. Patton, 1980). This is an appropriate approach for studying complex work settings as it provides open and flexible methods and techniques for exploring the intricate characteristics of work performance. Furthermore, it enables direct study of social interactions and behaviour of people in their actual work environment (Creswell 2007, pg. 37). This will allow the characteristics of CDM to emerge from the natural course of work performance in real world settings instead of placing it within pre-determined questions, conditions or theoretical framework in controlled conditions.

3.3. SELECTION OF GROUNDED THEORY METHODOLOGY

The choice of qualitative methodology influences the research study design (Creswell 1998). There are various such methodologies including Grounded Theory, Ethnography, Action Research, Phenomenology, Discourse and Conversational Analysis, and Case Study. They are suitable for different purposes and are employed depending on the research goals, what is being investigated, and how.

The goal of this study is to generate a theory of CDM based on exploration of its occurrence in real world conditions for which Grounded Theory Methodology (GTM) was considered to be suitable. One of several reasons for this choice is that the methodology places emphasis on the social construction of reality which arises from its philosophical foundation in Symbolic Interactionism (Blumer 1986; Goulding 1998; Goulding 1999; Blumer 2005). Hence, the approach of GTM towards interpretive research is to understand how the behaviour of studied people is shaped through social interactions in a particular context (Aldiabat and Le Navenec 2011). The aim of GTM then is to discover and conceptualize the essence of complex social interactional processes with respect to a particular phenomenon (Glaser and Strauss 1967).

Moreover, GTM is principally aimed at theory development. The core of this methodology is emergent theory generation grounded in the data collected (Glaser and Strauss 1967). It provides a systematic process for generating theory from data which itself is systematically obtained. This includes continuous interplay between the data collection and analysis as well as flexibility in inclusion of sample and data analysis (Glaser and Strauss 1967; Glaser 1978; Glaser and Holton 2004b). In addition, GTM offers a suite of procedures to follow from start to end of theory development. Another reason for choosing GTM is that it differs from the typical descriptive, thematic analysis attribute of other approaches to qualitative research such as Ethnography, Action Research, Case Study, and Phenomenology by being less descriptive and more favourable to conceptualization (Baker, Wuest and Stern 1992; Glaser and Holton 2004a) as it focuses on abstraction of time, place, and people to generate concepts and set of plausible hypothesis to explain human behaviour (Glaser 2002b).

3.4. INTRODUCTION TO GROUNDED THEORY METHODOLOGY

Grounded Theory Methodology (GTM) was developed by Barney Glaser and Anselm Strauss in the 1960s to provide steps and offer guidelines for theory generation (Glaser and Strauss 1967; Strauss and Corbin 1998). Glaser and Strauss wanted to encourage a methodology for theory generation that provides underlying principles to be adhered to but with the flexibility to modify the details of the procedure to suit the research needs (Larossa 2005). However, this has resulted in different interpretations and lack of consistency in the application of GTM. Glaser and Strauss later separated in their approach which resulted in two dogmas of the same methodology. The validity of each has been the subject of much debate as exemplified in *Theoretical Sensitivity* (Glaser 1978), *Basics of Grounded Theory Analysis* (Glaser 1992), *Qualitative Analysis for Social Scientists* (Strauss 1987), and *Basics of Qualitative Research* (Strauss and Corbin 1990; Strauss and Corbin 1998). This has developed into two main streams known as the Glaserian (also known as classical Grounded Theory) and Straussian schools of GTM.

The difference between the two approaches to employing GTM is in the execution style and terminology with Glaser advocating interpretive, contextual, and emergent approach to theory development whilst Strauss presenting a complex, highly structured process, and a paradigm that imposes a conceptual framework for data analysis. The main difference between the two approaches, according to Glaser (2001) is that his approach to Grounded Theory results in emergent theory generation whereas Strauss's approach forces theory from data. Other differences arise in terms of framing and use of research questions, approach to coding data, approach for generating theoretical framework, and the role of the researcher (Glaser 1992). Moreover, few other variations of GTM have arisen (Schatzman 1991; Clarke 2005; Charmaz 2006) leading to further versions of the methodology. Therefore, people employing GTM now have to choose between the two schools of thought and between other variations.

In this research, both Glasarian and Straussian approaches were implemented in the initial stages of the study. Subsequently, a decision was made to adopt the former approach only since it was simpler and less demanding on adherence to structure for data analysis, and presented greater potential to generate theory. Although, the Straussian approach seemed to present clearer guidelines, it made the analysis more cumbersome and difficult. Also, it was difficult to move from coding the data to theory development because of a large number of codes emerging through this process. The 'paradigm model' offered by Strauss for drawing relationships between concepts were restrictive whereas the 'theoretical coding' families prescribed by Glaser provided scope for flexibility and seemed to facilitate conceptualization. This study has tried to stay within the general guidelines prescribed by Glaser for employing GTM, but has adapted the use of prescribed procedures to develop the theory of CDM.

Theory generation through GTM can be informed by any activity that yields data (Glaser and Strauss 1967; Glaser 2002b). However, the most common techniques employed for data collection are interviews and participant observation (Glaser and Strauss 1967). Furthermore, the methodology is founded on the notion that generating useful concepts and theories of social behaviour requires familiarity with the specific setting in which it occurs (Huberman and Miles 1994). Therefore, field studies are considered to be appropriate means of collecting data to develop the theory of CDM as it focuses on exploring human behaviour in naturally occurring conditions (Cohen and Bailey 1997). The combination of GTM and field studies is suggested to be highly compatible (Robrecht 1995; Pettigrew 2000). In addition, the suitability of such methods and techniques in investigating work performance in natural settings is evident from its extensive usage in 'workplace studies' of CSCW research.

Air Traffic Control (ATC) was chosen as the domain of study with an Airport as the field study site since ATC work settings embody the characteristics of complex work settings. The complexity in these settings is characterised by the involvement of multiple personnel distributed in time and space, critical nature of work in terms of human and pecuniary safety, time pressure involved in undertaking work activities, and constantly changing work environment (Mongford et al. 1995; Berndtsson and Normark 1999; Koros et al. 2003; Hilburn 2004). Moreover, work activities of people involved in the ATC operations are interrelated which requires them to operate in collaboration with each other. The work process also requires people to make complex judgements and decisions in order to accomplish tasks. Hence, ATC provides an appropriate setting for undertaking this field research.

A general background of ATC operations and description of the Airport in which the field study was conducted is presented below. It is undertaken with the intention of establishing the milieu for discussion of analysis of data collected through the field study.

3.5. FIELD STUDY SITE DESCRIPTION

The airport is a vastly distributed work setting with vital placement in the ATC process. Work activities involved in ATC operations at the airport are distributed among multiple personnel who operate from different work units, are dispersed in and around the airport, need to function jointly, and are supported by myriad of technical artefacts. Also, decision making is an important aspect with decisions made by personnel in the distributed yet interrelated setting affecting each other's work activities.

3.5.1. Air Traffic Control (ATC) Operations: An Overview

The main aim and purpose of the civil Air Traffic Control (ATC) is to provide safe and efficient means of transportation for people while being cost effective for the organization providing the service. Aircraft safety is maintained by restricting the movement of aircraft within a Controlled Airspace (CAS) in air and in a restricted space on land at the airport. Aircraft movement is controlled through the enforcement of regulations by ATC Officers (ATCO). The main role of ATCO is to maintain safe separation between aircraft according to internationally agreed standards, and guide its movement on land at the airport and in the airspace between airports.

One or more air traffic controllers are responsible for aircraft movement within the airspace from ground upwards which is divided into sectors. As an aircraft travels through the divided space, it is monitored by the controllers who guide its movement by giving instructions to the aircraft pilots. When an aircraft leave an airspace division and move into another division, the air traffic controller hands over control of the aircraft to the controller responsible for the next airspace division. Every aircraft flight follows a typical profile as given below (Figure 3-1)

Pre-flight	Starts on the ground and includes flight checks, push back from the gate, and taxi to the runway.
Take-off	Aircraft pilot powers the aircraft, speeds down runway and aircraft lifts off the ground.
Departure	The aircraft climbs to cruising altitude.
En-Route	Aircraft travels through one or more controlled airspaces and nears the destination port.
Descent	Pilot descends and maneuvers the aircraft to destination airport.
Approach	Pilot aligns aircraft with the designated landing runway.
Landing	Aircraft lands on the designated runway, taxis to the destination gate, and parks in the terminal parking area.

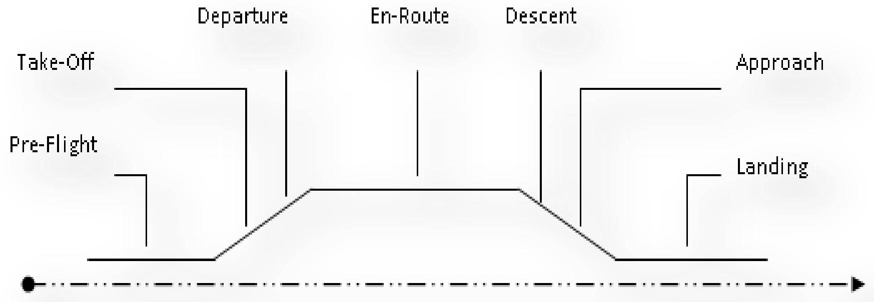


Figure 3- 1: Typical Profile of Commercial Aircraft Flight

A number of work units are involved in controlling the movement of aircraft through these phases of flight as depicted in (Figure 3- 2).

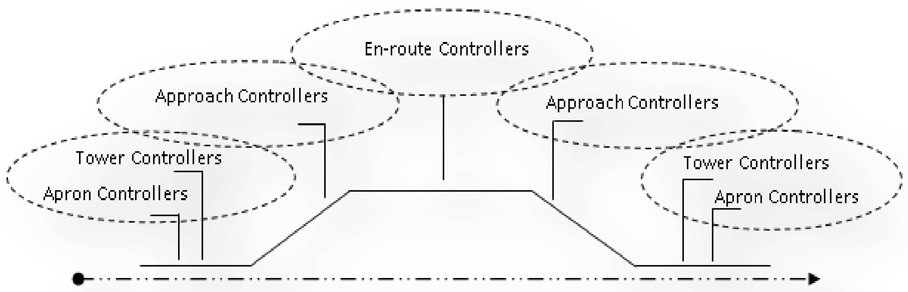


Figure 3- 2 : Air Traffic Control Work Units Managing Aircraft Movement at Different Phases of Flight

The Control Tower and Operations Centre are located in the airport whereas the Approach Control is outside the airport. There are also other work units located at different geographical locations from which air traffic controllers manage the movement of aircraft en-route from the source to the destination airport. The space managed by each of these work units is given below.

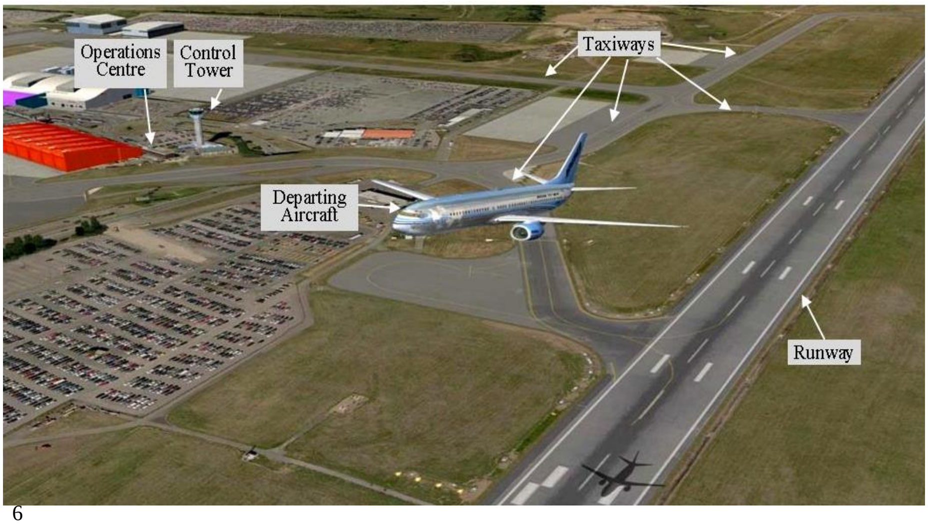
Tower Controller	Aircraft movement on land between 3 to 5 miles around the runway. This involves operations related to aircraft parking, landing, and takeoff.
Ground Controller	Movement of aircraft on the Taxiways betwen the parking stand in the Apron area and holding point near the Runway. Directs movement of people and ground vehicles on the Taxiways.
Apron Controller	Movement of aircraft and ground vehicles in the Apron area of the airport.
Approach Controller	Air traffic flowing into and out of the airport up to a minimum of 30 miles from the airport.
En-route Controller	Air traffic movement upwards in the airspace from a minimum of 30 miles from the airport.

3.5.2. Airport Work Setting Description

The field study was conducted at an international airport in London, UK. The area at the airport where aircraft movement takes place is the Runway (used for aircraft takeoff and landing), Taxiways (pathway for moving aircraft and other vehicles to and from the Runway to the Apron area and other facilities), and Apron area (site used for parking stand, loading, unloading, fuelling, and maintenance of aircraft) (Figure 3- 3). This is a single runway airport, hence takeoff and landing of aircraft has to be alternated. Aircraft entering and leaving the Runway have to wait at "holding points" on the Taxiways to obtain clearance from the air traffic controllers in the Control Tower for further manoeuvre.

A number of agencies are involved the management of safe and efficient movement of aircraft and are located both within and outside the airport (Figure 3- 4). Those located within the airport are various Airlines who have their own Hangers[3] in the Apron area. There are two Handling Agencies at the airport, which take care of various service[4] requirements of an aircraft and associated Airlines. These services are provided to aircraft during movement on the ground at the airport and when parked on the stand in the Apron area.

[3] Enclosed area used for aircraft repair and maintenance.
[4] Cabin, Catering, Passenger, and Ramp Service



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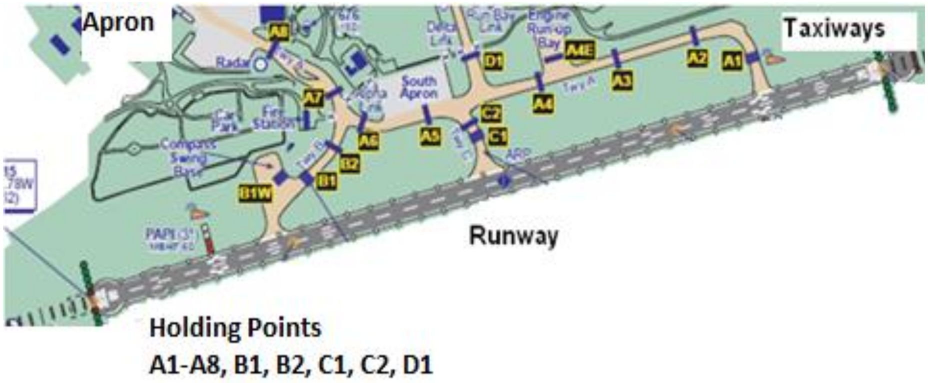

Figure 3- 3: Runway, Taxiways, Holding Points and Apron Area Layout at Studied Airport[7]

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[5] http://www.repulojegyutazas.hu/london-repuloterei-heathrow-luton-gatwick-stansted-london-city/
[6] http://www.simflight.com/2011/05/27/eiresim-reveals-london-luton/

The Control Tower and Operations Centre are two work units at the airport, which manage the movement of aircraft and ground vehicles on and around the Runway and Taxiways. The Engineers are located below the Control Tower and are responsible for maintenance of all systems on and around the Runway and in these work units. Other agencies operating in the airport include the airport management authority, fire station, medical service, and police service. The pilots of aircraft are another work unit located either within the airport or outside, depending on their location during flight. Agencies which are located outside the airport, but integral to its operations are the Central Flow Management Unit (CFMU), London Terminal Control Centre (LTCC), Met office (MET), and other airports.

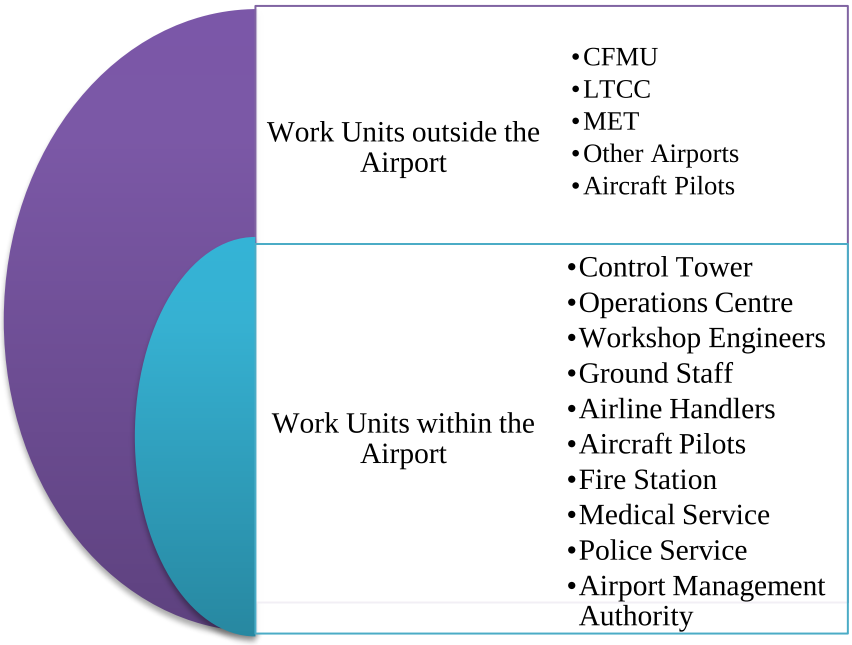

Figure 3- 4 : Work Units Identified in Airport ATC Operations during Field Study

These agencies together form a network of work units which function jointly to provide safe and efficient means of air transportation for people. They serve different purposes and are involved in various

[7] Obtained from Field Study Site

aspects of ATC operations. Hence, the work units have diverse goals and activities, and entail personnel with distinct expertise and responsibilities. The agencies are governed by international standards and rules which have to be followed during ATC operations. The work units are dispersed in space and time, and associated personnel can be either stationary or mobile.

The Control Tower and Operations Centre were identified as appropriate work units for undertaking this field study at the airport. Work carried out at these two units is integral to ATC operations and is closely integrated with the work activities of others. Hence, they provide an appropriate location to investigate work performance in the airport ATC setting. Involvement of personnel from other work units in ATC operations is perceived in relation to the work activities at the Control Tower, Operations Centre and aircraft Pilots. An overview of the different personnel, their responsibilities and operations undertaken from different work units in and around the airport is presented below whereas a detailed description of the same is given in (Appendix 1).

Control Tower

The Control Tower (Figure 3- 5) is located near the Runway higher than all the other buildings in the airport and is surrounded with glass window to allow visual surveillance of the area surrounding it. Personnel in the Control Tower manage the aircraft movement on the Runway and Taxiways as well as in the airspace around the airport. Aircraft can be maneuvered into this space by the pilots only with direct permission from the controllers in the Control Tower. This also applies to drivers of other vehicles requiring use of the Runway and Taxiways.

Figure 3- 5 : Control Tower at Studied Airport[8]

There are up to five air traffic controllers (Figure 3- 6, Figure 3- 7) working in the Control Tower at a time on a shift-basis. When the study commenced there were three positions within the Control Tower. They are: the Assistant, Tower Controller (TC), and Ground Controller (GC). During the later stages of the study, another position was included, called the Ground Planner (GP) to assist the GC. There is also a Supervisor's position, but this is not occupied at all times. There was also a move from paper Flight Progress Strips (FPS) to Electronic FPS (EFPS) in the during of this field study.

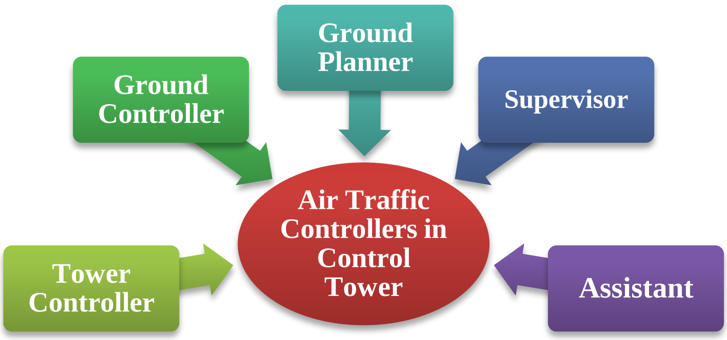

Figure 3- 6: Personnel Functioning in the Control Tower

The primary function of the Assistant is to ensure that safety of arriving and departing aircraft is maintained by providing required information to the GC and TC in the Control Tower at the right time. In addition, the

[8] Field study data

Assistant has to coordinate various activities with other agencies in the airport such as the accident services, maintenance services, weather office, apron control, pilot inquiries, and accounts department.

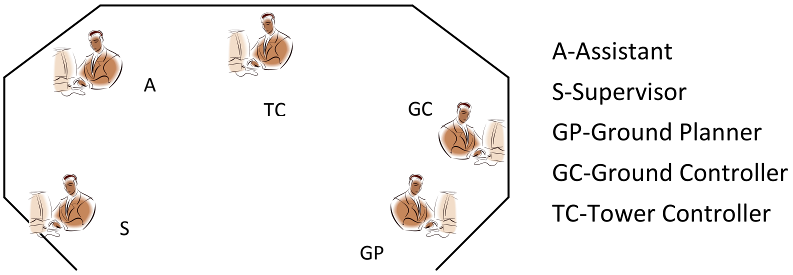

Figure 3- 7: Arrangement of Personnel Working in the Control Tower

The TC manages aircraft movement on the Runway and airspace surrounding the airport. The TC's main role is to issue clearance and instructions to aircraft pilots for takeoff and landing, and to ground vehicles requiring movement on the Runway. In contrast, the GC manages aircraft and other vehicle movement on the Taxiways and Apron area, except on the Runway. The GC issues clearance for departing aircraft pilots, taxi instructions to landing and departing aircraft pilots, and issues permission and instructions for ground vehicles drivers requiring movement on the Taxiways. The GP is positioned next to the GC in the Control Tower. With the inclusion of the additional position of GP, the first point of contact for pilots of departing aircraft is the GP instead of GC. GP position is active in the Control Tower only during peak hours in the morning, between 6.30 a.m. and 8.30 a.m., to assist the GC to plan and execute the departure sequence of aircraft from the airport.

Operations Centre

The Operations Centre is located in the airport next to the Control Tower. It was set up to integrate various operational facilities such as apron management and control, security, public information services, and passenger transportation into a single facility to improve operational services. There are three positions in the Operations Centre (Figure 3- 8) : Assistant, Arrival Controller (AC) and Departure Controller (DC) (Figure 3- 9).

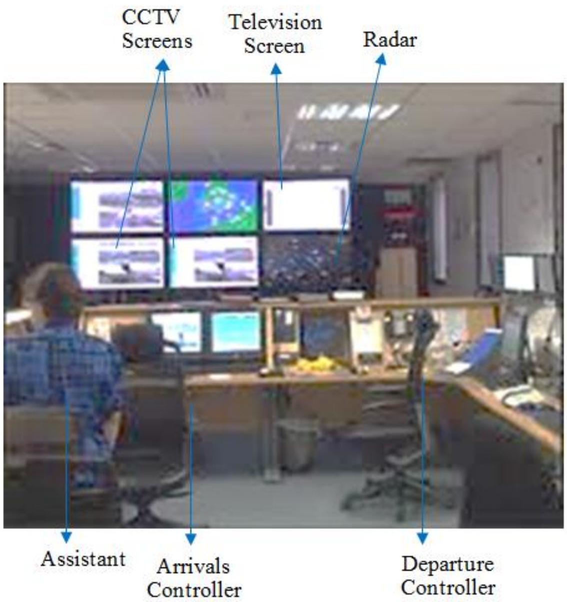

Figure 3- 8 : Arrangement of Personnel Working in the Operations Centre[9]

The Assistant is positioned at the switchboard whose primary function includes receiving information and passing it to relevant people within and outside the airport, answering queries about airport operations (both from the general public and personnel involved in airport operations), and maintaining a log of day-to-day events occurring at the airport. The Assistant performs various other functions in the Operations Centre such as updating weather information, attending to customer complaints, assisting the AC and DC, managing the access control systems, coordinating activities with security and emergency services, updating information to be displayed in the airport website, and making boarding calls, sending security messages, and ad-hoc announcements for passengers in the airport terminal.

[9] Picture obtained from http://guohengiv.com/business_airports_luton.htm

Figure 3- 9 : Personnel Functioning in the Operations Centre

The AC is mainly concerned with allocating the parking stand for inbound aircraft and coordinating activities with the DC. Another responsibility of the AC is to record information about aircraft flight status, such as estimated and actual landing time of arriving aircraft, flight cancellation, technical problems, and delay in aircraft arrival. This information is then sent to the airport management, accounts department for billing, and flight information displays in the terminal area by the Assistant. The DC in contrast, manages the preparation required for departing aircraft such as checking the departure slot time, verifying if the aircraft is departing on time, and updating information about the parking stand occupancy. Also, the DC is responsible for recording the estimated and actual aircraft departure times into the computer system to be used for displaying this in the flight information displays located in the airport terminal and for notifying the accounts department. Moreover, the DC coordinates the movement of aircraft in the Apron area with the ground staff and handling agents.

Approach Control

The Approach Control (Figure 3- 10) is the London Terminal Control Area (LTMA) located outside the airport. The airspace controlled by LTMA is divided into two groups – North and South. Based on the studies conducted in the Control Tower and Operations Centre, the following personnel were identified to be operating in the LTMA. There are three controllers (Radar Controller, Coordinator and Assistant) each in the North and South sectors and are known as Terminal Controllers. In addition, there are two Approach Controllers (Radar and Director) as well as a number of controllers known as En-Route Controllers who manage air traffic in different sectors of the airspace.

Figure 3- 10 : Approach Control (LTMA) [10]

Aircraft approaching the London airports are handed over to the Terminal Controllers by the En-Route Controllers. The former are responsible for controlling aircraft movement in their respective airspace sectors and arrange the sequence of aircraft flowing into and out of the London airports. The Approach Controllers then determine the landing sequence of aircraft arriving into the studied airport in coordination with the TC in the Control Tower (Figure 3- 11).

Figure 3- 11 : Types of Controllers in LTMA

The sequence is reversed for aircraft departing from the airport. The TC in the Control Tower hands over control of aircraft movement to the Approach Controllers which is then passed onto the Terminal

[10] *Picture obtained from http://www.ccd.org.uk/swanwick_atc.php*

Controllers and En-Route Controllers. In this research, since work activities of personnel in the Approach Control were observed while conducting the study from the Control Tower and Operations Centre at the airport, information obtained about the Approach Control was in relation to the work activities of these two work units. The descriptions presented here are hence somewhat limited.

Other Work Units

The pilots flying the aircraft are required to communicate with the air traffic controllers from different work units during various phases of flight from the source to the destination airport. They also need to consult the flight dispatcher and the Met office before departing. Every aircraft using the airport services has a Handling Agent to which the airline subcontract ground handling of its aircraft. The Handling Agent takes care of the service requirements for the aircraft. The maintenance engineers provide their services such as installation of new systems, maintenance and repair of equipment and computer systems in the airport including the Control Tower and Operations Centre. The ground staff include ramp agents who perform various functions in the aircraft parking stand such as ‘pushback’ for departing aircraft from the terminal gate, guiding arrival aircraft with hand signals and flash lights to position it in the gate, check the wheels of the plane after it halts, and guiding the Jetbridge to the aircraft door, towing aircraft to and from the parking gate, and baggage handling. Moreover, there are various emergency services operating in the airport such as the fire station, security, and medical services.

Nonetheless, a number of technical artefacts facilitate personnel working in these work units. A description of the artefacts utilized by controllers functioning in the Control Tower and Operations Centre is described in Appendix 1.

3.5.3. Cooperative Work Arrangement, Collaborative Work and Decision Making

Personnel involved in the airport ATC operations function in different work units, are distributed, manage various aspects of work performance and have their own expertise, authority, work practices, goals, and responsibilities. However, in order to carry out the activities of the tasks, they have to cooperate and coordinate with others both within and across work units. A number of technological artefacts facilitate and mediate communication and coordination between personnel involved in the ATC operations. Considering that the work environment is dynamic, activities in task performance, including collaborative work and decision making, is taken in real-time.

Collaborative work and decision making in airport ATC Operations is explored in this study through three primary tasks: aircraft arrival, departure and maintenance. Undertaking these tasks requires involvement of various personnel from different work units, both within and outside the airport. This is illustrated through a description of joint work performance involved in managing the movement of an aircraft arriving into the airport.

The En-Route Controllers in the LTMA direct arriving aircraft to different levels in the airspace above the airport and then hand over its control to the Terminal Controllers. The latter then hand it over to the Approach Controller (Radar) as the aircraft approach the 'holding stack'[11]. The Radar Controller guides the pilot of the arriving aircraft into the holding stack and directs its movement in the stack pattern. The Director in the Approach Sector then controls the movement of aircraft as it exits the holding stack and is responsible for organizing the sequence of aircraft approaching the airport. When the aircraft pilot is

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[11] Area in the airspace with a pre-defined track pattern where aircraft fly in circles until given clearance by the air traffic controllers to exit the pattern and approach the airport.

ready to exit the holding stack, control is then handed over to the Tower Controller in the Control Tower of the airport.

Personnel working in the Control Tower of the airport are responsible for guiding the landing of arriving aircraft on the Runway and its movement on the Taxiway until it reaches the parking stand in the Apron area. The Assistant in the Control Tower has to print the Flight Progress Strip (FPS) half an hour before the aircraft arrives, write the parking gate number provided by the Operations Centre, set the FPS in the arrival strip holder[12] and then place it on the Tower Controller's (TC) holding bay. Ideally, this would be done before the arriving aircraft makes contact with the TC. However, this was not always the case as observed during the field study. Sometimes, the Assistant is unable to provide the FPS to the TC before the aircraft makes contact. In these circumstances, the TC continues to perform the required operations without the FPS by using only the Radar and verbal communication with the pilot of the arriving aircraft. The parking gate number is provided by the Arrivals Controller in the Operations Centre through the Flight Schedule computer system. If the number is not available in the system at the required time, the Assistant has to telephone the Operations Centre to obtain it verbally.

The Tower Controller (TC) in the Control Tower of the airport guides the movement of air traffic approaching the airport (by maintaining a separation of eight miles on average between the aircraft) and landing them on the Runway. The pilot of the arriving aircraft makes contact with the TC in the Control Tower at an average distance of six miles from the airport. Control of guiding its movement is then transferred to the TC after which the TC annotates the FPS with an 'A' (Figure 3- 12). The TC then gives the aircraft Pilot clearance to land and the Taxiway

[12] Strip holders are color coded with arrival aircraft strip holder in blue while that of departing aircraft in orange

number to exit the Runway. The TC has to coordinate with the Ground Controller (GC) in the Control Tower to ensure that the departing aircraft are not using the Taxiway.

When the aircraft lands on the Runway and reaches the Taxiway, the TC gives the aircraft pilot clearance to leave the former and move onto the latter, hands over control of the aircraft to the GC, and then crosses the ‘A’ on the FPS. Once the TC hands over control of the arriving aircraft to the GC he places the FPS into the blue box on the floor.

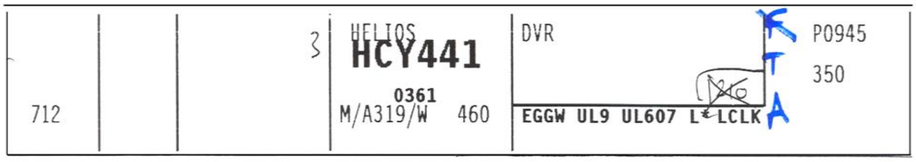

Figure 3- 12 : Annotation of Flight Progress Strip (FPS) by Tower Controller in Control Tower

The GC then gives clearance to the aircraft pilot to move from the Runway to the Taxiway. The Assistant takes the strips from the blue box and enters information such as the arrival time and parking gate number into the computer system which is used to log information about airport usage to be sent to the billing department. When the aircraft reaches the parking stand, the maintenance engineers perform a safety check.

The above example demonstrates that performing the task of manoeuvring aircraft arriving into the airport involves a number of personnel at different stages of its movement. This requires collaborative work performance, including cooperation, coordination and communication. Moreover, decisions have to be made by personnel at each stage of aircraft movement. For example, controllers in the LTMA, Control Tower and Operations Centre have to make decisions about spacing and sequencing of arriving aircraft in the airspace above the airport through to its landing on the Runway and onto the Taxiway until the aircraft reaches the parking stand in the Apron area. In relation to this, further decisions have to made about instructions to be given and information to be transferred to the aircraft pilots and other controllers, and actions to be performed individually and in coordination with that of others. Decisions include that which are made individually and jointly with other personnel both within and across work units. Therefore, a number of decisions need to be made by different personnel at different points in the course of aircraft arrival. The nature of collaborative work and decision making in this setting is depicted in the data collected from the field studies which are presented in the ensuing discussions in this thesis.

3.6. DATA COLLECTION METHODS AND PROCEDURES

Data was collected over three phases in this study. The first and second phase studies were conducted in the Control Tower at the airport while the third phase studies were undertaken in both the Control Tower and Operations Centre. During the field studies, data collection took place through a combination of interviews, think-aloud protocol with concurrent probing, observation and document analysis.

Such a triangulation of data through interviews, observation, and documentation is considered to be advantageous because it facilitates validating and comparing consistency of information obtained from the study site besides gaining additional perspective on key issues (Mays and Pope 1995; Patton 1999; Corley and Gioia 2004). Also, using concurrent protocol in conjunction with observation makes the data more reliable. Data collected include organizational documents and photographs of the study site and information obtained from the literature about the studied domain. The following sections describe the deployment of these techniques.

3.6.1. Interviews

In this study, semi-structured, in-depth interviews were chosen to gather data from air traffic controllers in the Control Tower and Operations Centre at the airport. This technique was particularly suitable because the field of work is a dynamic environment, and the interview questions needed to be adapted to the changing context of work in order to capture the essence of the air traffic controller's experience and behaviour in their natural work environment. The strategies involved in undertaking semi-structured interviews were to ask open-ended questions about the interviewees activities in relation to the key topics covering this research, and to allow discuss this at length it from their perspective. Planned (Appendix 2) and unplanned probes were employed to uncover their behaviour and experience during task performance. In addition, note taking was employed while conducting the interviews.

All the interviews were tape-recorded with the interviewee's permission and later transcribed verbatim anonymously for analysis, an example of which is given in (Appendix 4). Furthermore, the air traffic controllers were informed of the voluntary nature of their participation and right to withdraw at any point.

3.6.2. Concurrent Protocol

The semi-structured interviews were supplemented with concurrent verbal protocol (think-aloud) (Ericsson and Simon 1980; Fonteyn and Fisher 1995; Cabello and O´Hora 2002). The interviews were mostly conducted whilst the interviewees were undertaking their work activities and were asked to talk about what they were doing in relation to the task at hand. This helped to obtain insight into the interviewee's understanding, goals, intentions, expectations, and judgement during everyday task performance. However, the drawback of using this technique is that it can cause strain on the interviewees as they have to think, talk, and attend to the work being carried out at the same time (Young 2005). This was addressed during data collection by the interviewees pausing to do their work when it effected their activities and then resumed the conversation when convenient. They displayed this behaviour instinctively, when either the workload increased or the work required increased concentration. In case the interviewees digressed from what they were talking about, probes were used to re-focus the talk. Although thinking aloud may slow down the primary task performance, the participants perform the primary task well whether or not they provide the verbal reports (Bowers and Snyder 1990; Ericsson and Simon 1993; Ericsson 2006).

3.6.3. Observation

Another technique for data collection is observation which involves actively looking, listening and recording events, human behaviour and usage of artifacts in order to ascertain what is actually happening in the studied setting. This includes understanding how personnel engage with each other, artifacts and surrounding environment during their work activities, checking for nonverbal expressions and determining how various activities are conducted during task performance. The advantage of performing observational studies in a naturalistic setting is that it facilitates gaining first hand experience of the nature of work performance and understanding the context in which it takes place. It helps to capture human behavior and experience within the context of work activities and those that might have been overlooked or unavailable during interviews.

There are different variations to performing observational studies such as structured and unstructured, participant and non-participant, as well as overt and covert (Coolican, et al. 2004). In this study, overt, non-participant observation was conducted, involving a combination of unstructured and structured ones which allows for both breadth and depth in studies as well as balances researcher bias. Furthermore, non-participant observation was employed because ATC is a complex safety-critical domain.

This is an overt observational study since personnel in the studied setting were made aware of the research. Although, data obtained through such a technique are considered to be strong in validity because of the depth of information obtainable, it raises concerns about validity and reliability because of the observer effect as people may behave differently when they are aware of being observed. The highly sensitive nature of the work environment of ATC required that studied personnel were informed by their authority before the observation took place. This drawback is overcome to some extent because of the purpose and non-threatening nature of the study.

The observed data was recorded through written descriptions in the form of field notes, audio recordings, and photographs. These notes included making written descriptions of direct observation (Appendix 3, 14, 15) as well as inferences drawn. Audio recordings of interaction between individuals and photographs (Appendix 1) supplement written descriptions whilst artifacts (Figure 3- 12) enrich the observations made.

3.6.4. Secondary Data Sources

Apart from getting first hand data from the site, several secondary sources of data were identified, such as organization and technical documents about the airport and studies conducted by others in the area of ATC.

3.6.5. Data Management

For peliminary qualitative analysis the data was coded and categorized manually. Once the volume of data obtained through the field studies started gaining strength it was considered more effecient to use a software package for the analysis. A range of packages known as CAQDAS (Computer Assisted Qualitative Data Analysis Software) is available with different features. They are generally intended to manage the complexity of analyzing a large volume of data that might be difficult if performed manually. After much examination, Atlas/ti was selected because it is based on the Grounded Theory approach to qualitative analysis, easy to learn and use, and is more suitable for small research undertaking (Barry 1998) like this study. The software was predominantly used to manage the data collected, code the transcripts and model relationships between concepts (Appendix 5, 7, 8. 9).

3.7. DEVELOPING GROUNDED THEORY OF COLLABORATIVE DECISION MAKING

The essential elements of a theory are delineated by Whetten (1989) as follows:

Factors (variables, constructs, concepts) considered to be relevant to explain the phenomenon of interest.

The relationship between identified factors which delineates patterns and causal relationships, thereby adding order to the conceptualization.

Underlying dynamics (such as psychological, economic, and social) that justify the selection of factors and proposed relationships. This reflects the logic of theory generated.

These constituting elements correspond with the desired outcome of Grounded Theory Methodology (GTM) which is a well-grounded theory that not only describes and explains the occurrence of the subject of interest but also presents clear concepts and their relationships (Glaser and Strauss 1967). Furthermore, GTM is aimed at eliciting underlying social dynamics from which the relevant factors and relationships, explaining the matter of inquiry are delineated.

3.7.1. Scope and Unit of Analysis

The scope of analysis chosen for this research undertaking reflects the ongoing realization for the need to address the bigger picture of contextual and social factors in studies of decision making in complex work settings (Lipshitz 1994; Alby and Zucchermaglio 2006; Hutchins and Kendall 2009; Goel et al. 2012). Therefore, it includes work activities taking place during task performance and associated interaction between entities in the cooperative ensemble of complex work setting. Focusing on these factors is deemed to be appropriate means of understanding the context of CDM in realworld settings (Brehmer 1992; Hoffman and Yates 2005). Supporting view is held by others (Leont'ev 1974; Lave 1988; Bødker 1989; Kuutti 1991; Nardi 1996; Engeström 1999; Kofod-Petersen and Cassens 2005) who contend that activity and the larger system in which it takes place present appropriate scope of analysis to understand the context of work performance. Furthermore, the environmental state of the real world complex work settings is dynamic and unpredictable. Work performance in such settings is situated. So, it is necessary to characterize the 'situation'[13] in which CDM is carried out (Moon 2002). In order to do this, the scope of analysis also includes the identity, location and status of entities as well as time in the geographical space (Dey, Abowd and Salber 2001).

Literature reviewed in the previous chapter revealed that CDM in complex work settings takes place in the cooperative work arrangement. Hence, the unit of analysis of this research includes multiple individuals who are distributed in the work setting and who need to function collaboratively to perform tasks. This was addressed at different levels: at the individual, within work-unit, and between work-

[13] Defined as circumstances of task performance by Suchman (1987)

units. With this scope and unit of analysis, the process of answering the research question of this thesis has led to the development of the theory of CDM.

3.7.2. Concept of Theory and Theorizing in Grounded Theory Methodology

The theory generated through Grounded Theory Methodology (GTM) is not a full conceptual description of a 'substantive area'[14]. Instead, it is about a concept which is the 'core variable' and its related concepts that account for the occurrence of the subject of inquiry (Glaser, 2001, pg. 199). The concepts generated through GTM represent social patterns identified in the research data and are an abstraction of time, place, and people (Glaser 2002a). In classical GTM, a theory is a set of concepts which are integrated through relationships in the form of a theoretical framework to explain the occurrence of the matter of interest (Glaser and Holton 2004a). This entails patterning, interpreting and generalizing through abstraction, all of which is done systematically.

Both Glaser and Strauss, the creators of GTM, recommend its use to stimulate theory development by staying within the general guidelines offered by them but at the same time adapting the procedures and techniques to suit the requirements of individual studies (Glaser and Strauss 1967; Strauss 1987). Hence, the application of GTM tenets can vary and it is necessary to specify the chosen procedure and how it was employed in a research undertaking (Ambert et al. 1995; Babchuk 1996). Regardless of the ambiguity surrounding the application of GTM, there are certain principles concurred by its various proponents (Glaser and Strauss 1967; Strauss and Corbin 1990; Schatzman 1991; Clarke 2005; Charmaz 2006). They are as follows:

[14] Area of inquiry (Glaser & Strauss, 1967, pg. 32)

Generation of new theory rather than verifying existing theory.

Continuous interplay between data collection, analysis, and theory development.

Data analysis primarily though coding.

Theory generation in the form of relationships between concepts generated through coding.

Analytical process comprises Constant Comparison and Theoretical Sampling.

Backbone of theory generated is a central concept known as 'core category'.

The specific procedures for implementing GTM then follow on from these basic principles.

3.7.3. Applying Guiding Principles of Grounded Theory Methodology

GTM places emphasis on the continuous interplay between data collection, analysis, and conceptualization. This process includes gathering data, transcribing collected data, labelling data to derive codes, relating codes to derive categories, drawing relationships between categories, deriving core category, strengthening core category, saturating codes and categories, and written records of the data abstraction from the analysis in the form of 'memos'. These activities are not undertaken in a linear manner and are interchangeable.

Figure 3- 13 Presents an overview of the key elements of GTM and the process of theory development through this methodology. The following sections describe how the above depicted process has been implemented in this research.

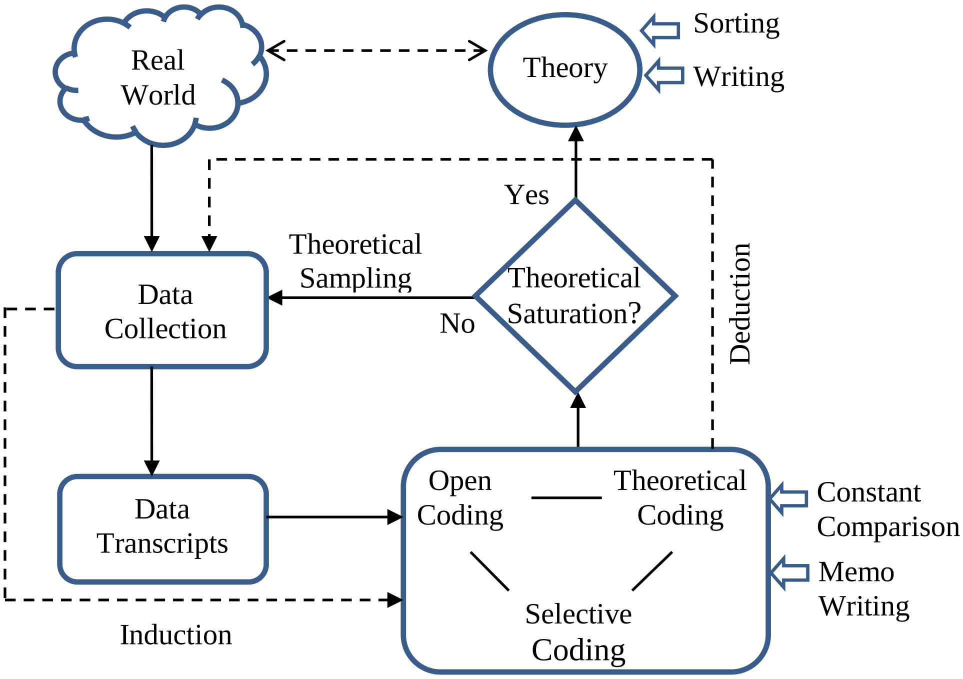

Figure 3- 13: Diagrammatic Representation of Theory Generation Process in Grounded Theory Methodology

3.7.3.1. Identification of Substantive Area, Research Question and Literature Review

Theory generation through GTM commences with the identification of the 'substantive area'. This is the subject of inquiry about which theory development takes place. Glaser (1967, 1978, 2004) does not provide any criteria for determining the 'substantive area', but states that it should be a specific area of investigation. In this research, the 'substantive area' is collaborative decision making.

According to Glaser (1967, 1978), the research founded on GTM should not start with a precise question, problem statement, or hypothesis. Just an identification of the topic of study will be sufficient. This is required to avoid predisposed focus of data collection, to enable discovery of "what is going on and why" in the studied area, and to allow the problem and question to emerge from the data (Glaser 1992; Glaser 2001).

This research, however, commences with the following research question:

> ***How do people in a complex heterogeneous working environment make decisions collaboratively?***

The above question is conceived from the literature reviewed at the onset of the research and is formulated to be broad and open enough to allow the flexibility required for exploring the occurrence of CDM in real world complex work settings. This is a slight deviation from the recommended guideline for employing GTM. Glaser (1978, 2001) does not prescribe reading literature in the relevant field before the theory seems "sufficiently grounded and developed" in order to prevent prejudice or developing preconceived notions before entering the field. Nevertheless, a key process of doctoral studies is undertaking a critical review of literature in order to understand the subject of inquiry, elicit gaps in existing knowledge, identify problems to be addressed and generate the research question. Hence, prior literature was reviewed keeping with the traditional approach to a research undertaking. Based on this, the area of interest was identified as collaborative decision making and the corresponding research question was formulated. However, the reviewed literature was not used to inform data collection, but was employed in the capacity to sensitize and interpret the data collected. As data analysis progressed more specific questions were generated. Moreover, this research did not commence as a Grounded Theory study. Instead, the problem statement and research question were first drawn from the literature reviewed. Subsequently, GTM was chosen as an appropriate methodology for the purpose of this research.

3.7.3.2. Theoretical Sampling

In GTM, sampling is based on concepts emerging from the data during analysis rather than representative individuals. Sampling is selected by potential for generating theory and deepening understanding[15]. Sampling in GTM is Theoretical Sampling (Glaser 1978; Goulding 1999; Glaser 2001; McCallin 2003). Glaser (1967, pg. 45) describes the process of Theoretical Sampling as follows:

> *Theoretical sampling is the process of data collection for generating theory whereby the analyst jointly collects, codes, and analyzes his data and decides what data to collect next and where to find them, in order to develop his theory as it emerges. This process of data collection is controlled by the emerging theory.*

The theory emerging from the data directs who and what to study and subequent questions to be addressed during data collection. However, before sampling, decisions have to be made about where the subject of interest can be found and data can be collected, who will be studied and how will data collection take place (Glaser 1992) as discussed earlier in this chapter. Theoretical Sampling then begins at the next stage of data collection (Coyne 1997).

In this study, for example, the aim of the first visit to the field site was to gain an understanding of the work environment and to identify relevant work activities and social processes. The study commenced in the Control Tower of the airport. It was found that the work of personnel in this work unit was tightly integrated with each other's within the work unit as well as with other work units. The field studies first focused on the collaboration between personnel involved in the airport ATC operations.

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[15] Sampling in GTM based on interplay between induction and deduction as data collection and analysis takes place in tandem. GT is inductive because relevant theoretical concepts are allowed to emerge from data during the coding process instead of starting with a hypothesis or preconceived notion. The deductive nature is best described in Glaser's words as "deductive work in grounded theory is used to derive from initial codes as to where to go next in order to sample for more data to generate the theory" (Glaser 1978). This is a cyclic process in which the researcher goes back and forth between induction and deduction.

3.7.3.3. Coding and Conceptualization

Data collected from the field studies are conceptualized through 'coding', which is the foundation of Grounded Theory development. A 'code' is the label given to a concept identified in the data and can refer to words, phrases, sentences, or incidents. It presents an abstraction of the data collected and acts as the bridge between raw data and theory generated (G. B. Glaser & J. Holton, 2004). In GTM, coding is conducted in phases and the procedure varies depending on which school of GTM is being followed. In classical GTM, which is employed in this research, Glaser (1967, 1978) prescribes coding through three phases, namely - Substantive, Theoretical and Selective Coding. These phases are not linear and work in conjunction with each other.

Substantive coding or 'open coding' is the first step in data analysis. In classical GTM, it is carried out by breaking down data into distinct units of meaning and conceptually labelling them (Goulding 1999). In this research, data transcripts were read line-by-line, divided into smaller sections (which can be words, phrases or incidents), analyzed, and labels assigned to the identified concepts as 'codes'. Also, 'open coding' was undertaken by asking the neutral questions given below as prescribed by Glaser (Glaser 1978, 1992; Glaser and Holton 2004).

What is the data a study of?
What category or what property of what category does this incident indicate?
What is actually happening in the data?
What is the main concern being faced by the participants?
What accounts for the continual resolving of this concern?

The questions helped identify the 'core variable' which was the research focus and subsequently that of the emergent theory. An illustration of open coding of an interview transcript is presented in

Appendix 6. This was done using the Atlast.ti software as illustrated in Appendix 5. Also, the concepts and codes were compared wherever possible in the course of analyzing the data to draw similarities and differences between them. As ‘open coding’ progressed categories were developed from abstracting patterns of similar concepts represented by the codes and attributing a conceptual name to it (Appendix 7). In addition, the properties and dimensions of categories were delineated from the codes to enrich their definition and meaning. Appendix 12 provides the complete list of categories generated during data analysis which formulate the theory of CDM presented in this thesis.

Then the developed categories were related to be integrated into theory (B. G Glaser, 1978). This forms the Theoretical Coding phase of data abstraction. In this study, as category development progressed, the relationships between categories were determined in order to generate conceptual ideas. The relationship between categories were drawn by employing the ‘theoretical coding families’ recommended by Glaser (1978). There are eighteen ‘coding families’ which help sensitize analysis to the array of behavioral patterns in the data. However, the coding families chosen to draw relationships between categories is driven by the data. The first of these families and the one most utilized for Theoretical Coding in this study is the “Six Cs”- Causes, Contexts, Contingencies, Consequences, Covariance and Conditions (Figure 3-14).

Context	ambiance in which the phenomenon occurred
Cause	reason, source or explanation for the occurrence of the phenomenon
Condition	an intervening variable
Contingency	a moderating variable
Covariance	correlation where one category changes with another
Consequence	anticipated or unanticipated result of the phenomenon and is dependent on “Cause”
Strategy	a conscious act to manoeuvre elements associated with the phenomenon
Dimension	parts of the phenomenon, dividing the whole into parts
Type	a variation of the whole phenomenon
Degree	the relative position of the phenomenon in a continuum
Interactive	mutual effects between the phenomenon and another variable where the temporality of the interaction is not taken into account
Mainline	societal aspects of the work process such as the social organization, social order, social interactions

Figure 3- 14 : Coding Families of Glaser (1978) Employed during Theoretical Coding

Apart from the six Cs, other ‘theoretical coding families’ were also included as depicted in Figure 3- 14. Table 3- 1 exhibits the relationships generated between categories in this study and the associated coding families.

Table 3- 1 : Relationship between Categories drawn during Theoretical Coding and their Coding Families

Coding Family	Relationship
SIX Cs	
CONTEXT	is-context-for
CAUSE	is-cause-of is-trigger-for is-source-of is-causal-condition-for
CONDITION	is- intervening-condition-for
CONTINGENCY	has-effect-on, leads-to, is-dependent-on
COVARIANCE	is- intervening-condition-for
CONSEQUENCE	has-effect-on leads-to is-dependent-on
STRATEGY	is-maneuver-for is-managed-by is-mechanism-for is-means-of is-strategy-for is-through
TYPE	is-a is-form-of is-type-of
DIMENSION	is-aspect-of is-property-of
DEGREE	is-level-of
INTERACTIVE	is-reciprocal-to
MAINLINE	is-stratification-of

The core variable which is the main theme arising from the data is identified during the Substantive and Theoretical coding. This 'core category' explains the occurrence of the studied phenomenon (Goulding 1999). The criteria for judging the 'core category is prescribed by Glaser (1978) as: centrality, frequent recurrence, meaningful and easy connection to other categories, and the clear implication for formal theory. Once the 'core category' is selected, further data collection and analysis is delimited to the ‘core category’ which forms the Selective Coding phase. Hence, the data collection and analysis focussed on the ‘core category’ which led to the theory of CDM being developed by including only categories and theoretical connections related to the ‘core category’ (Figure 3- 15).

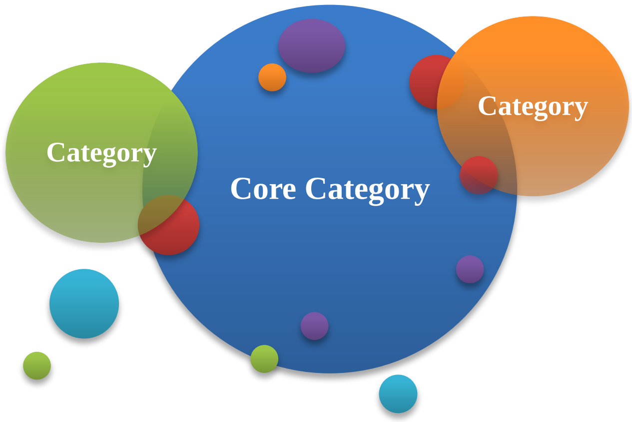


Figure 3- 15 : Diagrammatic Representation of Delimiting Categories and Theoretical Connections to the Core Category during Selective Coding

The question driving the search for the ‘core category’ during Substantive and Theoretical coding was:

> *What is the central concept explaining the occurrence of collaborative decision making during task performance?*

This led to the identification of *managing interdependencies* as the main concept accounting for CDM and hence was categorized as the ‘core category’. Then, further data collection and analysis was delimited to this ‘core category’ and addressed questions such as:

> *What is the nature of dependencies arising between work activities?*
>
> *How do personnel across different work units manage interdependencies between their work activities?*
>
> *What factors affect managing interdependencies?*
>
> *What consequence does managing interdependencies have to collaborative decision making?*

The process ultimately resulted in delimiting six theoretical constructs for conceptualizing the theory of CDM. The relationship between these constructs is drawn based on the Six Cs Theoretical Coding family (B. G Glaser, 1978) and described in detail in subsequent chapters.

3.7.3.4. Constant Comparative Analysis

The aim of coding data in GTM is to identify and conceptualize underlying patterns about what is going on in the data (B. G. Glaser, 2001). This is achieved through the process of constant comparison in all three coding phases. Constant comparison during Open Coding took place between the data, codes and categories. As new data were obtained they were compared with existing findings and codes. The data that were not similar to existing findings was given new conceptual labels or 'codes'. These were compared with each other to look for similarities and differences with the former bring grouped into categories. During Theoretical coding, categories were compared to identify relationships and formulate higher level concepts. Another important role played by the process of constant comparison is in delimiting data collection and analysis during Selective Coding. It facilitates identification when saturation is reached during coding. In this study, data collection was ceased when the process of constant comparison did not yield new properties of the 'core category' and theoretical saturation was reached.

3.7.3.5. Theoretical Sensitivity

Theoretical sensitivity refers to the ability to relate concepts generated from the data analysis to theory generation (Glaser 1978; Glaser 2002a). In this study, the neutral questions put forth during Substantive coding and the 'theoretical coding families' employed during Theoretical coding helped foster theoretical sensitivity as prescribed in the classical GTM procedure (B. G. Glaser & J. Holton, 2004). Theoretical sensitivity was also established through reading literature. However, one of the tenets of classical GTM is to avoid reading extensive literature before the emergence of 'core category' and associated theory.

Nonetheless, the literature review was undertaken before the study commenced. The knowledge gained from the literature review facilitated in making sense of findings in the data and to focus the analysis.

3.7.3.6. Theoretical Memoing

Theoretical Memos are written records of the abstraction achieved during data analysis, which could be reflections, the meanings ascribed, theoretical explanations of relationships between concepts, and ideas on categories. ‘Memo’ writing is an important aspect of theory generation which takes place throughout the theory development process right from its inception to the end. The memos written for the purpose of this research captured the interpretation of observation and description of findings from the field, as well as the meanings and relationships between codes and categories (Appendix 10). The memos were recorded in Atlast.ti software (Appendix 9) and on paper (Appendix 16).

3.7.3.7. Theoretical Sorting

Sorting in GTM is conceptual and is an important aspect of developing and presenting the theoretical framework. Theoretical Sorting helps to maintain the theory at the conceptual level while presenting it and prevents regression to description of data. In this study, sorting commenced with the identification of the ‘core category’ and continued until further data collection and analysis did not add new concepts to the theory. Sorting was facilitated by the ‘theoretical coding families’ prescribed by Glaser (1978). In particular, the ‘Six Cs’ coding family was employed to delimit the emerging theoretical framework. Sorting was undertaken to fit the concepts and theoretical constructs by constantly questioning and comparing each of them to the emerging outline of the theory of CDM. Furthermore, sorting was facilitated through modelling in Atlast.i software and diagrams on paper.

3.8. METHODOLOGICAL CONSIDERATIONS

3.8.1. Role of the Researcher

The researcher is the principal device for collecting data and this includes his/her interpretation of the data collected. Hence, one issue to be addressed here is the plausible researcher bias affecting the credibility of the investigation. I embarked on this investigation after having identified the area of interest and conducted a literature review in relevant subjects in order to arrive upon the research question to be addressed. This did not result in suggesting a hypothesis, but helped to identify gaps in the area of interest. Moreover, I did not have any prior knowledge or experience in the field of investigation that would generate pre-conceived views and pre-formulated judgement about the area being investigated. Considering the safety critical nature of the studied environment, I could not be a participant in the work process. Consequently, observational studies were conducted as a novice and an outsider. Therefore the data collected were to a large extent perceived from the point of view of the studied personnel, and interpretations made were verified with them. In addition, employing concurrent protocol by presenting non-leading probes to the interviewed personnel was beneficial in avoiding bias. Also, they were briefed on my role in their workplace and the use of data collected from the field which may have made them forthcoming in their discussions.

3.8.2. Ethical Considerations

Four ethical issues were considered while conducting the field studies. The first one was informing the participants clearly about the nature of the investigation and obtaining their consent to being observed and interviewed. When permission was obtained from National Air Traffic Services (NATS) to conduct the field studies, the respective managers and personnel were informed by the airport authority. In addition, before commencing the studies, flyers (Appendix 11) were placed in the Control Tower and Operations Centre, which included information about the use and implications of the information obtained from them through the studies conducted. The personnel were also verbally briefed who confirmed their volunteered participation.

Secondly, the anonymity of personnel was maintained by: 1) ensuring confidentiality of data obtained from interviews and observation, 2) identifying interviewees and studied personnel by using abbreviations of their role instead of their names, and 3) ensuring their faces are not recognizable in the photographs taken from the field study site. Thirdly, ensuring the participant was not physically or mentally harmed during the studies. Since, ATC personnel were interviewed and observed as they performed their work, I had to be careful and considerate to not interfere and hinder their work performance, particularly because of the safety-critical nature of the work environment. Lastly, they were not exploited for personal gain and their contribution to this research is acknowledged.

3.9. SUMMARY

In summary, this chapter has described the methodological approach, the domain of study and the procedures employed for data collection and analysis. The chapter presents the rationale for taking a qualitative approach and the choice of Grounded Theory Methodology to develop the theory of collaborative decision making. The Air Traffic Control work setting in which the field studies were undertaken and the techniques exercised to gather required data have been delineated. The methodological considerations undertaken to maintain credibility of data collection in terms of avoiding researcher bias and conducting the studies ethically are also outlined. Data analysis undertaken through the employment of the procedures prescribed in classical GTM has been included. The following three chapters explain the findings of this research by describing the codes, categories and relationships emerging from the data analysis which formulate the theory of collaborative decision making.

CHAPTER 4

CONCEPTUAL FRAMEWORK OF COLLABORATIVE DECISION MAKING: A SYNOPSIS

4.1. INTRODUCTION

An overview of the conceptual framework of Collaborative Decision Making (CDM) developed through this research is presented here. It portrays CDM taking place during everyday work performance in the cooperative arrangement of complex work settings as a process of managing interdependencies. The findings on which such a depiction is based are explained through a theoretical framework emerging from the application of Grounded Theory Methodology (GTM). This is structured using the 'Six Cs' theoretical coding family prescribed by Glaser (1978) which was described in the previous chapter. The 'Six C's' focus on the 'core category' which in this study emerged to be *managing interdependencies*. Briefly, the 'Six Cs' include Cause, Context, Contingency, Consequence, Covariance, and Condition. The key constructs of the theory of CDM are structured (Figure 4- 1) in this thesis by adapting the model of 'Six Cs' presented by Glaser (1978, pg. 74).

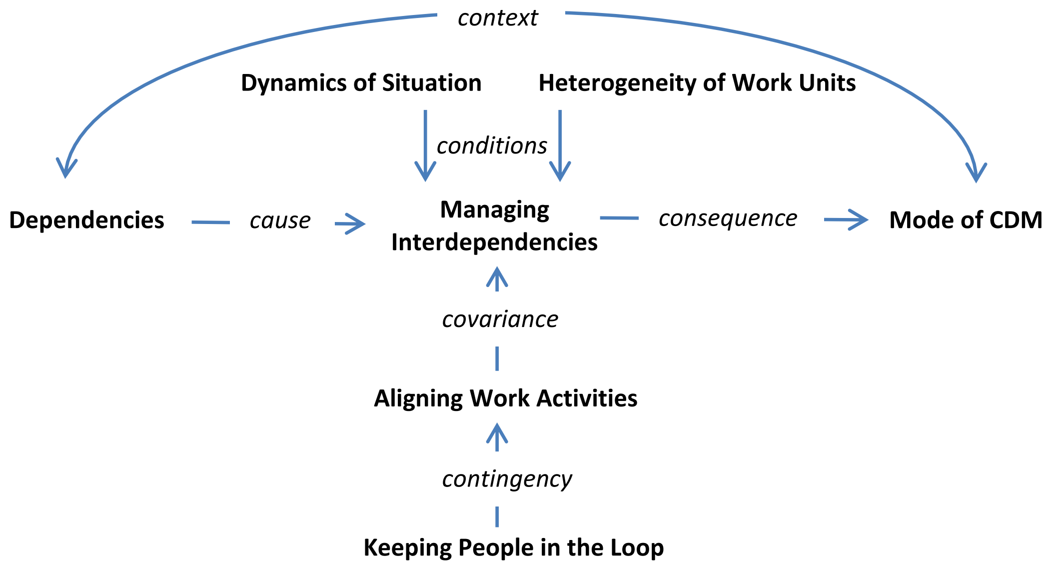


Figure 4- 1 : Six Cs of Core Category

A synopsis of the main findings and associated categories developed during data analysis that formulate the framework are presented here. A detailed explanation of this is given in chapters 5 and 6 supplemented with the data obtained from the studies conducted in this research. The contextual and causal conditions are described in detail in chapter 5. The emergence of the core category as well as the covariance, contingency and consequence components of the theoretical framework are explicated in chapter 6.

4.2. Collaborative Decision Making in the Cooperative Arrangement of Complex Work Setting

The studies conducted in this research indicate that CDM in a real world complex work setting occurs in a cooperative arrangement and in the course of performing tasks. Hence, it is influenced by the characteristics of this arrangement and is aimed at fulfilling the requirements arising during task performance. Two fundamental characteristics of the cooperative arrangement are work distribution and interconnections between work activities. The former leads to decision making being distributed across personnel undertaking tasks whereas the latter causes the need for their involvement during decision making. Thus, undertaking CDM in this setting involves managing the distribution as well as the interconnections in decision making. Additionally, the environment of complex work settings in the real world is dynamic. Hence, the way CDM is undertaken needs to be adapted to the constantly changing conditions. The conceptual framework of CDM developed through this research explains how this is achieved by personnel during everyday work activities. For the purpose of this thesis, a decision is considered to be the pertinent action selected for fulfilling the requirements arising during task performance, decision making is the process through which this is undertaken, and CDM is the involvement of multiple personnel in this process.

4.3. CONDITIONS INFLUENCING COLLABORATIVE DECISION MAKING

Three conditions which influence the occurrence of CDM were identified in the studied setting to be *dynamics of situation*, *heterogeneity of work units*, and *dependencies* between work activities (Figure 4- 1). The first two are classified as contextual[16] conditions as they present possibilities and constraints in carrying out the actions and interactions involved in decision making. The third is considered to be a causal condition as it was found to create the need for personnel to undertake decision making in collaboration with others performing the task. Whilst these conditions generally affect work activities involved in task performance, they are addressed here with respect to the influence they bear on decision making. The findings emerging from

[16] In this thesis, context is considered to be features of the work setting which play a role in undertaking social actions and interactions.

this study in relation to these three conditions and their effect on CDM are briefly described below. A detailed explanation of the same is presented in chapter 5.

The dynamic nature of work environment in a real world setting gives rise to constantly changing conditions, which is captured during data analysis in the category *dynamics of situation*[17]. This category represents the changing nature of situation of task performance and the type of situation emerging. Based on the criticality and predictability of occurrences in the work environment, personnel were found to consider situations arising during task performance as *typical* and *atypical* (Figure 4- 2). The former represents occurrences which take place in accordance with procedure and plan. In these situations, activities of task performance including decision making can be carried out as expected. Even if issues arise, they can be foreseen and personnel are prepared to address them. These are situations that can be *anticipated* to occur during task performance. Nevertheless, they tend to deviate from *typical* to *atypical* when occurrences in the work environment do not take place as planned, arise unexpectedly and cause issues which hinder task performance. Additionally, personnel consider both these situations to be *critical* and *non-critical* based on the degree of detrimental effect they have on human and fiscal wellbeing.

The findings show that these types of situations present possibilities and constraints in undertaking decision making during task performance. In particular, the *dynamics of situation* was found to affect CDM by influencing the temporality, intensity, structure and flexibility of interaction in decision making. Also, the actions and interactions employed by personnel to participate in decision making was found to alter with the type of situation.

[17] 'Situation' is characterised in this study by taking into account how personnel in the studied work setting define and respond to it. This helps to comprehend how they behave in a particular situation during task performance.

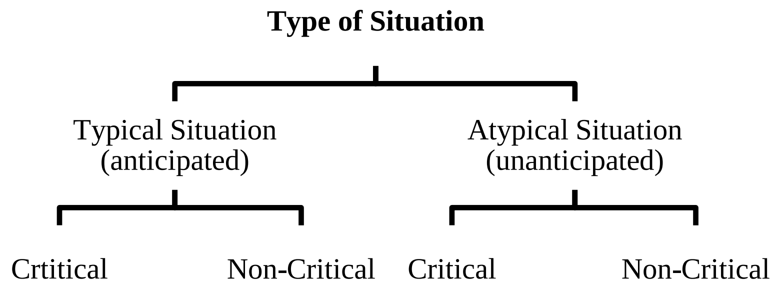


Figure 4- 2 Classification of Situation Types

Another contextual condition affecting CDM is the *heterogeneity of work units*. In the cooperative work arrangement, task performance requires involvement of multiple personnel from various work units that are distributed in the work setting. This category depicts differences between the work units involved in undertaking the task. Considering that the work units serve diverse purposes, personnel functioning in them have distinct expertise, roles and responsibilities as well as differing requirements. Also, based on the work unit they are operating from, personnel have access to certain viewpoint and information in the work setting. These differences influence their participation in CDM.

In this study, the differences between work units are categorised as *dimensions of heterogeneity* (Figure 4- 3) which include *spatio-temporal*, *procedural*, *resource*, and *situational heterogeneity*. *Spatio-temporal heterogeneity* depicts the difference in physical location of work units and the associated temporal variation. In a complex work setting, the work units are distributed across physical space. Some units are co-located whereas others are vastly distributed and this influences how personnel participate in decision making. In the studied setting, although some work units were co-located, personnel did not have possibility for direct face-to-face interaction and it was limited to technology mediation. Personnel communicated verbally over the telephone or non-verbally by making changes to information representation and dissemination artefacts.

The *procedural heterogeneity* represents the difference in procedural location in the work process at which personnel are involved. The work units serve distinct purposes in undertaking a task. Hence, personnel operating from them are responsible for different aspects of task performance and consequently located at different points in the work process. This influences their participation in decision making with respect to the information they can provide, actions they can perform and decisions they can make. Thus, when personnel come together during CDM they make distinct contributions. Also, personnel involved in decision making can have varying goals and requirements based on the procedural location of their work unit which needs to be resolved.

Resource heterogeneity depicts the difference in facilities available in the work units for undertaking CDM. In this study, it is mainly addressed with respect to technological artefacts aiding awareness, communication and coordination. In particular, the findings reveal that personnel involved in decision making employ different means and mechanisms to interact with others across work units. For instance, coordination of activities required for decision making is organized between personnel operating from certain work units verbally over the telephone whereas that between others is mediated through technology.

Situational heterogeneity indicates the difference between the type of situation encountered at different work units during task performance. The findings show that based on their work unit, personnel involved in decision making can be functioning in different situation types. For instance, the situation type at one work unit can be *typical* whereas that in another can be *atypical*. This was found to influence the time available for personnel to undertake decision making in collaboration with others. Thus, when personnel come together to undertake CDM they are operating in varying conditions and this influences their contribution.

Chapter 5 explains in detail the emergence of these *dimensions of heterogeneity* and how they work in conjunction to influence the actions and interactions of personnel participating in decision making. Having briefly described the contextual conditions influencing CDM, the causal condition identified in this research is presented next.

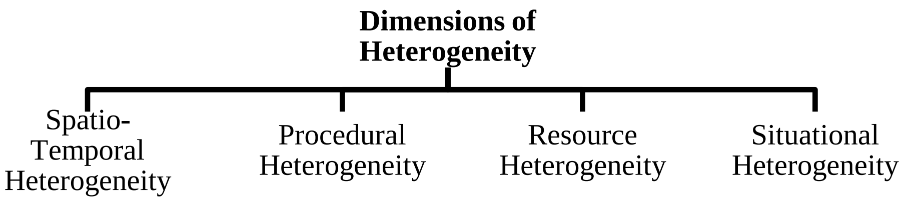


Figure 4- 3 : Dimensions of Heterogeneity

The findings indicate that interconnections between work activities in the cooperative arrangement of a complex work setting manifest in the form of *dependencies* in task performance. During decision making, personnel are found to be dependent on each other for obtaining required information, performing necessary actions and making related decisions. The relational orientation emanating from the *dependencies* need to be managed which creates the need for collaboration in decision making. Hence, *dependencies* are portrayed as the causal condition for undertaking CDM in the theoretical framework developed in this study.

Besides causing the need for personnel to come together to undertake decision making, *dependencies* were also found to structure the collaboration involved. Different types of *dependencies* were identified to arise based on the situation, procedure to be followed, information requirements to be fulfilled, and temporality involved in carrying out task performance activities. Consequently, the types of dependencies arising during decision making are categorised here as *situational*, *procedural*, *information*, and *temporal dependency* (Figure 4- 4). These work in conjunction and provide a structure for managing the interconnections involved in decision making by organizing who does what, where, when and how across the different work units. This is explained in detail in chapter 5 with a brief description of the types of dependencies being presented here.

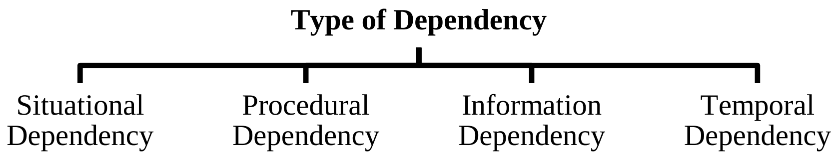


Figure 4- 4 : Types of Dependency Configurations

The first, *situational dependency,* depicts the *dependencies* between personnel's work activities brought about by the situation of task performance. The findings indicate that the type of situation creates certain *dependencies* with respect to who needs to be involved and how they contribute to decision making. For instance, in a *typical non-critical* situation, decision making requires personnel from certain work units to come together to provide required information, perform necessary actions and make related decisions. However, in an *atypical critical* situation, making the same decision requires either the involvement of additional personnel or limits who is involved in decision making based on the contribution required from them. This type of dependency was found to influence CDM with respect to structuring who is involved, their contribution, as well as the intensity and flexibility of interaction taking place between them.

The second, *procedural dependency* depicts the *dependencies* raised by the procedures laid down by the organization for carrying out task performance. In the cooperative work arrangement, the procedure to be followed reflects the distribution of work activities between personnel belonging to different units and their interrelationships during decision making. This was found to configure the 'depender-depended' relationship between personnel, that is who is dependent on whom for what during decision making. For instance, when multiple personnel participate in decision making, the *procedural dependency* structures who is dependent on whom for required information, action performance and making related decisions. This helps set expectations, possibilities and limitations in undertaking CDM.

The third, *information dependency* represents the *dependencies* raised by the information requirements arising during decision making. Since personnel involved in task performance belong to different work units, they possess only partial and provincial access to information, knowledge of occurrences in the work setting and viewpoints with respect to the boundaries of their work units. Hence, during decision making they are dependent on each other for information which is beyond the realms of their access. This type of dependency influences CDM by structuring information sharing between personnel involved in decision making.

The fourth, *temporal dependency* depicts the *dependencies* arising out of the temporality involved in task performance. The findings indicate that not all personnel undertaking the task come together at the same time during decision making. Instead, they are dependent on each other for contributions at particular instances in time. Personnel's participation in decision making is structured by the dependency in the timing of their work activities. For instance, the findings show that personnel need to be obtain information from others at a specific point in time in order to make informed decisions or request others to perform certain actions at a particular point in time to aid decision making.

These four types work in conjunction and present a configuration of dependencies which structures participation in decision making, thereby influencing the way CDM is undertaken during task performance. Thus, the findings of this research show that in the cooperative arrangement of a complex work setting *dependencies* cause the need for personnel to come together to undertake CDM. It also reveals that the structure of

CDM is influenced by the *dependencies* in decision making arising during task performance. These form two key findings of this research.

4.4. Collaborative Decision Making as a Process of Managing Interdependencies

The conceptual framework developed through this research depicts CDM as a process of managing interdependencies. As mentioned, the findings indicate that personnel come together during decision making as they are dependent on each other for obtaining required information, performing necessary actions and making related decisions. Hence, when they participate in CDM they are essentially found to be managing the dependencies involved in decision making. During data analysis, *managing interdependencies* emerged as a 'core category' since it accounts for the contributions made by personnel during CDM and their social behaviour. Hence, in the framework of CDM presented in this thesis *managing interdependencies* is placed as the central construct and other categories are related to this through the 'Six Cs' theoretical coding family prescribed by Glaser (1978). The following section briefly describes how personnel in the studied setting undertake CDM in the process of managing the interdependencies involved in decision making. This is explained in detail in chapter 6.

4.5. Managing Interdependencies by Aligning Work Activities and Keeping People in the Loop

In this study, *managing interdependencies* depicts the process of fulfilling the requirements brought forth by the *dependencies* arising during decision making. The findings indicate that this involves *Aligning Work Activities* (AWA) of personnel by synchronizing their actions, decision making, and perception (Figure 4- 5). These three modes of synchronizing are not mutually exclusive and work in conjunction. Through this the research shows that articulating CDM in the cooperative arrangement of complex work settings is a complex activity.

Two key relationships of AWA emerge from the data analysis. Firstly, AWA is covariant to the configuration of *dependencies* arising during decision making as the former occurs in relation to the latter. Secondly, AWA is contingent upon *Keeping People in the Loop* (KPIL).

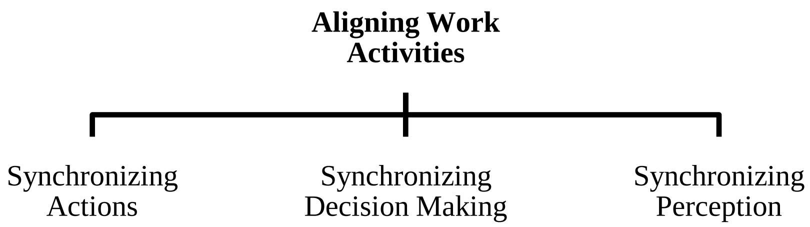


Figure 4- 5 : Mechanisms for Aligning Work Activities

In this study, KPIL is considered to be the process of sharing information as well as involving others in decision making through various communication acts and modes of interaction. KPIL was found to be a key factor for AWA because without "being in the loop" personnel will not be able to perform the required synchronization. The findings indicate that KPIL takes place through various communication acts which are implemented in two modes: *anticipatory* and *reactionary interactions*

(Figure 4- 6). The former takes place in preparation for making decisions, whilst the latter takes place in response to decisions taken by others during task performance. These interactions give a sense of each other's planned actions, requirements to be fulfilled, and constraints in AWA across different work units. In addition, the data show that KPIL relies on the *fitness of information* exchanged during task performance. This is determined by the form, medium and timing of information transfer between personnel undertaking the task (Figure 4- 6). The use of standard and non-standard mechanisms, verbal and non-verbal means, and timing of information exchange present possibilities and constraints in establishing the understanding required for AWA.

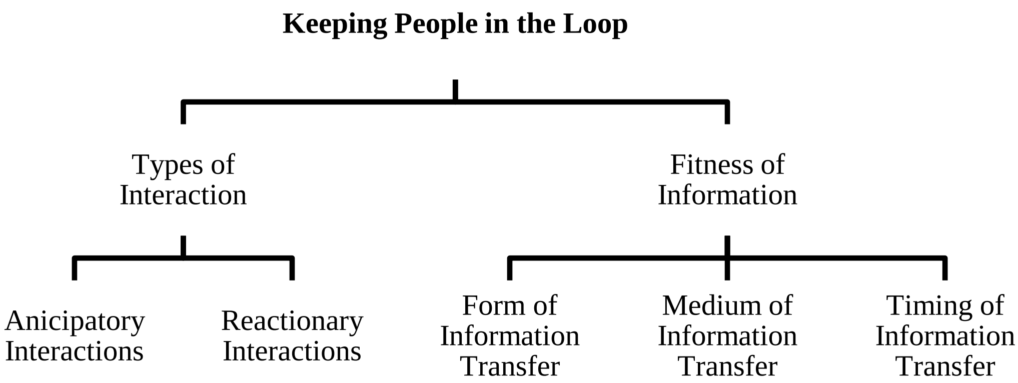


Figure 4- 6 : Mechanisms for Keeping People in the Loop

4.6. MODES OF UNDERTAKING COLLABORATIVE DECISION MAKING

Four modes of undertaking CDM transpire from the way personnel manage the configuration of *dependencies* arising during task performance. They are: *sequential*, *mutually-consented*, *manipulative*, and *emergent decision making* (Figure 4- 7). In the first mode, personnel participate in CDM by making decisions in response to the actions and decisions taken by others. Deicsions are made individually but becomes a collaborative act through such a correlation. For instance, due to the distribution of work performance in the cooperative arrangement, undertaking decision making involves reliance on others for performing required actions. When a request is made for the required action, further decisions will need to be made by those performing the action with respect to the request thus leading to CDM being undertaken in sequential mode.

Alternatively, the *mutually-consented* mode of CDM occurs when personnel make joint decisions. Data analysis shows that this takes place explicitly through verbal interaction. This was also found to take place tacitly by personnel demonstrating their acknowledgement to decision made by others by performing the consequential activities. For instance, during task performance personnel can make inferences about the decisions made by others based on their behaviour. Due to the interconnections between their activities in the cooperative arrangement, decisions made by personnel will requires others to perform certain related activities. When they do so without consultation with each other, they display their agreement to decision made tacitly and the decision attains mutual agreement.

In the third mode of CDM personnel tend to manipulate decisions made by others during task performance to fulfil their own requirements. The data analysis reveals that this takes place by personnel influencing the context on which decision making rests. For instance, they were found to manipulate the information used by others to inform their decision making. Thus, influencing their decisions and indirectly participating in decision making.

Furthermore, undertaking CDM is an emergent activity in the varying conditions of the dynamic environment in a complex work setting. Participation and contribution of personnel in decision making is found to change with the type of situation emerging during task performance.

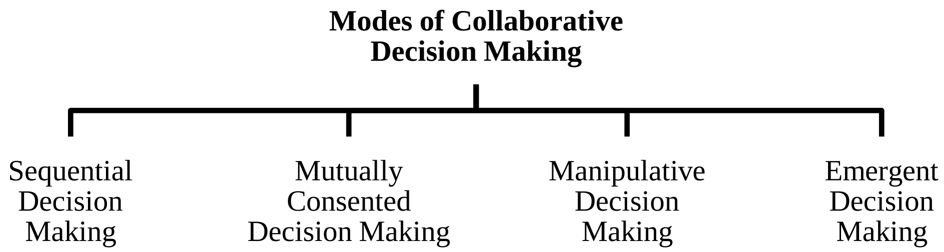


Figure 4- 7 : Modes of Collaborative Decision Making Activity

4.7. CHAPTER SUMMARY

The chapter briefly depicts the conceptual framework of CDM constructed in this research through GTM. It puts forth a new perspective on the way personnel make decisions collaboratively in a real world complex work setting. The main categories and their relationships in the framework show that CDM is fundamentally an activity of managing interdependencies. This reveals how collaboration in decision making is structured by the interdependencies arising during task performance. Also, the embedded nature of decision making in everyday work activities is brought forth. The following two chapters will explain the emergence of the theoretical constructs presented here. Chapter 5 describes the context and causal components in the theoretical framework whilst chapter 6 presents the core category, covariance, contingency, and consequence components. Appendix 12 provides the complete list of codes and categories used to develop the conceptual framework of CDM presented in this thesis.

CHAPTER 5

CONDITIONS INFLUENCING COLLABORATIVE DECISION MAKING IN COMPLEX WORK SETTINGS

5.1. INTRODUCTION

This chapter explains two of the 'Six Cs' forming the theory of CDM. The conditions affecting CDM in the cooperative work arrangement of the studied complex work settings are described here. These have been classified as contextual and causal conditions in the conceptual framework depicted in the previous chapter. The former includes *dynamics of situation* and *heterogeneity of work units*. These are considered as contextual conditions as they present possibilities and constraints in undertaking CDM. The latter emerges from the data to be *dependencies* between work activities of personnel as it was found to create the need for multiple personnel to be involved in decision making during task performance. The chapter explains the influence these conditions bear on undertaking CDM in a complex work setting. The emergence of these three theoretical constructs is described here through the codes and categories derived from the data analysis founded on Grounded Theory Methodology (GTM).

In this chapter and next, the data used to illustrate the derived concepts are obtained from the field studies conducted in the airport air traffic control work setting. Transcripts of interviews and observation data are presented here along with the codes, categories and their relationships developed during data analysis. Abbreviations are used to represent personnel in the studied setting. These include Tower Controller (TC), Ground Controller (GC), Management (M), and Approach Controller (AC). The researcher collecting the data is represented as the Interviewer (I).

5.2. CONTEXTUAL CONDITIONS

In order to comprehend how CDM is carried out by personnel during everyday work activities, it is important to understand the context in which it occurs and the influencing conditions. In the studied complex work setting, decision making takes place in constantly changing conditions and requires involvement of personnel from multiple work units. This is conceptualized during data analysis as *dynamics of situation* and *heterogeneity of work units*, respectively. These two conditions influence the way CDM is undertaken by presenting possibilities and constraints in performing actions and interactions involved in decision making. Hence, they are considered to be contextual conditions (Figure 4- 1).

5.2.1. Dynamics of Situation

The data indicate that there are two main types of situations arising during task performance, which are categorized as *typical* and *atypical*. These form properties of the theoretical construct labelled *dynamics of situation* (Figure 5- 1). The situations differ in terms of predictability and criticality. On this basis these are further coded as *anticipated*, *unanticipated*, *critical*, and *non-critical*. Such distinctions are elicited from the views presented by the interviewees in the data collected. In the following section, the different types of situations are firstly illustrated followed by how each one of them is handled and its influence on undertaking CDM.

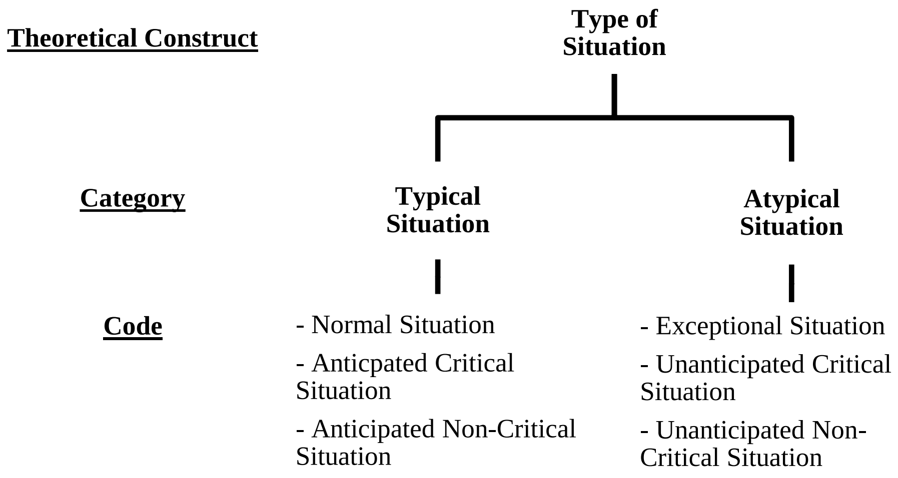


Figure 5- 1 : Codes and Categories of Theoretical Construct: Type of Situation

A typical situation is one that arises regularly and can be *anticipated* to occur during task performance. It represents occurrences in the work environment which take place as planned and as per the procedure. Work activities can be carried out as expected and typically there are no issues arising in these situations. Even if they do personnel can foresee them and be prepared to address them accordingly. In addition, *typical situations* consist of both *critical* and *non-critical* conditions. The former has a detrimental effect on human and physical wellbeing whilst the latter does not.

An example of the above is depicted in the management of air traffic arriving into and departing from the studied single runway airport. A *typical situation* which is *anticipated* and *non-critical* is alternating between one landing and one departing aircraft on the Runway. The following transcript of an interview with the Tower Controller (TC) illustrates this.

TC *So the only way possible is constant one in, one out. Say if you have 2, every 2 minutes, so its 30 an hour. We are having one landing, one departing, one landing, one departing. That way you can get the aircraft closest together in 2 minutes.*

Alternatively, a *typical situation* which is *anticipated* and *critical* is the 'peak hours' during which there is increased flow of air traffic into and out of the airport. The next transcript (below) of an interview conducted with the Tower Controller (TC) describes the timing of peak hours in the studied work setting.

TC	*We get four peaks during the day. This is the early morning peak, which runs between half 6 and 8 o'clock. Then we have a mid day one after about 12, one'ish about that time. Late afternoon about 5ish, 6ish. Evening one about half 9. yeah 4 peaks. You still get the peak traffic at those times but peaks expand. So it covers a lot of area.*

Occasionally, situations tend to deviate from *typical* to *atypical* when the events occurring in the work environment do not take place as planned and occur unexpectedly (*unanticipated*). In the studied work setting, *atypical situations* arise during task performance due to issues such as system failure, changing weather conditions, or human error. Moreover, these situations can be either *critical or non-critical*. An illustration of an *atypical situation* which is *unanticipated* and *critical* is presented in the following scenario. The transcript is obtained from an interview conducted with the Tower Controller (TC).

TC	*I had awkward situation the other day where I had a tight gap on the Approach, for inbound normally you have an aircraft on the Runway and an aircraft on the Approach. Now the inbound had got in just before 2 miles and the outbound was rolling. So thought everything was fine. The outbound had just got airborne and the inbound called going around, because he wasn't stable. That's not good for the approach as well…… because this one has climbed to 3000 ft and the other one, outbound underneath him had climbed to 4000.*

In this scenario, the situation changed from *typical* to *atypical* when the pilot of the aircraft approaching the airport decided not to land on the Runway as it was unstable for landing. This is indicated in the description of the situation by the TC. His decision, "going around", in order to come back and try again to land on the Runway posed a problem for the TC in managing both inbound and outbound aircraft. This was because the space between the two aircraft was at the minimum distance permitted by the standard operating procedure. There was also a possibility for the two aircraft getting closer than the acceptable distance which would have posed a safety threat. Hence, this situation is *unanticipated* but at the same time *critical*.

An example of *atypical situation* which is *unanticipated* and *non-critical* is given below. This transcript is extracted from the field-notes taken during the observation sessions undertaken in the Control Tower.

> *One of the stop-bars near the Runway stops functioning. TC to the pilot of a landing aircraft – "Saudi Seven Three Two Nine, tower. We've got a launching problem at the moment. The alpha stop-bar is not deselecting so will have to hold you in that position. We will require Marshall guidance to take you on and off the Runway and the stop bars. Hold your position. We will get you sorted out in the next line".*

In the above scenario, a stop-bar (signal to taxiing aircraft) near the Runway unexpectedly ceases to function. The stop-bars are important points between the Taxiways and Runway. According to the standard operating procedure, departing aircraft have to wait at this point and the pilot has to get clearance from the Tower Controller (TC) before proceeding onto the Runway. The stop-bar ceases to function suddenly and causes problems for the TC in guiding the movement of the aircraft from the Taxiway onto the Runway. The TC now has to deploy other means of performing the operation. Although the situation was *unanticipated*, it is manageable and does not present any detrimental effect. Hence, it is conceptualized as a *non-critical situation*.

The nature of different types of situations faced by personnel during task performance are characterised. A wide range of scenarios exemplifying this classification are obtained from the data some of which are shown here. The complete list of the different types of situation generated during data analysis in presented in (Appendix 13). The different situation types are classified as contextual condition in the model illustrated in Figure 4- 1 as they were found during data analysis to present possibilities and constraints in undertaking actions and interactions involved in decision making. The following section explains how the dynamics of different situations are handled and the effect it has on undertaking CDM.

Critical situations, irrespective of being *anticipated* or *unanticipated*, present a situation which is deviant from the norm. Hence, the way personnel handle these is different from how they would act under normal circumstances. This is described by one of the interviewed Tower Controller (TC) as:

TC	*…because you are operating in a different method you are not normally used to. It takes more of your thinking time as well and takes more concentration. It sucks away the normal natural way you are doing the job.*

Accordingly, handling *critical situation* requires more thinking and increased concentration than when handling *non-critical situations*. In addition to being *critical*, if the situation is *unanticipated*, personnel need to make changes to plans that were devised in anticipation of certain state in the work process, have less time to think and plan changes, and have to perform the required coordination "quickly" with those involved in task performance. The following interview transcript illustrates this.

TC	*So it's a quick call to Radar (Approach Control), saying that' this one is going around, I've turned him left heading North, 3000 ft coming to you'. I also gave the outbound to him as well, because he could sort them out. So it's the case of changing the plan quickly that you have set up, coordination with them on the phone to tell them what's going on. That's the case of thinking quickly on the spot because this one has climbed to 3000 ft and the other one, outbound underneath*

him had climbed to 4000. It's that situation and if you let them run together they get very close. It's a lot of talking on the phone and lot of thinking quickly.

The above scenario depicts how the TC handles a 'missed approach' when the pilot of approaching aircraft is unable to land on the Runway. The pilot makes the decision in this case to not land the aircraft on the Runway. The TC is in agreement with the decision made by the pilot and displays this by performing the associated actions and interaction. When the pilot informs the TC that he is "going around" instead of landing on the Runway, the TC in turn informs the Radar Controller in the Approach Control, gives him the necessary information and hands over control of the aircraft. However, handling this situation requires *thinking quickly on the spot*, *changing the plan quickly*, and coordinating with related people 'quickly'. Actions and interactions in decision making have to be performed 'quickly' by all related personnel as the dynamics of the situation restricts time available for making decisions in collaboration with others involved in undertaking the task. This scenario illustrates the contextual condition (Figure 4- 1) in which decisions have to be made in the course of task performance. In particular it depicts the change in context from typical to atypical situation and the remifications it has on the way decision is made by personnel involved in performing the the task.

Also, the data reveal that when acting in an *atypical situation*, there is *increased instruction transmission* between personnel across different work units and requires *increased concentration*. In the above scenario, the change in plan needs to be communicated to other related personnel (*lot of talking on the phone*) in order to perform *quick coordination*. The inference is that decision making in *atypical situations* requires "quick" action and reaction from personnel as they are not prepared to manage the requirements of such situations and the time available for involving others in decision making is limited.

Moreover, the interconnected nature of decision making requires that personnel comprehend changes occurring in the work environment within the realms of their own work unit as well as those occurring beyond. This is facilitated by "*keeping the interaction between each other going"* across work units and is depicted in the following scenario. The transcript is obtained from one of the interviews conducted with a Ground Controller (GC) in the Control Tower at the airport.

GC	*There are lot of issues with the police helicopters because we use our taxiway as a runway for them basically. The tower will give them permission to take-off. So, he is giving helicopter permission to take-off and then my taxiways, so can you see we talk a lot to each other. If he* (an aircraft) *turns right and stops, this helicopter will go up in scrambles. He wants to make it right, if nothing is happening, I will just tell him* (tower)*. He is scrambling because he is going to* call the radar to let them know *that the police helicopter is on the way, he is going to be making space for them to get out. So it is important to keep the interaction between each other going.*

The police helicopter pilot places a request for take-off to the GC. Since, these pilots can take-off any time as required; they do not have to file a flight plan ahead of time. So when the request is made, it creates a contextual condition which is an *unanticipated situation* for the controllers in the Control Tower. Also, the location from which the helicopter takes off creates a *critical situation*. These present constraints in performing actions and interactions involved in making the decision to give permission to the helicopter pilot to take-off from the taxiway. The helicopter take-off occurs from the Taxiway which is under the control of the GC, but the permission to take-off has to be given by the Tower Controller (TC). This situation creates complications in making the decision to permit the helicopter to take-off as the operation is a deviation from the normal one. In order to handle this *atypical situation,* the controllers in the Control Tower of the airport and those in the Approach Control need to *keep the interaction between each other going* about occurrences in the setting of their individual work unit and requirements arising during task performance in order to make informed decisions.

In contrast to *atypical situations*, decision making in *typical* ones takes place by planning actions in response to expected events. An important aspect of this process is *gaining "a look-ahead*" which facilitates anticipation of occurrences during task performance and provides the required awareness. This is achieved through various 'anticipatory cues' obtained through verbal, visual, and auditory means. The cues provide indications about the state of other's activities during task performance and requirements to be fulfilled as well as events expected to occur in the work environment. An example of anticipatory cues established through visual observation is illustrated below. The transcript depicting the scenario is obtained from an interview conducted with the Ground Controller (GC) in the Control Tower of the airport.

I	*When they* (departing aircraft pilot) *first contact you do you put them in the Pending bay there?*
GC	*Yes, first contact and clearance I put them in there. This is an example here* (pointing to the strips in the pending bay), *two* (aircraft) *next to each other. We have had these two next to each other quite sometime. He has shut his doors, he might be calling soon. I've just pushed him back and see where he is turning, see the one that is boarding, I imagine his doors are shut and I think he is going to be calling soon. There is no where he can go is there? I've just pushed the aircraft behind him….pull forward to stand 8. So it gives that guy chance to stand out. So that's why need to have the stand numbers annotated there. So it gives us awareness to where the aircraft are and we can start planning.*

The GC is explaining the arrangement of Flight Progress Strips (FPS) on the strip holding bay and its reflection of the departing aircraft's movement from the parking stand to the Runway. In this scenario, there are two aircraft in the Apron area, parked next to each other on the stand (stand 7 and 8), and waiting to depart. The corresponding FPSs are arranged by the GC next to each other on the 'pending' section of the strip holding bay (Figure 5- 2).

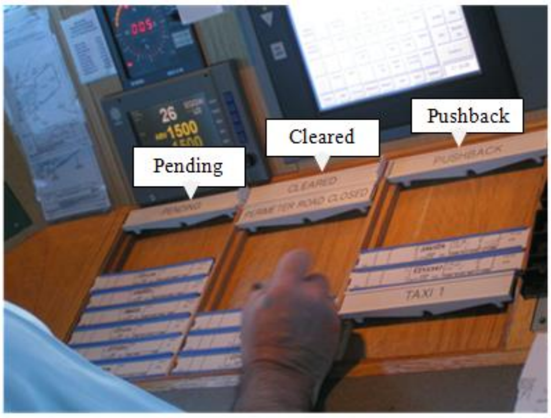


Figure 5- 2 : Flight Progress Strip Holding Bay on Ground Controller's Position in Control Tower

From the Control Tower, the GC also visually observes occurrences in the parking stand (7 and 8) corresponding to where the two aircraft are parked. He notices that the door of the aircraft on stand 7 is closed, which is considered to be an indication that the pilot of the departing aircraft will be contacting the GC to request permission to ‘push-back’. The GC is performing this operation in parallel with that of aircraft pilot in stand 8 who has already been granted permission to do so. The GC visually observes the movement of the two aircraft and that of the corresponding FPS on the strip holding bay. He anticipates that the pilot of the aircraft in stand 7 will be contacting him shortly. Based on this expectation the GC plans the actions to take and corresponding decisions to make in managing the movement of both departing aircraft. The dynamics of this situation here presents possibilities for planning ahead and provides sufficient time to determine pertinent action to be taken.

As seen above, a vital aspect of decision making in a contextual condition that is *typical situation* is anticipating the state of related entities and planning the course of action accordingly. In addition to anticipatory cues, two other factors which facilitate anticipation are found in this study to be *adherence to procedure* and “*getting tuned to each other*”. *Adherence to procedure* during task performance helps personnel to form expectations of forthcoming events and behaviour of others during task performance. The following transcript of an interview conducted with the Ground Controller (GC) in the Control Tower provides an illustration of this through decision making taking place in the performance of an 'engine run'.

GC	*When he* (Ground Controller) *took over from X, a Thompson aircraft from the East Apron wanted to perform an engine test in the Thompson Stand. It just wanted to start its engine and test it. In such cases, they are permitted to perform the test anywhere in the airport. They need to get permission from the Control Tower for this. So if any aircraft has to perform an "engine run" the aircraft handling agent (e.g. Signature, Monarch, Thompson etc.) or the aircraft operators have to first call the Operations Department and inform them that they want to perform an engine run. The Operations Department calls the Assistant in the Control Tower to request permission. The Assistant writes the information (aircraft type, where the test going to be done, what exactly is going to be done, time the test is going to be done, duration of test, etc.,) passed onto her on a pink flight strip, and places it front of the GC. The pilot of the aircraft later calls the GC requesting permission to perform the engine run.*

Figure 5- 3 : illustrates the sequence of communication taking place between personnel from different work units in order to perform the 'engine run'. This is structured by the procedure to be followed which necessitates *requesting permission*, *getting approval*, *giving permission*, and *information transfer* to perform the task of 'engine run'. Appropriate personnel are informed in advance of the requirements to be fulfilled and expected state of entities in the work setting. Hence, by adhering to the standard procedure, the corresponding interactions help form expectations of forthcoming occurrences in the work environment, requirements to be fulfilled, and actions of other personnel. When the aircraft pilot calls the GC to request permission, the dynamics of this situation has provided opportunities for the latter to anticipate the request and determine the pertinent action.

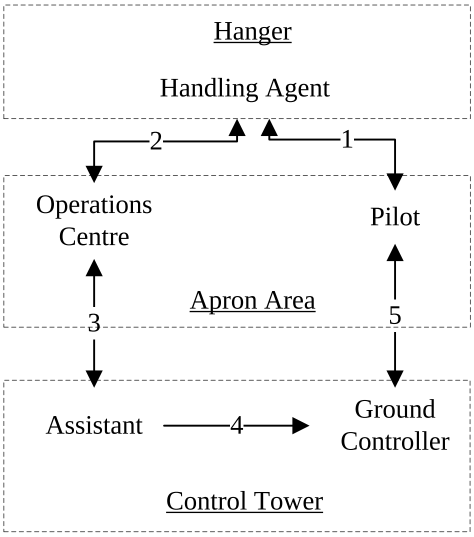


Figure 5- 3 : Sequence of Communication while performing 'Engine Run' Operation

Furthermore, experience (‘*getting tuned to each other’*) of collaborating with others helps anticipate their requirements and actions. This is reflected in the following field-note made during an observation session in the Control Tower.

> *They (personnel in the Control Tower) follow one shift pattern for a period of 5 months and after which it is changed. One of the controllers said she prefers it to be this way because it is easier to get tuned to the way other people work, which makes it easier for her to anticipate their requirements and cater to them accordingly.*

Similar to undertaking decision making in *unanticipated critical situations, anticipated critical* ones also involve performing “quick” actions, increased concentration, and increase in information exchange between related entities. For instance, this is illustrated in the scenario presented previously on managing air traffic during ‘peak hours’ in the airport. At these times the workload of personnel in the Control Tower increases and presents time constraint in undertaking CDM during task performance. Such situations can be *anticipated* to occur because information about the expected state of relevant entities is available beforehand. For example, the FPS which contains information about arriving and departing aircraft is made available to the controllers in the Control Tower half an hour before the arrival of aircraft. This helps them to anticipate the number of arriving and departing aircraft during the ‘peak hour’ and undertake decision making accordingly.

The findings presented above describe the different types of situation arising during task performance and the ways in which they are handled by personnel. A reflection on how this influences involvement of personnel in CDM is presented next. The data is indicative of how the *dynamics of situation* of task performance shapes participation in CDM by presenting possibilities and constraints in undertaking the activity. The situation dynamics were classified according to their predictability and criticality during task performance. These comprise the contextual condition aspect of the conceptual framework presented in Figure 4- 1. The data shows that such contextual conditions specifically have an effect on the temporality, intensity, structure and flexibility in performing actions and interactions involved in decision making. The main difference between *typical* and *atypical situations* presented by the findings is that in the former, there is sufficient time available for personnel to interact with each other, plan, and make decisions. However, when the situation changes from *anticipated* to *unanticipated* and *non-critical* to *critical*, personnel have to work under time constraint. They are restricted not only in the time available to interact, plan, and make decisions but also in undertaking actions and interactions consequential to decision made. Hence, *unanticipated* and *critical situations* require “quick” response from personnel which is depicted in the codes *changing the plan quickly*, *thinking quickly on the spot*, and *quick coordination*. With respect to intensity of interactions, the findings reveal that frequency of information exchange increases in *atypical situations* including both *unanticipated* and *anticipated critical* ones. This is depicted for instance in the codes *lot of talking on the phone, increased instruction transmission, keep everyone informed* and *we talk a lot each other*. Conversely, in *typical situations* the intensity of information exchange was not found to increase.

Furthermore, the *dynamics of situation* structure who will be involved in CDM during task performance. Variation in situation types begets involvement of different personnel. In the example of the 'stop-bar' not functioning on the Taxiway presented previously, 'follow-me' vehicles are used to guide the aircraft movement into and out of the Runway. Under normal circumstances, when the 'stop-bar' is functioning, the Tower Controller (TC) will only have to interact with the aircraft pilot. However, in this case the TC has to liaise with the 'follow-me' vehicle and the pilots of the aircraft. Hence, the change in situation from *typical* to *atypical* changes the structure of interaction taking place during decision making. The findings also reveal that while performing tasks in *non-critical situations* there is more flexibility in undertaking actions and interaction involved in decision making than in *critical* ones. For example, in the former, personnel have flexibility in the time taken for interacting with each other, whereas in the latter, this is restricted because of the time constraint.

Another condition affecting CDM in the studied setting was found to be the heterogeneous nature of work units. Since task performance requires involvement of multiple personnel from different work units; differences between work units forms another contextual aspect of CDM. The dimensions along which the studied work units are heterogeneous and the effect this has on personnel's participation and contribution to decision making is described next.

5.2.2. Heterogeneity of Work Units

In the studied setting, differences were identified between work units performing ATC operations at the airport. This is has been described previously in chapter 3 and Appendix 1. The *heterogeneity of work units* is addressed here at a more conceptual level and the emergence of the theoretical construct - *dimensions of heterogeneity* - during data analysis is explained.

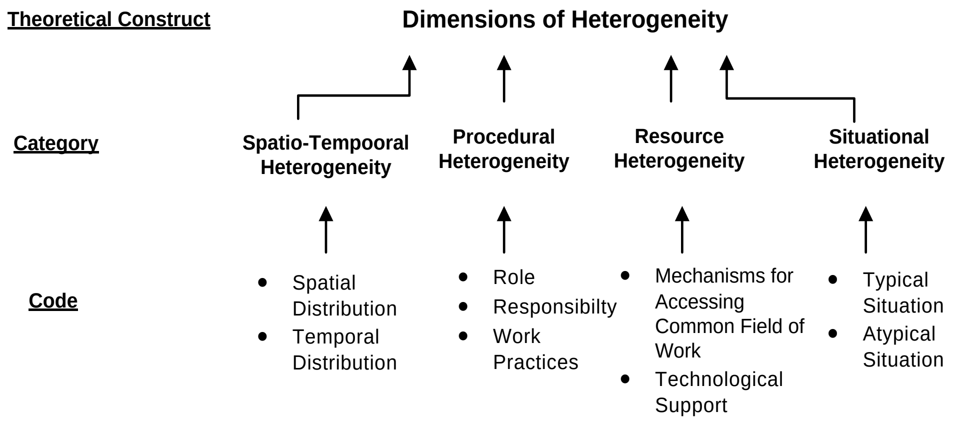


Figure 5- 4 : Codes and Categories of Theoretical Construct: Dimensions of Heterogeneity

Differences between work units in the studied setting were identified with respect to their physical location, workplace setup, personnel's expertise, role and responsibility in the work process, work practices and technological resources used. These are categorized into four forms of heterogeneity which include *spatio-temporal*, *resource*, *procedural*, and *situational* (Figure 5- 4). These *dimensions of heterogeneity* were found to influence the way personnel undertake CDM during task performance and is therefore considered to be a contextual condition (Figure 4- 1).

Spatio-Temporal Heterogeneity

The airport is characterized by multiple work units which are physically distributed in the space of the vast setting. The physical location of the work unit presents certain contextual conditions which provide possibilities and constraints in undertaking CDM. For instance, only some work units have direct access to the common field of work in the airport (Runway, Taxiways and Apron Area), such as personnel in the Control Tower, Fire Station, Operations Centre, Airline Hangers and Maintenance Workshop as well as the aircraft pilots. The following transcript from an interview conducted with the Ground Controller (GC) in the Control Tower illustrates this aspect.

GC	*(pointing outside to an aircraft in its stand)* ….you see the guy *(ground staff)* walking over there now unplugging the leather flaps while he talks to the pilots and then we will be expecting him to taxi any minute now…any second now..

This depicts the visual access personnel in the Control Tower have to the common field of work in the airport. In the above scenario, the GC can visually observe the behaviour of ground staff in the aircraft parking stand. Based on his actions, the GC makes inference about when the aircraft pilot will contact the Control Tower to request clearance to commence departure. The spatial location of the Control Tower provides a context based on which inferences can be drawn during decision making. The location allows the GC in the Control Tower to visually observe occurrences in the common field of work and determine its relevance to decisions to be made during task performance. Although personnel in the Control Tower, ground staff and aircraft pilots are physically distributed, they are within visual range. Conversely, some work units are so vastly distributed that it would not be possible to have access to the common field in an immediate way as in the case of personnel functioning in the Central Flow Management Unit (CFMU), MET Office, Approach Control, and Emergency Services. Access to the common field of work is mediated through technology such as CCTV camera and Radar. The spatial distribution of work units affects direct access to the common field of work and means of obtaining information required for decision making during task performance. Hence, location of the work unit provides certain contextual conditions which determine possibilities and constraints for undertaking actions and interactions during CDM.

Moreover, the physical location of the work units provides different viewpoints to personnel. One of the challenges presented by this heterogeneity is that undertaking decision making in collaboration with personnel across physical distance has to take place through limited means of communication and interaction as it restricts possibilities for direct face-to-face interactions. Also, during task performance the contextual condition of work units varies with its location. For example, personnel can be functioning under different time constraints depending on the *dynamics of situation* in their respective physical location. Hence, when they come together during decision making they can have differing temporal requirements.

Procedural Heterogeneity

The findings show that difference between work units also exists with respect to their location in the work process, which is depicted as *procedural heterogeneity* during data analysis. Based on the procedural location of the work unit personnel have different expertise, viewpoints, roles, responsibilities and work practices. They focus on different aspects of task performance. The procedural location of personnel during task performance presents certain contextual conditions which influence the way CDM is undertaken across work units. The findings indicate that this influences their involvement in CDM with personnel contributing to decision making in different ways. For instance, decision making involved in landing an aircraft on the Runway requires participation of multiple personnel from different work units. The following transcript from an interview conducted with the TC depicts the differences in participation in CDM through the information provided by personnel to facilitate decision making.

TC	*For the arriving aircraft, mostly information is given by the Approach. We can give the clearance to land, we give the wind... surface wind. Again when we have issues like today…poor visibility…we will give the Runway visual range and again if the aircraft are operating around helicopters, we give traffic information.*

The controllers in the Approach Control and those in the Control Tower participate in decision making at different instances. Also, they provide specific information which is accessible only from their work unit. The pilot of the aircraft assimilates this information and manoeuvres the aircraft. Based on their procedural location personnel from all three work units participate in CDM by contributing in diverse ways.

Resource Heterogeneity

The findings show that work units also vary in the facilities available to them for undertaking CDM. The difference in resources available for participating in CDM is depicted as *resource heterogeneity* during data analysis. The resources provided in each work unit presents possibilities and constraints for performing actions and interactions, and thereby certain contextual conditions for personnel undertaking CDM. For instance, the awareness required for involvement in decision making is established through different means in different work units. The controllers in Approach Control and Operations Centre are in an enclosed building with no direct view of the outside world. They can observe what is happening in the common field of work only through technological artefacts such as the Radar and CCTV cameras. In complete contrast, the controllers in the Control Tower have both direct visible access to the common field of work and are supplemented with technological artefacts such as Radar. This study focuses particularly on the technological artefacts facilitating awareness, communication and coordination during decision making.

The findings indicate that the means and mechanisms employed by personnel to participate in CDM vary with the work units. This is demonstrated in performing the task of aircraft departure from the airport. Communication between Ground Controller (GC) in the Control Tower and the departing aircraft pilot takes place verbally over the telephone whereas that between the GC and Coordinator in the Approach Control is through a technological artefact (*Departure Status Information* (DSI) System). The different means of interaction present varying possibilities and constraints in collaborating with other personnel during decision making. For instance, the following transcript of an interview conducted with the GC in the Control Tower illustrates his use of the DSI system to communicate the decisions made by him to the Coordinator in the Approach Control when performing the task of aircraft departure. Based on this the Coordinator makes further decisions thereby collaborating with the GC.

GC | *The next screen is the Departure Status Information. This gives message to the Radar centre at West Drayton as to what state the traffic are in. When I give an aircraft pushback or annotate it with an active sign, the Assistant at West Drayton will put the strip in front of the Coordinator. When it taxis out to the holding point, our Assistant will then put a hold and again take-off on the screen (on her Departure Status Information screen). So basically what it is, is situation awareness with the Radar centre down the road….*

In the above scenario, the GC makes a number of decisions with regard to guiding the departing aircraft pilot to move from the parking stand to the Taxiway. When the GC decides to give permission to the pilot to 'pushback' from the stand, he annotates the DSI system to reflect his decision. This is disseminated to the Coordinator's system in the Approach Control. Similarly, when he makes the decision to give the aircraft pilot permission to Taxi to the Runway, the Assistant in the Control Tower annotates the DSI system correspondingly which get reflected in the Coordinator's system. As a result, the Coordinator in the Approach Control can make further decisions in relation to this departing aircraft movement such as deciding to slow incoming air traffic in order to arrange a gap to make it possible for the aircraft to depart. Whilst the DSI system facilitates decision making in collaboration with personnel across work units, it constraints the interaction between controllers across the two work units to non-verbal means and does not permit verbal interaction. Conversely, the GC communicates with the aircraft pilot verbally through the radio telephone making it possible to discuss and make clarifications during decision making. Therefore, the technological resources by presenting these possibilities and constraints provide certain contextual conditions when undertaking CDM.

Situational Heterogeneity

Heterogeneity of work units also exists pertaining to the situation in which they operate. When personnel from different work units are involved in CDM, the situation faced by them varies with their location (spatial and procedural). The findings indicate that the situation type at one work unit can be *atypical situation* whereas that in another work a *typical situation*. The scenario depicted in the following field-note taken during the observation and interview sessions in the Control Tower illustrates this aspect.

TC	*Was on the phone with someone(?).em.. hang on a second… she comes over to GC and asks minimum spacing for two six is it four?*
GC	*Four miles*
TC	*She goes back to the phone and says … we will take four…four minimum.*
GC	*Let's just pack it (aircraft) together.*
I	*What happened?*
GC	*The radar control system… they wanted to pack on the approach on two six one four miles. gives us time to land them. quite a half turn to come off. . once we start clearing then the next one can land……….*
TC	*To GC…um…I think…oh bugger!!... he is about to get stitched today… TC comes over to GC's desk…they (approach) have suspended my freight flights as well…*

In the above scenario, the controllers in the Control Tower are operating under *typical non-critical situation,* whereas those in the Approach Control are operating under a seemingly critical one. The situation at each work unit presents certain contextual conditions which influence the way personnel undertake CDM. The above transcript demonstrates that personnel in the Approach Control are having issues in managing the flow of incoming air traffic (indicated particularly in the last lines). Hence, they have requested those in the Control Tower to allow the approaching aircraft to have minimum separation. Also, the TC's conversation with the GC emphasises that the situation in the Approach Control is *critical*. This illustrates the differing requirements raised by *situational heterogeneity* when personnel collaborate during decision making. Here, the decision of having minimum separation between incoming aircraft is made by the controller in the Approach Control in collaboration with those in the Control Tower. The controllers in both units are operating under varying conditions and therefore have differing requirements. However, this is reconciled by the controllers in the Control Tower agreeing to cater to the requirement of those in the Approach Control.

The findings show that the *dimensions of heterogeneity* of work units affect CDM with respect to a number of aspects. These are classified as contextual conditions in the model depicted in Figure 4- 1 as they present possibilities and constraints in performing actions and interactions to undertake CDM. In particular, difference in spatial location influences the means (direct or indirect) of obtaining information required for participating in decision making. This also presents different viewpoints and limits the means of interaction across physically separated work units with communication mostly mediated through technology. In addition, the temporal heterogeneity gives rise to variation in the time available for personnel to participate in decision making. The *type of situation* in which they function also varies with the physical location. Consequently, when participating in decision making personnel operate in varying conditions and requirements. Various means and mechanisms are employed by personnel to interact with others involved in decision making. Also, their contribution during CDM varies with the procedural location of their work unit. This gives rise to diverse requirements which needs to be reconciled.

5.3. CAUSAL CONDITION

The data analysis indicates that personnel from different work units are brought together to undertake CDM as they are dependent on each other for required information, performing necessary actions and making related decisions. For instance, during decision making, personnel require information which is beyond the access of their work unit and available in another, thereby bringing personnel from different work units together. Similarly, the cooperative work arrangement begets reliance on others during decision making for performing required actions and making related decisions. Hence, *dependencies* are conceptualised in this study as the causal condition bringing personnel together to undertake decision making in collaboration with others during task performance. Furthermore, the findings suggest that CDM is structured by the *dependencies* arising during decision making.

5.3.1. Dependencies between Work Activities

In this thesis, 'dependency' is considered to be the state of reliance on somebody or something for information, actions, and decisions at the task level, and at the social level for guidance, control, and assistance. *Dependencies* indicate the relational orientation between personnel undertaking the task and interconnections between their work activities.

A classification of *dependencies* was developed in this study from the analysis of data and conceptualized as *types of dependencies*. The classification is based on the factors influencing the configuration of *dependencies* arising during task performance which include the type of situation, the procedure to be followed as well as the emerging information and temporal requirements. These factors are not mutually exclusive and work in conjunction. Consequently, the *dependencies* arising during decision making are classified as *situational*, *procedural*, *information*, and *temporal* (Figure 5- 5).

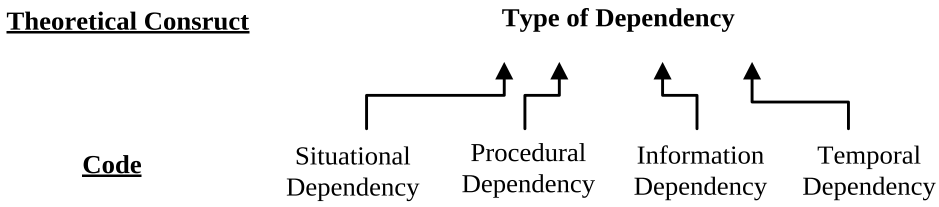


Figure 5- 5 : Codes of Theoretical Construct: Types of Dependencies

Situation Dependency

This type refers to *dependencies* brought about by the *type of situation* arising during task performance. For instance, during aircraft departure under *typical situation*, *dependencies* arise between the TC and aircraft pilot. The latter is dependent on the former to guide the aircraft movement from the Taxiway onto the Runway, to give clearance for takeoff, and provide necessary information to depart from the airport. This is depicted in the following transcript from an interview conducted with the TC.

TC | *When he* (aircraft pilot) *is cleared to take-off, by then he is given all the information he needs as far as weather conditions are, QNH…all you are going to tell him on a normal day on a normal procedure is the wind, 'cleared to take off and the wind is….' In bad conditions like the weather today, the visibility, we also give the Runway visual range. The visibility hasn't been too bad today. It has been constant above 1500. The cloud has been a problem.. so today we give the RVR and the wind and the clear to take off. so its three things. On a nice day you might have lots of other aircrafts knocking around out in the zone. So you might give traffic information…'Easy 123 we have a light aircraft 2 miles to the East and ---- VFR, cleared to take off…the wind is'. You give the traffic information because its only thing that allows the pilot to know where traffic is and avoid it.*

In the above example, the dependency between the aircraft pilot and the controller acts as a causal condition (Figure 4- 1) that brings these personnel together to undertake CDM. Their participation is structured by the nature of dependency between them. The TC provides the necessary information to the aircraft pilot who then can make an informed decision to avoid the air traffic during take-off. However, when the situation changes to *atypical* one it raises different requirements and consequentially different *dependencies*. This is illustrated in the scenario of system failure (stop-bar failure) presented in section 5.2.1. When the 'stop-bar' near the Runway ceases to function unexpectedly, the configuration of *dependencies* changes during aircraft departure. The following transcript from an interview conducted with the TC in depicts this.

TC	(Some problem with the stop bar). (To GC) *You probably have to get a Marshall out there but I haven't mentioned it to the Apron at the moment.* *Can you call the Apron and ask them to send a Marshal?*
GC	(To TC) *Right can we tell the electricians then about this stop bars. Say the stop bar is not dropping.*

In the above scenario, a 'stop-bar' (an important point between the Taxiways and Runway) located near the Runway ceases to function unexpectedly. Procedurally, the departing aircraft pilot has to wait at this point before getting onto the Runway and get clearance from the TC before proceeding. As the stop-bar is not functioning, it causes problems in directing aircraft from the Taxiway onto the Runway and the TC has to deploy other means of performing the operation. This situation now raises *dependencies* between the controllers in the Control Tower and Apron Control, ground staff (marshal), and engineers in the workshop. Also, the TC in the Control Tower has to coordinate the movement of the marshal and departing aircraft pilot simultaneously while directing aircraft movement from the Taxiway onto the Runway. The TC describes this situation illustrates as follows:

TC	*Yeah. we are not allowed to allow the aircraft to cross over the red stop bar. So we have to get a vehicle to drive over the stop bar in front of them. they follow the vehicle, backtrack the vehicle then goes back to the holding point. Absolutely ridiculous! the aircraft have been standing on the ground there. I have missed two gaps because of this. I've only given them seven miles as well.* (Gives

instructions to pilots) *This is a very busy period in the evening around after 6 when there is heavy inbound traffic.*

As seen here, during aircraft departure under *typical situation*, *dependencies* are raised between the pilot of the departing aircraft and the TC. Yet, when performing the same task under *atypical situation*, *dependencies* are raised between the pilot, TC and the marshal. In this scenario, when the situation changes, dependencies between work activities of personnel involved in task performance is a causal condition which produces the need for others to be involved to enable the TC to make the decision to give permission to take-off .

Procedural Dependency

In the studied work setting, procedures are laid down by the organization, which have to be followed to perform tasks. This reflects the work distribution between personnel belonging to different work units and their interconnections. *Procedural dependency* depicts the configuration of *dependencies* brought forth by the procedures laid down by the organization. An illustration of this is the clearance given to the pilots of arriving and departing aircraft by the controllers in the Control Tower. The following transcript from an interview conducted with the Ground Controller (GC) in the Control Tower demonstrates the dependency created by the procedure to be followed when performing the task of aircraft departure.

GC *The first thing that you have to give is the Departure Route, which is his clearance to move. No aircraft can go anywhere without a clearance. They need to know where to go basically and if you don't give them a point where to go and where to go from and where to go to and a route, they are in limbo. Basically that's what it is. You have to tell him (aircraft) where to go. Otherwise he is going to come up to you and say 'what do I do? What stand am I? Which way do you want me to go?' So clearance is the main part of what we do when we are issuing instructions and this clearance is his permission to travel from* *here to his destination.*

In this scenario, the dependency brought forth by the procedure to be followed acts as a causal condition that produces the need for the GC and the pilot to work together to make the decision during aircraft departure.

The following field-note transcript of an observation in the Control Tower provides another illustration of the dependency configuration between personnel and technological artefacts raised by the procedure to be followed during task performance and its role as a causal condition for their involvement in decision making.

> *For inbound and outbound aircraft, the parking gate number for the aircraft has to be written on the strips. The parking gate number is provided by Apron Control and is fed into the Flight Schedule Window system by them. If the gate number is not available in the system, the assistant has to telephone the Apron Control Authority to find it and write it on the strip.*

The controllers in the Control Tower are dependent on those in the Operations Centre to provide them the required information for managing arriving and departing aircraft movement in the airport and making related decisions. The procedural dependency between these personnel causes their involvement in the decision making. As per procedure, information exchange between the controllers in the two units takes place through an information representation and dissemination artefact. The controllers are dependent on the 'flight schedule window' system to transfer this information between the two work units. In the event of a problem or an issue arising with this system the alternative means of obtaining the required information is verbal communication through telephone.

Information Dependency

This type of dependency is brought forth by the information requirements in task performance. Distribution of work activities across different work units leads to personnel being able to obtain only partial and provincial knowledge of the work process with respect to the boundaries of their individual work unit. This also limits the access to information required during decision making and creates *dependencies* between information available across work units. For instance, this is depicted in the responsibility of the Arrival Controller (AC) in the Operations Centre. In order for the Ground Controller (GC) in the Control Tower to make the decision to land an aircraft in the airport, the stand number in the Apron area for parking the arriving aircraft needs to be provided by the AC. This is illustrated in the words of one of the management personnel (M) interviewed in the Operations Centre:

> M | *Today X is working in the arrivals position. She is looking at the aircraft that are coming in and the EFPS. She is looking at the stand planning information and telling tower where to park the aircraft by entering the stand number and also for transferring the personal information which is used for billing and regulatory into AMOS. So she is looking at both these things and moving between the two.*

Here, the information dependency was found to act as a causal condition which creates the need for personnel from different work units to participate in decision making and also structures information sharing between them.

Temporal Dependency

Temporal dependency depicts the *dependencies* raised by the temporality involved in task performance. This type of dependency structures the timing of participation in CDM. The findings reveal that not all personnel involved in decision making participate at the same time in the cooperative work arrangement. Instead, they contribute to CDM at particular instances and this is structured by the *temporal dependency* between their work activities. The transcript given below from an interview with the Ground Controller (GC) in the Control Tower illustrates this.

GC | *CTOT is Calculated Take-off Time, that's the time we aim for the aircraft to be rolled on the Runway… we have a buffer period around that because we try and get the aircraft off the deck exactly on the slot. for every single aircraft is waiting, we have a boundary of 5 minutes before that time to 10 minutes afterwards…to actually get the aircraft air borne. So 8.55 is the actual time for this aircraft … so we can get him air borne any time between 8.50 and 9.05…*

According to the procedure to be followed, the pilot of the aircraft has to commence departure from the airport within the allocated time period (15 min). Here, making the decision to depart the aircraft within the Calculated Take-Off Time (CTOT)[18] requires involvement of personnel from different work units. The *temporal dependency* between their work activities acts as a causal condition that creates the need for their involvement in decision making. The Central Flow Management Unit (CFMU) provides the slot information to the Ground Controller (GC) in the Control Tower half an hour before the 'Off-Block Time'[19]. Personnel in the CFMU contributed to decision making by providing the required information at a specific point in time. The GC in response schedules the flow of other aircraft departure so that the pilot can move within the CTOT. Hence, personnel from different work units perform actions and interactions at specific instances to aid decision making based on the *temporal dependency* between their work activities.

This study demonstrates that the *dependencies* cause the need for personnel to come together during task performance to undertake CDM and has been depicted as the causal condition in the model presented in Figure 4- 1. It also structures the way CDM is undertaken. The classification of *dependencies* described above illustrates this. For instance, *situational*

[18] The time the departing aircraft has to take-off. This is the time provided by the CFMU with a tolerance of -5 to +10 minutes.

[19] Time at which the aircraft is ready to commence departure movement from the airport. This includes all doors of the aircraft are closed, and aircraft pilot and push back vehicle are ready to receive start up clearance from the Control Tower and push back.

dependency determines who needs to be involved in decision making, the structure and intensity of interaction taking place between them, technological artefacts used and the flexibility involved in undertaking CDM. Additionally, *procedural dependency* determines what personnel are dependent on each other for (such as information, actions, decisions, guidance, control and assistance) and who is dependent on whom (depender-depended relationship). It also helps personnel to set expectations, possibilities, and limitations while undertaking CDM. Moreover, *information dependency* structures information sharing and *temporal dependency* structures the timing of participation in CDM.

5.4. SUMMARY

The conditions influencing the occurrence of CDM during task performance in a complex work setting have been discussed in this chapter. The conceptualisation of *dynamics of situation* and *heterogeneity of work units* as contextual conditions in this study and their effect on CDM is explained. The emergence of *dependencie*s as a causal condition is described besides illustrating its role in structuring the way CDM is undertaken. The next chapter presents the emergence of *managing interdependencies* as the 'core category' and its related categories formulating the theory of CDM.

CHAPTER 6

COLLABORATIVE DECISION MAKING AS A PROCESS OF MANAGING INTERDEPENDENCIES

6.1. INTRODUCTION

The chapter describes the emergence of the central concept on which the conceptual framework of Collaborative Decision Making (CDM) is constructed. It is the 'core category' in Grounded Theory Methodology (GTM) which was identified to be *managing interdependencies* in this study. The 'Six Cs' theoretical coding family employed to structure the theoretical framework of CDM focuses on this core category. The previous chapter describes the contextual and causal conditions of this framework whilst the covariance, contingency and consequence constituents are explained here. Through this, the chapter explicates how CDM in the cooperative arrangement of complex work settings is a process of managing interdependencies. A complete account of the theoretical constructs, categories, codes and their relationships which lead to such a depiction is presented.

6.2. MANAGING INTERDEPENDENCIES AS 'CORE CATEGORY'

In Grounded Theory analysis, the researcher keeps a look out for the 'core category' during the various coding phases. This is the main theme arising from the data and can be any kind of theoretical code such as a process, a condition, a dimension, or a consequence (Glaser 1978). In this study, *managing interdependencies* emerged as the 'core category'. As presented in chapter 5 the findings indicate that personnel are brought together to undertake decision making in collaboration with each other by the *dependencies* arising between their work activities. The way personnel manage the relational orientation emanating from the *dependencies* accounts for much of their social behaviour and contribution in CDM. This led to the emergence of *managing interdependencies* as the core category explaining the occurrence of CDM in a complex work setting. Moreover, during data analysis this was a frequently occurring concept in the data and formed meaning links between the categories forming the theory of CDM, which satisfies the criteria presented in GTM for it to be considered a 'core category' (Glaser 1978; Glaser 2001). The model presented in Figure 4- 1 focuses on this core category. Hence, *managing interdependencies* is placed at the centre and the other concepts placed in relation to this in the depicted conceptual framework of Collaborative Decision Making (CDM).

In this study, *managing interdependencies* denotes the process of managing the reliance on somebody or something to fulfil the requirements arising during task performance. With respect to decision making in a cooperative work arrangement this involves managing the reliance on others for obtaining required information, performing necessary actions and making related decisions. The following transcript of an interview conducted with the Ground Controller (GC) in the Control Tower illustrates this.

GC | *The first thing that you have to give is the Departure Route, which is his clearance to move. No aircraft can go anywhere without a clearance. They need to know where to go basically and if you don't give them a point where to go and where to go from and where to go to and a route, they are in limbo. Basically that's what it is. You have to tell him (aircraft) where to go. Otherwise he is going to come up to you and say 'what do I do? What stand am I? Which way do you want me to go?'*

In the scenario presented above, the pilot of the departing aircraft is dependent on the GC to obtain the information required for decision making. Managing this dependency requires the former to provide the latter with the required information thereby leading to CDM.

The findings reveal two key processes involved in *managing interdependencies*. They are *aligning work activities* and *keeping people in the loop*. Emergence of these theoretical constructs from the data is described next.

6.3. MANAGING INTERDEPENDENCIES BY ALIGNING WORK ACTIVITIES

In this study, *aligning work activities* (AWA) denotes the process of synchronizing work activities of personnel in order to manage the *dependencies* during task performance. The data analysis brings forth the covariance relationship between AWA and *dependencies* as the former takes place in response to the latter. The findings indicate that in order to manage the *dependencies* arising during decision making, personnel align their work activities through three modes of synchronization. This includes *synchronizing actions*, *decision making*, and *perception*. These are not mutually exclusive and work in conjunction with each other.

6.3.1. Synchronizing Actions

The way personnel synchronize their actions to manage the *dependencies* arising between their work activities is depicted through the categories *correlating actions* and *managing temporality*. The codes generated during the analysis which form these categories are depicted in Figure 6- 1.

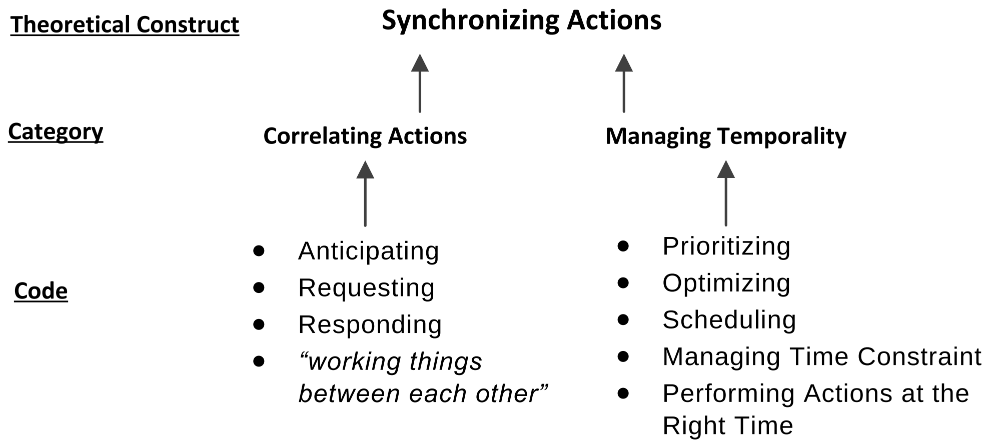


Figure 6- 1 : Codes and Categories of Theoretical Construct: Synchronizing Actions

In this study, *correlating actions* denotes the establishment of orderly connections between actions through anticipatory and reciprocal relations. The former involves anticipating each other's requirements, behaviour, and state of entities in the work setting. Based on the expectations formed, personnel plan and organize work activities in relation to that of other's. Conversely, the latter involves *responding* to stimuli such as requests to perform actions and information obtained from others. An example of *correlating actions* through these means is illustrated in the following transcript obtained from an interview with the Ground Controller in the Control Tower. The transcript depicts the procedure for undertaking maintenance work on aircraft in the airport.

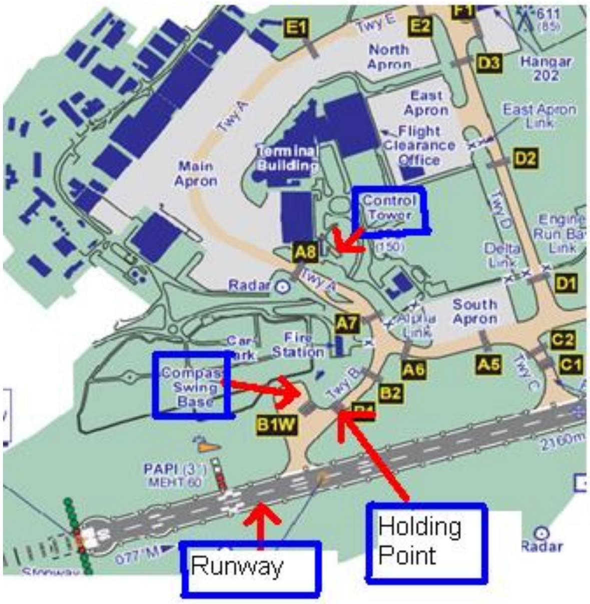
GC | *If they* (aircraft) *want any maintenance work to be done they need the permission of the Apron Control first. The airline operator or the maintenance operator will call the Apron Control. Say for example if that aircraft want to do a 'compass*

> *swing' and they say 'yeah'. There is no booking time for the compass swing and they say 'yeah, you can do it at that time. Giving you permission'. Then they tell the Assistant, tell them what's going on. The Assistant will then write it and put it in front of us. We just sit there waiting for them to call us and then do the necessary when he calls up.*

In this scenario, decision making involved in giving permission to the aircraft pilot to perform maintenance work requires managing the dependencies between the work activities of personnel from different work units. This takes place by means of correlating their actions through *anticipating*, *requesting* and *responding*. Anticipation of aircraft pilot's requirements and behaviour is established based on the information obtained from other personnel. When any maintenance work has to be performed on an aircraft, the corresponding airline operator places a request with the Ground Controller (GC) in the Apron Control (Operations Centre) first, who informs the Assistant in the Control Tower, who in turn informs the GC in the Control Tower. Based on the obtained information, the GC in the Control Tower anticipates the requirements to be fulfilled and behaviour of aircraft pilot, and determines actions needed to be performed to correlate his actions with that of the aircraft pilot. Also, in the above example, the GC in the Operations Centre correlates his actions with that of the airline operator by *responding* to the request made by him to provide permission to perform the operation.

This scenario demonstrates the relationship depicted in the conceptual framework presented in Figure 4-1. *Aligning work activities* of the airline operator, pilot and controllers in the Apron Control and Control Tower takes place in relation to the *dependencies* that arise in making the decision to allow the aircraft pilot to perform the maintenance work. Furthermore, *aligning work activities* takes place by *synchronizing actions* of these personnel which leads to *managing interdependencies* arising between their work activities in performing the operation of aircraft maintenance.

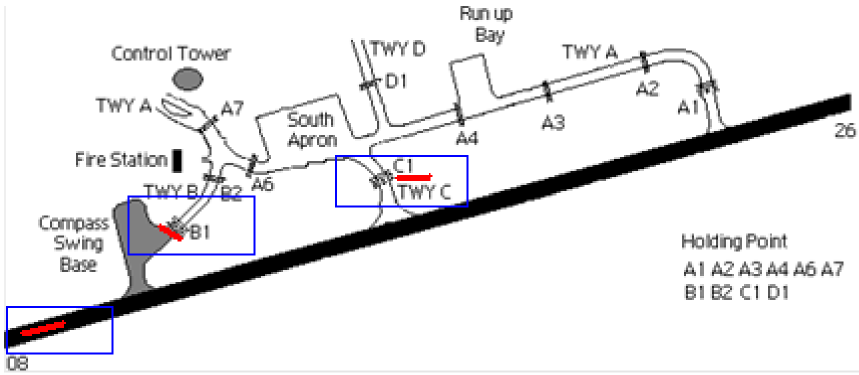
Another means of *correlating actions* is by "*working things between each other*" as depicted in the following transcript which is a continuation of the interview presented above. The chart of the airport Aerodrome is also provided below to help understand the scenario described in the interview transcript.



The Compass Base… aircraft are landing in runway 26…they come upto to Bravo... the compass bay is there… see there (pointing to the compass base in front of the tower near the runway)*… so there is a bit of a issue there. The first issue is against the flow of traffic. Also another issue is that it's crossing an active holding point, which is protecting the runway. So I've coordination to do with the tower there to cross the holding point to get onto the runway. So there are times when I have to talk to the tower and also I have to make sure there is gap in the traffic to be able to get the truck across, because you have lots of traffic coming. I will need this little bit of space. So it gives a case to talk to the tower. Just work this between when you can do it.*

In this case, the aircraft to be taken for maintenance work on the 'compass base' is at the parking stand in the Apron area. When the pilot of the aircraft calls the GC in the Control Tower, he needs to issue clearance to allow the aircraft to be towed to the compass base. However, the compass base is at a critical location near the Runway and causes issues in aircraft movement on the Taxiway. Hence, the GC has to coordinate with the TC to arrange a gap between incoming aircraft so that the aircraft on the ground can be allowed to be towed from the parking stand to the compass base. In addition, to arrange the required gap in incoming air traffic, the TC and the Approach Controller need to correlate their actions by "*working things between each other*".

Synchronizing actions to align work activities of personnel across work units also requires *managing temporality*. Data analysis shows that this involves *prioritizing*, *optimizing*, and *scheduling* actions of personnel involved in decision making. This is illustrated in the following transcript of the field-note obtained from the observation sessions conducted in the Control Tower.



> *In another situation there is a light aircraft waiting to take off at holding point C1 and a police helicopter* (green strip) *at holding point B1* (highlighted in red in the above figure). *Also, there is an approaching aircraft on runway 08. The TC (This is going to be a good one!) wants to send these two VFR flights and land the approaching aircraft at the same time. He can allow the two flights to take-off at the same time because they take different routes once they take off. He calls the Approach Control and asks them to slow the approaching aircraft so that he can get these two aircraft to take-off and manages to do all three within a minute.*

In this case, performing the departure and landing of the three aircraft simultaneously requires synchronizing the actions of the aircraft pilots and that of the Tower Controller (TC) by managing the temporality between them. The TC achieves this by *prioritizing* and *scheduling* the timing of aircraft departure and landing. Also, the TC requests the Approach

Controller to slow the approaching aircraft so that both the helicopter and light aircraft can depart at the same time from the Runway. Here, the TC and Approach Controller synchronise their actions and align work activities in relation to the *dependencies* arising task performance. As depicted in Figure 4-1 this leads to *managing interdependencies* involved in making the decision to allow the departure and landing of the three aircraft simultaneously.

6.3.2. Synchronizing Decision Making

Synchronizing decision making of personnel in the cooperative work arrangement occurs by managing the distribution in decision making as well as the interconnections involved. The former is achieved by *correlating decisions* made by different personnel whilst the latter by bringing them together during decision making which is labelled during data analysis as *cohering decision making*. In this study, *correlating actions* denotes the establishment of orderly connections between decisions of personnel involved in task performance whereas *cohering decision* making indicates unifying their decision making. The codes generated during data analysis which form these categories are depicted in Figure 6- 2.

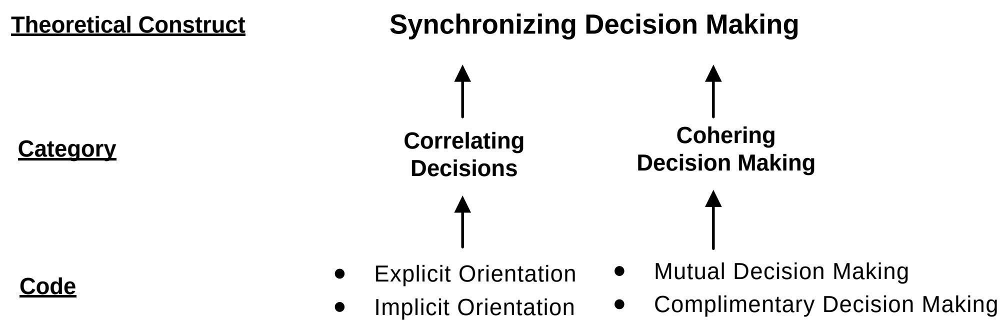


Figure 6- 2 : Codes and Categories of Theoretical Construct: Synchronizing Decision Making

The findings reveal that managing the dependencies arising during decision making requires *correlating decisions* made by personnel from different work units. This is found to take place through explicit and implicit orientation. The following example demonstrates how the controllers in the Control Tower and Approach Control correlate their decisions through *explicit orientation.*

I	*What does the coordinator do from those places?*
GC	*The coordinators are those… when you are down at the Radar Centres…you have the tactical controls…you are working on the Radar itself…bending the traffic around…the coordinator stands behind them and they will be talking to other units, accepting aircrafts into their sectors at certain level, planning how traffics go into sectors, go out of sectors…so will phone up the coordinator to say 'we have got Easyjet 3309 sitting around here…got to release him'…he will see the traffic levels to see if anything is in the way and then gives us permission to launch it basically…that's what coordinator does… if we say got to release Easyjet 3309…if it can go he says released if it cant go says no will call you back.*

In the above scenario, the controllers in the Control Tower and Approach Control share operational responsibility for coordinating the arrival and departure of aircraft at the airport. Decision making involved in giving the pilot of an aircraft waiting to depart permission to 'release' necessitates that the Tower Controller (TC) obtain clearance from the Approach Controller due to the *dependencies* between their work activities. When this happens, the latter in turn needs to make a decision to allow or not to allow the release of departing aircraft based on the incoming air traffic. Thereby, decisions made by controllers in both work units are correlated through explicit orientation. Here, the TC, Approach Controller and departing aircraft pilot align their work activities by synchronizing decisions. This leads to *managing interdependencies* in decision making which illustrates the relationship drawn between *aligning work activities* and *managing interdependencies* depicted in Figure 4-1.

Alternatively, this takes place through implicit orientation by embedding decisions in actions and information transferred. The following transcript obtained from an interview conducted with the Ground Controller (GC) in the Operations Centre illustrates this.

GC	*That's an engineer asking permission to turn an aircraft, turn the engine on its stand. They can do it only after they get the permission from us. So I now put that information there.* (Standard form) - *Stand 1. In the remarks column put the engine run, idle power. Title is aircraft. When they* (aircraft pilot) *call ground for permission, then the controller looks for the strip and that's it. All the information is there ready.*

The above transcript depicts the task of performing maintenance work on aircraft from the perspective of controllers in the Operations Centre. In the example presented above, the engineer performing the maintenance operation has to first request permission from the GC in the Operations Centre. When the GC makes the decision to permit the operation to take place, he fills in a form in the Electronic Flight Progress Strip (EFPS) and enters information such as the aircraft parking stand number where the maintenance work is to be carried out, aircraft call sign, and type of maintenance work. Then he sends it to the GC in the Control Tower through the EFPS. By doing this the GC in the Operations Centre has embedded his decision (to allow the engineer to conduct the maintenance operation) in the information transferred to the GC in the Control Tower. The latter then makes his decision based on this information, thereby decisions made across work units is implicitly correlated.

Synchronizing decision making also involves *cohering decision making* of personnel undertaking the task. The findings indicate that this takes place explicitly and implicitly through *mutual* and *complimentary decision making* respectively. An example of *mutual decision making* can be observed in the interaction taking place between controllers in the Control Tower and Approach Control in the process of arranging gaps between incoming traffic in order to allow departing traffic from the airport. The following field-note taken during observation sessions carried out in the Control Tower illustrates this.

TC	(Was on the phone with someone) *.em.. hang on a second… she comes over to X (GC) and asks minimum spacing for two six is it four?*
GC	*Four miles*
TC	*She goes back to the phone and says … we will take four…four minimum.*
GC	*Let's just pack it* (aircraft) *together.*

In the above transcript, the decision to slow the movement of air traffic coming into the airport by increasing the distance between aircraft to four miles is jointly undertaken by controllers in the Control Tower and Approach Control thereby *cohering decision making* of personnel across work units.

Alternatively, decision making of multiple personnel is unified implicitly through *complimentary decision making*. This occurs when decisions are made in causal or reciprocal relation to other's decisions. For instance, in the example of decision making involved in performing maintenance work on an aircraft cited above, the decision made by the engineer to conduct the maintenance operation in turn causes decisions to be made by the Ground Controllers in the Operations Centre. In the above scenario, personnel involved in guiding the aircraft movement in and out of the airport synchronize their decision making explicitly and implicitly. *Dependencies* between the controllers in the Approach Control and the Control Tower structure the way they synchronize their decision making. Consequently, in the process of *aligning work activities* by *synchronizing decision making* personnel are *managing interdependencies*. This demonstrates the relationships drawn in Figure 4-1.

6.3.3. Synchronizing Perception

The findings of the study reveal that *synchronizing perceptions* is particularly important to establish the common knowledge and understanding required for Aligning Work Activities (AWA) across different work units. As described in chapter 5, since the work units involved in task performance are placed in different physical and procedural locations in the cooperative work arrangement; personnel possess partial and provincial viewpoints depending on the location of their work unit. Their perception is limited by the boundaries of their work units and so to align their work activities their perceptions need to be synchronized. Furthermore, due to the constantly changing dynamics of the situation of task performance, *synchronizing perceptions* of personnel across work units is momentary and short-lived, and needs to be constantly updated. The findings show that personnel synchronize their perceptions to manage the *dependencies* arising between their work activities by not only integrating viewpoints but also by *avoiding misunderstanding* and *avoiding surprises*. The codes generated during data analysis which form these categories are depicted in Figure 6- 3 .

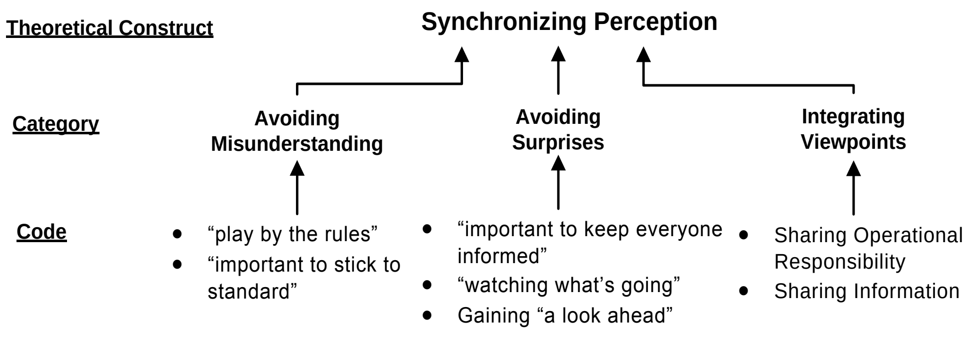


Figure 6- 3 : Codes and Categories of Theoretical Construct: Synchronizing Perception

In the studied work setting, strict adherence to the procedure is required for undertaking tasks. The findings revealed that when personnel "*play by the rules*" and "*stick to standard*", it facilitates prediction of each other's requirements and behaviour during task performance. The procedure and standard work practices form a common frame of reference which aids *avoiding misunderstanding* of information exchanged, requirements to be fulfilled, and behaviour of personnel across work units during task performance.

Also, for *synchronizing perceptions* of personnel in the constantly changing conditions of task performance, it is "*important to keep everyone informed*" of changes taking place in the work setting, "*watching what's going on*" during task performance, and "*gaining a look-ahead"*. The following scenario depicts the importance of keeping each other informed to synchronize their perceptions during task performance. The transcript is obtained from an interview conducted with the Tower Controller (TC).

TC	*Just as 76 started rolling on X* (TC) *realised she hadn't asked for release. X* (TC) *called to ask for release* (and apologised) *just as a/c got airborne. She remarked that when something like this scenario happens, need to be focused so some things are easy to drop. This was interesting as the general level of workload/traffic wasn't especially high - but for a few minutes the situation required lots of monitoring to check that 76 was moving and that gap was large enough. [X* (TC) *remarked that in such a situation it's important to keep everyone informed of what's going on - so they know why things are happening and they're ready to go quickly when they need to: "expect late landing clearance", "following traffic...."]*

In this scenario, the departing aircraft is taking off from the Runway. Typically, the TC should have asked permission from the Approach Control to "release" the departing aircraft before it takes off from the Runway. However, the TC forgot to do so, but remembered just as the aircraft was taking off. She then informs the Approach Control about her mistake and apologizes. By doing so, she has created visibility to her actions through which controllers in the both work units have synchronized their perception of the state of task performance and entities in the work setting. If she had not informed the controller in the Approach

Control, he could have misunderstood the state of departing aircraft during task performance. Also, this has avoided surprising the controller in the Approach Control because if he had not known that the aircraft was airborne, he would not have been prepared to accept the aircraft in his zone of control.

Another means of *avoiding surprises* during task performance is by "*watching what's going on*" and "*gaining a look-ahead"* as illustrated in the following transcript obtained from an interview with the Ground Controller (GC) in the Control Tower.

GC	*You also keep your eyes out on the window watching what's going on. I've been looking out there. He has got steps down so, no he doesn't want to go. ----- probably he is going to be against here.*

In the above transcript, the GC explains how by "*watching what's going on*" he gains a *look-ahead* of the occurrences that would take place in the work setting during task performance. Here, there is an aircraft due to depart from the parking stand. The GC has the corresponding FPS which provides the expected time of departure. But he also looks outside the window to see the status of the departing aircraft. He sees that the passenger stairs is still attached to the aircraft and anticipates that the aircraft pilot will not be calling to 'push-back' soon and that it would be in conflict with another departing aircraft ("*probably he is going to be against here"*) based on the FPS strip arrangement on the strip 'holding bay'.

Besides *avoiding misunderstanding* and *avoiding surprises, synchronizing perceptions* of personnel across work units was also found to be achieved by integrating their viewpoints. The data shows that this takes place by *sharing operational responsibility* and *sharing information*. This is illustrated in the example of the Ground Controller (GC) in the Control Tower and Radar Controller (RC) in the Approach Control *sharing* *operational responsibility* for performing the task of aircraft departure. It involves *sharing information* through a technological artefact called Departure Status Information (DSI) system (Figure 6- 4). The following transcript is obtained from an interview conducted with the GC in the Control Tower. In this part of the interview he is explaining the function of various technological artefacts used by him to undertake work activities.

GC | *The next screen is the Departure Status Information. This gives message to the Radar centre at West Drayton as to what state the traffic are in. When I* (Ground Controller) *give an aircraft pushback or annotate it with an active sign, the Assistant at West Drayton will put the strip in front of the Coordinator. When it taxis out to the holding point, our Assistant will then put a hold and again take-off on the screen* (on her Departure Status Information screen)*. So basically what it is, is situation awareness with the Radar centre down the road.*

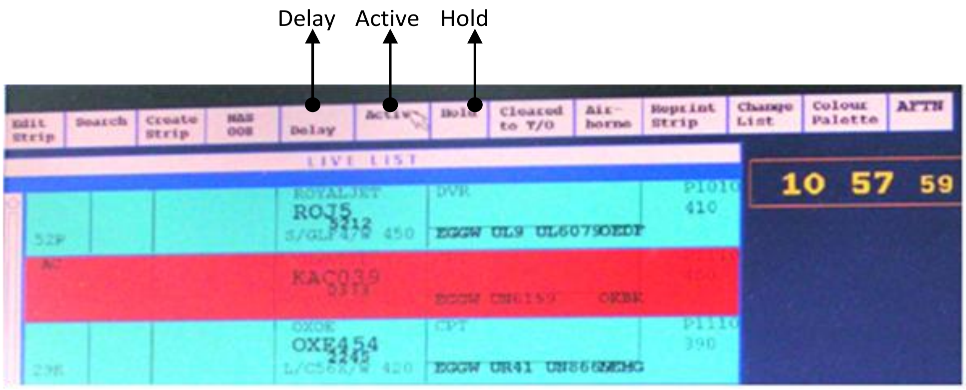


Figure 6- 4 Status of Departing Aircraft Represented in Departure Status Information System

The DSI system facilitates placing information in common across the two work units. In this scenario, when the GC in the Control Tower has given the departing aircraft pilot permission to push-back from the stand, he annotates corresponding aircraft information in the DSI system to "active", which changes the strip colour (from blue to red) on the screen (Figure 6- 4). This is reflected in the DSI system of the Assistant in the Control Tower and Approach Control. The Assistant in the Approach Control will then print the paper FPS and hand it over to the corresponding controller there. When the aircraft moves from the parking stand onto the Taxiway and reaches one of the 'holding points' near the Runway, the Assistant in the Control Tower will change the status of the strip in the DSI system to "hold". This changes the colour of the strip again in the DSI system which gets reflected in the corresponding systems of the GC in the Control Tower and Assistant in the Approach Control. In the case the aircraft is unable to depart at the allocated slot time after 'push-back' clearance, the status of the strip in the system is changed to "delay" in which case the Assistant in the Approach Control will remove the strip from the coordinator's strip holding bay.

As demonstrated above, the aircraft information in the DSI system is constantly updated to reflect the changing conditions in the airport. The Approach Control is spatially separated from the airport and the controllers located there cannot view the aircraft movement at the airport. This system helps overcome the drawback by making visible the state of departing aircraft across work units. By *sharing information* through the DSI system the controllers in both work units can integrate their viewpoints and synchronize their perception. They align their work activities through this process which leads to *managing interdependencies* between the GC and RC in making the decisions involved in aircraft departure. This illustrates the relationships depicted in the model presented in Figure 4-1.

The above discussion has presented the three modes of synchronization involved in *Aligning Work Activities* (AWA) across work units, and how the work activities of personnel belonging to different work units are brought into accord and integrate during task performance by synchronizing their actions, decision making, and perception. Associated scenarios from the field data presented here illustrate the relationships between *dependencies, aligning work activities and managing interdependencies* drawn in the conceptual framework depicted in Figure

4-1. In addition, findings of this study revealed that *aligning work activities* is contingent on the ability of personnel to keep each other "in the loop" during task performance. This relationship is also depicted in Figure 4-1. The following section explains and presents a discussion of this aspect of the conceptual framework.

6.4. KEEPING PEOPLE IN THE LOOP AS CONTINGENCY FACTOR

Keeping people in the loop (KPIL) is an important aspect of task performance as without being "in the loop" personnel will not be able to work in concurrence with each other and perform the required synchronization for AWA. KPIL is particularly vital to determine the requirements to cater to, make informed decisions, and perform the necessary synchronization across heterogeneous work units under constantly changing dynamics of situation of task performance. In this study, KPIL (Figure 6- 5) denotes sharing information with personnel involved in task performance and involving them in taking required actions and decisions. This takes place through various communication acts which can be implemented as *anticipatory* and *reactionary interactions*. Another aspect of KPIL is establishing the common understanding required for AWA across the heterogeneous work units. This is influenced by the *form*, *medium*, and *timing* of information exchanged between the involved personnel during task performance.

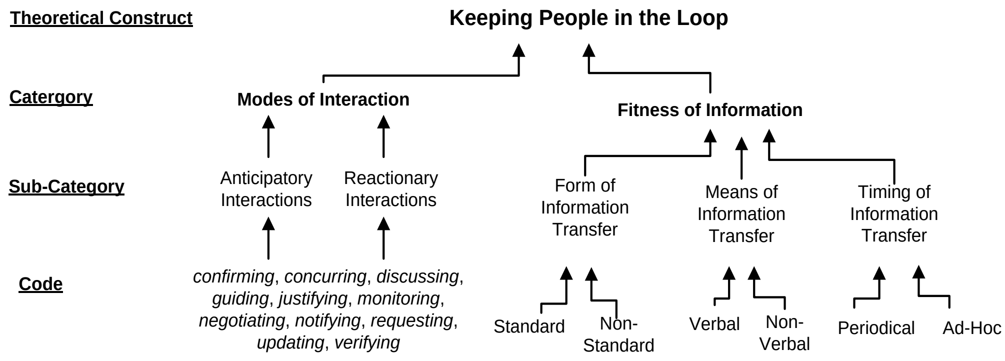


Figure 6- 5 : Codes and Categories of Theoretical Construct: Keeping People in the Loop

6.4.1. Modes of Interaction

The findings of this study reveal that personnel interact during task performance through a number of communication acts which include *confirming*, *concurring*, *consulting*, *discussing*, *guiding*, *justifying*, *monitoring*, *negotiating*, *notifying*, *requesting*, *updating*, and *verifying*. These communication acts take place both verbally and non-verbally, and were found to be performed in two modes: *anticipatory interactions* and *reactionary interactions*. *Anticipatory interactions* occur in preparation for taking actions and making decisions, whereas *reactionary interactions* take place in response to stimuli occurring during task performance. These two *modes of interactions* help establish the knowledge and understanding required by personnel to perform the synchronization required for AWA. This is illustrated below by describing how the communicative act of *confirming* is employed as both *anticipatory interaction* and *reactionary interaction* during task performance.

As *anticipatory interactions*, the communication acts serve to *provide "a look-ahead"* of occurrences in the work environment and state of entities in the work setting. This helps personnel to determine requirements and organize their work activities during task performance. An example of how the communication act of *confirming* is employed as *anticipatory interaction* is depicted in the following transcript obtained from an interview conducted with the Ground Controller (GC) in the Control Tower.

I | *Do you have to give them* (departing aircraft pilot) *any information after they come to the holding point?*

GC | *You might notice on the way in especially on the 08, one might give them the taxi route because they could go in either direction and I choose which way I want to send them. So -------- must be the holding point. In this case Alpha 1. I'll tell them the runway in use 26, just to confirm that and QNH to make sure that -----.*

The above transcript depicts the scenario in which the GC has to direct the pilot of the departing aircraft by providing relevant information. In this case, there are three Taxiways (highlighted in red in Figure 6- 6 :) through which the pilot can reach the Runway.

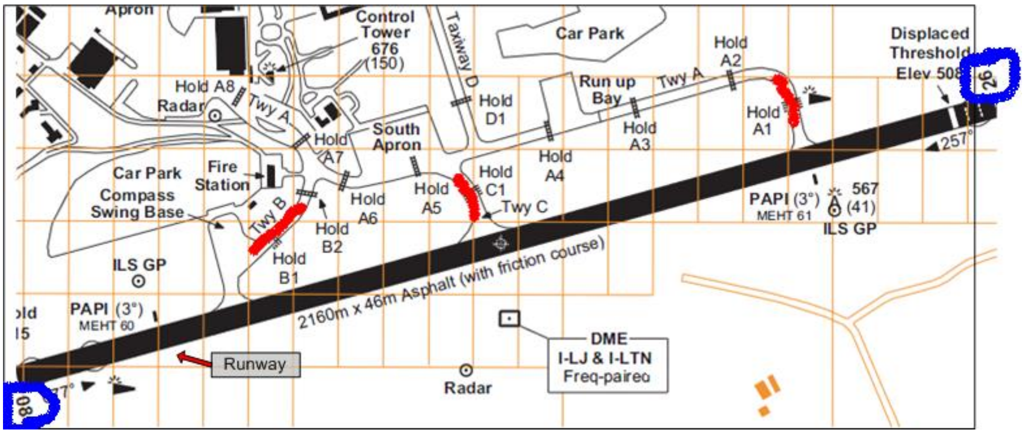


Figure 6- 6 : Aerodrome Layout

The Taxiway to be used depends on the direction on the Runway being currently used to depart and land aircraft on the runway. The information is made available to the pilot of the departing aircraft before departure through the flight information management system as depicted in the transcript given below from an interview conducted with the GC in the Control Tower.

GC | *it will be programmed into their flight management computer that will come up on their screen. They will have a primary flight display which will show them what the aircraft is doing. -------- they will have that route printed on their computer ---*

So, when the pilot contacts the GC to obtain clearance to start moving from the parking stand to the Runway, he or she confirms this information as depicted in the transcript given below from an interview conducted with the GC in the Control Tower.

GC | *When they* (pilot of departing aircraft) *call up for taxi, I will write in the holding points, the runway they are going to and their QNH. These are important information that they should have got.*

Although, the pilot has this information before commencing the departure, the GC confirms it at the time of performing the task. The GC by *confirming* with the pilot the Taxiway to use, the 'holding point' to go to enter the Runway, and the direction of take-off from the Runway, has provided a "look-ahead" of ensuing occurrences in the course of performing the task. By doing this, he has not only confirmed that both pilot and GC have the same information, but also common understanding of the situation that would unfold, thereby synchronizing their perception of forthcoming occurrence while undertaking the task of aircraft departure. Based on this knowledge and understanding both parties synchronize their actions and decisions, and align their work activities in the course of task performance. This illustrates the contingency relationship drawn between *aligning work activities* and *keeping people in the loop* in the conceptual framework presented in Figure 4-1.

On the other hand, *reactionary interactions* depict communication acts taking place in response to stimuli occurring during task performance such as requests and information received from other personnel as well as actions performed and decisions made by others. *Reactionary interactions* help determine actions to be taken and decisions to be made in relation to other's work activities during task performance. For example, in the following transcript, the communication act of *confirming* takes place as a *reactionary interaction*.

I	*What was the call about? What was he* (Pilot of Aircraft in the stand) *telling you?*
GC	*Fox76 is the Engine Run... they want to do on their stand…. underneath the Thompson sign... he wants to push out initially just onto the stand… so all I was confirming if he was going to be sticking out his bump out onto the taxiway.*

The above transcript depicts the scenario of performing aircraft maintenance operation (Engine Run) in the airport. In order to do this the pilot of the aircraft has to obtain permission from the Ground Controller (GC) in the Control Tower. Since, the pilot wanted to perform this operation in the stand and "push out" the aircraft from the stand; this could have obstructed movement on the Taxiway. Hence, the GC confirms with the pilot that this is would not be the case. This communication act has been labelled as *confirming* and not *verifying* because the pilot also knows that he cannot obstruct the Taxiway while performing the operation. The GC by confirming the knowledge and understanding of the pilot has established the common understanding required for *aligning work activities* across the work units, thus demonstrating the contingency relationship drawn between *aligning work activities* and *keeping people in the loop* in Figure 4-1.

6.4.2. Fitness of Information

The findings of this study reveal that the *form*, *medium*, and *timing* of information exchanged between personnel across different work units affects their ability to keep each other "in the loop" during task performance.

Form of Information Transfer (Standard and Non-Standard)

Personnel employ both standard and non-standard forms of information transfer during task performance. The former refers to the use of standardized mechanisms set by the organization for communicating with others. An example of this is the use of *standard phraseology* for transferring information across different work units. The following transcript is obtained from an interview conducted with the Ground Controller (GC) in the Tower Controller illustrates this.

GC	*Um, yeah so lets just say you want to exchange information. There is everyone kind of passing information. You have to pass on the information to the fire service. When you do that you do it in a standard message. You have 7 or 8 different emergency categories. So you don't just press the alarm and say there is one coming in and he has got an engine fire. So you have to categorise it in one of the categories. So for an engine fire I would probably say full emergency. And then go on to say full emergency and if it is a big aeroplane, you have to put it in A, B, or C. so they know how big it is. So it will be full emergency, category alpha, engine fire, 3 minutes, runway two six. So these standard kind of message for everything. So it can be easily communicated.*

In the above example, the GC explains the standard mechanism used for transferring information to the fire service in case there is a problem with an aircraft such as 'engine fire'. The *form* in which the information is disseminated follows a standard as described in the above transcript, which helps establish the understanding required for AWA. One of the consequences of *straying away from standards* during information transfer across work units is personnel misconstruing the interpretation of information as described in the following transcript by the Tower Controller in the Control Tower.

TC	*I think one thing you cant do, eh…, you can never really joke, it is quite hard to joke. You have to be really careful. Because all I got is the voice control …..things like standard flight instructions, we have standard flight… and that's because there is a possibility of being misunderstood, whenever you have to stray way from whats standard, if you have to explain something non-standard, like to, most bizarre situation, I mean anything can happen. Like*

the dog running loose on the taxiway. So you aren't going to say to a flying pilot there is a dog loose on the taxiway. We stick to our standard ….hold position. You don't want to go into all the details. I mean it is nice if you can try and explain things as much as you can. All you need is only get the basics across to get them to do what you want them to do.

Hence, standardization of information representation and dissemination facilitates ease of communication and similar interpretation of information by personnel across different work units. Besides, adherence to standard form of information representation allows personnel to identify issues and problems during task performance as standardization allows them to set expectations. When there is a deviation from the standard it draws attention as well as points out issues and problems.

The communication between personnel from different work units also takes a non-standard form such as that taking place between the GC in the Control Tower and Controllers in the Operations Centre depicted in the following transcript of an interview conducted with the GC in the Control Tower.

I *Yeah. Have you had any such incidents with the operations centre down there in the airport?*

GC *…….That's quite a different dilemma because you sort of…* (Gives instructions)*… It is kind of hard to generate incidents from the kind of communications that we have with them.*

I *Because it takes time to discuss and confirm things with them?*

GC *Not because of that. Because, um, the things that we are discussing, if they were mis-communicated, the chances of miscommunications on that would the same as if you were ringing up the plumber from your house. And you said I need the boiler fixing. That's the kind of thing. it is telephone to telephone which is more sort of human communication and we don't use this sort of set phrases and standard phraseology so much. The moments you could, I mean the possibility is always there of misunderstanding but rarely rarely happens.*

Here, although the communication between the GCs in the Control Tower and Operations Centre does not take the standard form, the opportunity for misunderstanding information exchanged is limited. Keeping people in the loop through verbal communication over the telephone allows for clarifying information exchanged and establishing required understanding for *aligning work activities*. However, when it is mediated through technology, communication is structured by organizational norms and personnel are required to adhere to the set standards of operation.

Means of Information Transfer (Verbal and Nonverbal)

As described above, communication between personnel across work units takes place through verbal and non-verbal means, and occurs both explicitly and implicitly. In terms of verbal communication, it takes place explicitly through information exchange over the telephone, and implicitly by keeping a *"listening watch"* which implies overhearing other's verbal communication.

There are different medium through which personnel exchange information non-verbally across the different work units, one of which is *visual observation* of each other's activity. This is observed primarily in the activities of personnel functioning in the Control Tower, pilots, and ground staff as their physical location in the work settings facilitates this. For example, the controllers in the Control Tower can visually observe the movement of aircraft arriving and departing from the airport. Similarly, they can observe the actions of ground vehicles and ground staff in the Apron area of the airport. Visual observation also takes place through the aid of technological artefacts when the physical location and setup of the work unit does not permit direct visual observation. These artefacts provide a dynamic representation of the occurrences in the work environment such as the Radar in the LTCC and CCTV cameras in the Operations Centre.

Another medium of non-verbal information exchange is through information representation and dissemination artefacts. These artefacts present both pre-planned and dynamic information. Each work unit is equipped with such artefacts which helps personnel to share information across different work units. They are labelled as *common information artefacts* in this study. Examples of such artefacts in the studied setting are presented in Figure 6- 7. Besides providing means of information exchange across work units, the *common information artefacts* were identified to present certain characteristics for KPIL (Figure 6- 7, Figure 6- 8 :).

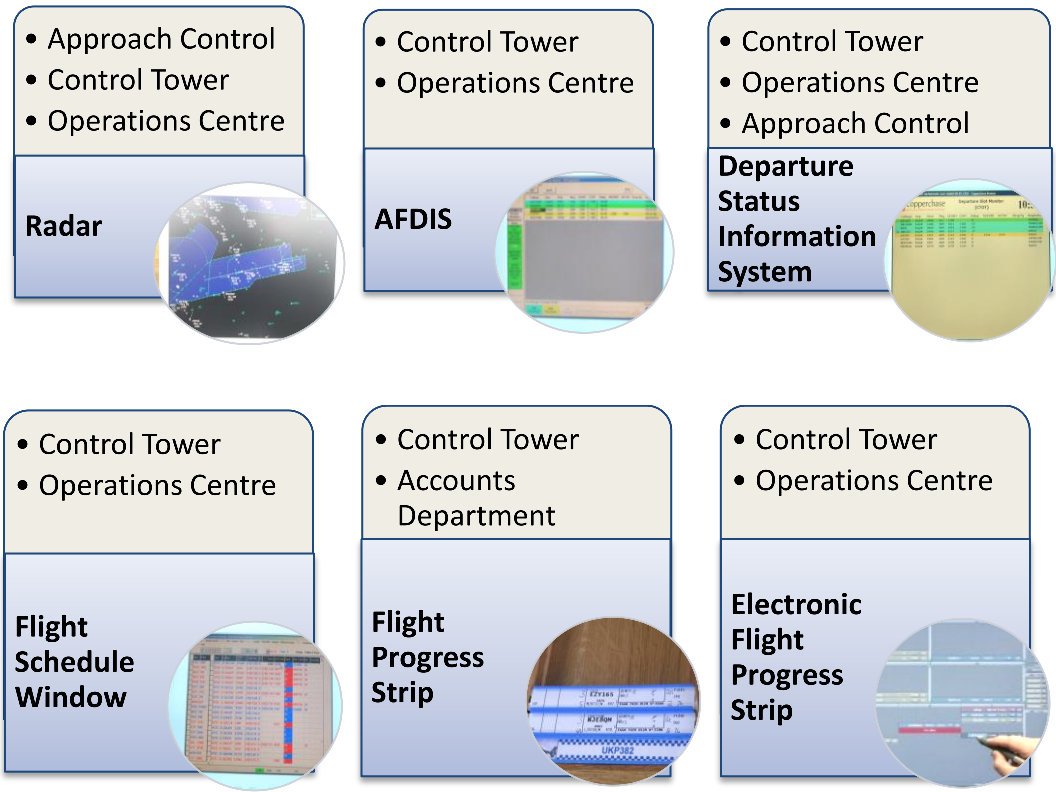


Figure 6- 7 : Common Information Artefacts between Work Units 2021

Changes made to the information represented in these artefacts indicate various aspects of task performance such as status of work activities of

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[20] AFDIS – Aircraft Flight Display Information System

[21] Electronic Flight Progress System image obtained from : http://www.airport-int.com/upload/image_files/suppliers/gallery/2737/thumb_air-traffic-management-systems/electronic-flight-strips.jpg

personnel, action completion, and task handover. This was found to allow the artefacts to function as tools that serve as a record keeping system, reminder setting system, notification system, information updater, and "good communication system". Such functions facilitate personnel to keep track of changes occurring during task performance, gain general overview, assess other's task performance status, assess situation in which task performance takes place, and determine any issues or problems arising during task performance. Thereby, the *common information artefacts* facilitate sense making, aid memory, and direct attention. Furthermore, making changes to information represented in the *common information artefacts* has various implications for AWA across work units such as triggering, sequencing, handing over tasks, and representing closure of actions (Figure 6- 8).

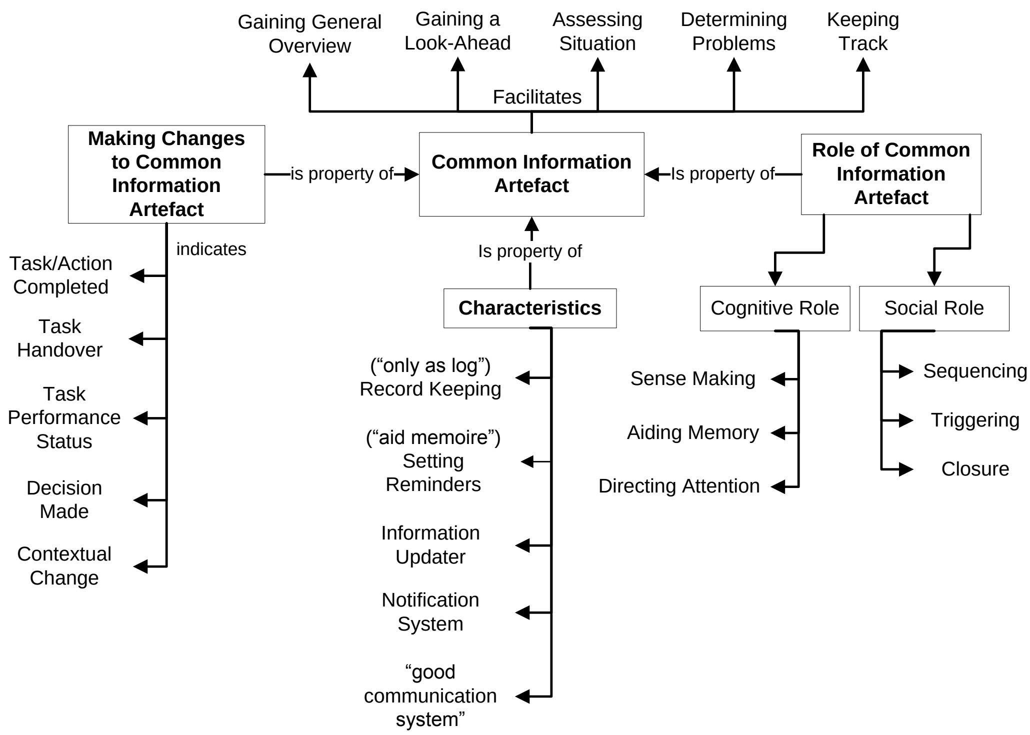
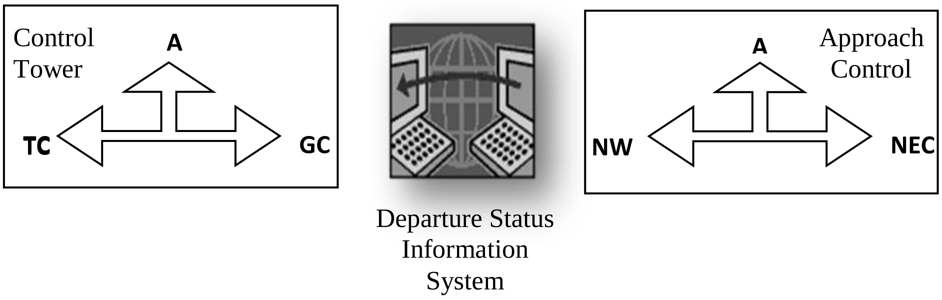


Figure 6- 8 : Characteristics of Common Information Artefact Identified during Data Analysis

Common information artefacts not only help personnel to determine their individual actions, but also structures communication and coordination between those across the different work units. This is depicted in the use of the Departure Status Information System (DSI) and illustrated in the following transcript of an interview conducted with the Ground Controller (GC) in the Control Tower.

GC | *The 'Departure Status Information' screen is used to give messages to the Radar Centre* (Approach Control*) as to what state the traffic is in the airport. When I* (ground controller) *give an aircraft pushback or annotate it with an active sign, the Assistant at the Radar Centre will put the strip in front of the Coordinator there. When it taxis out to the holding point, our Assistant will then put a hold and again take-off on her Departure Status Information screen. So basically what it is situation awareness with the Radar centre down the road? Delay, if he decided he couldn't go now…if he has got a technical problem or if the passengers haven't turned up, the strips sitting out there now at the Radar Centre (now I've done that), they don't want loads of strips cluttering their bays if they are not going, so if it wasn't anything going I will press the delay button… the assistant would probably go and pick the strip off the display, put it back in the pending bay, to remove the strips off the board because there are a hell of lot of strips down in the Radar because they have a lot of traffic to deal with…*

The DSI system is used "in common" by air traffic controllers functioning in the Control Tower and Approach Control (Figure 6- 9). Each controller is equipped with a DSI system and uses it to communicate with others by making changes to information represented in the system. In the above scenario, the GC in the Control Tower informs the Assistant in the Approach Control about the status of a departing aircraft by making changes to the information represented in the DSI system. The changes made reflect the instruction given to the aircraft pilot by the GC at different stages of aircraft departure from the airport. The information in the DSI system is constantly updated to reflect the departing aircraft movement in the airport. The Approach Control is spatially separated from the airport and the controllers functioning from there cannot view the aircraft movement in the airport. This system helps overcome the drawback by creating awareness of the state of the departing aircraft across work units. Based on the information provided by the system, the Assistant in the Approach Control then works in concurrence by performing actions in response to the changes made to the *common information artefact*. Hence, these artefacts act as a mediatory device which is employed for KPIL and mediating the synchronization involved in *aligning work activities* across the different distributed work units.



A – Assistant, TC – Tower Controller, GC – Ground Controller
NWC – North West Coordinator, NEC – North East Coordinator

Figure 6- 9 : KPIL across Work Communities through Common Information Artefact - Departure Status Information System

Timing of Information Transfer (Periodical and Ad-Hoc)

The timing of information transfer across work units is an important factor affecting KPIL and consequently AWA. The way personnel interpret information transferred across work units and discern its relevance to their usage is influenced by the timing of information exchanged across work units.

For example, in the case of receiving notifications from other work units, as illustrated below in the scenario of the Tower Controller (TC) in the Control Tower receiving a warning from the Coordinator in the Approach Control about a light aircraft “straying” into the control zone.

TC | *X got a call from a coordinator about a "wildie" light a/c that appeared to be lost and had strayed into the control zone. Not in radio contact and squawking 7000. Required careful monitoring, but in the end posed no threat.*

The timing of information transferred across the work units makes a difference in the way the TC interprets the information shared and its relevance to her activities. If the Coordinator had provided the information after the light aircraft had moved out of the control zone it would not have affected the activities of the TC and hence, would not have been held in importance. Although, in this case the aircraft did not pose any threat to the traffic movement in and out of the airport, the consequence of not having provided the information at the right time could have been dire since the aircraft was not in "radio contact". Hence, the timing of information exchange plays an important role in KPIL across the work units.

Determining the "right time" for information transfer is based on various factors such as the context of work and the procedure to be followed to perform tasks. It emerged from the data that there are two ways in which timing of information transfer can be managed. One is by undertaking periodical information transfer which occurs at fixed intervals as illustrated by the following field-note taken while observing the work activities of the Assistant in the Control Tower.

> *Another role of the assistant is to make weather observations and pass on the information to the controllers and to the pilots. The assistant has to make weather observations every half an hour and make entries into a system called the Copperchase Weather Editor which contains information about the climatic condition in and around the airport*

Another way in which periodical information transfer is undertaken is in an ad-hoc manner as and when the requirement arises. This is presented in the above example of an aircraft "straying" into the control zone.

Based on the findings of this study, the inference is that communication is key for *synchronizing actions*, *decision making*, and *perception* of personnel participating in decision making and is achieved by KPIL during task performance. It takes place through various communication acts which are implemented as *anticipatory interactions* and *reactionary interactions* through which personnel not only share information but also involve others in decision making. Furthermore, KPIL helps them to determine the requirements to be fulfilled, and establish the common knowledge and understanding required for performing required synchronization. The intervening condition for KPIL is emerges to be *fitness of information*. The *form*, *means*, and *timing* of information transfer taking place during *anticipatory* and *reactionary interactions* determines the ability of personnel to synchronize their actions, decision making and perceptions.

6.5. Consequence: Mode of Collaborative Decision Making

The findings of this study reveal there are variations in the way CDM is undertaken based on the dependencies arising during decision making and the way they are managed. These variations are depicted during data analysis in the theoretical construct - *mode of CDM*. This comprises four modes including *sequential*, *mutually consented*, *manipulative*, and *emergent decision making* (Figure 6- 10).

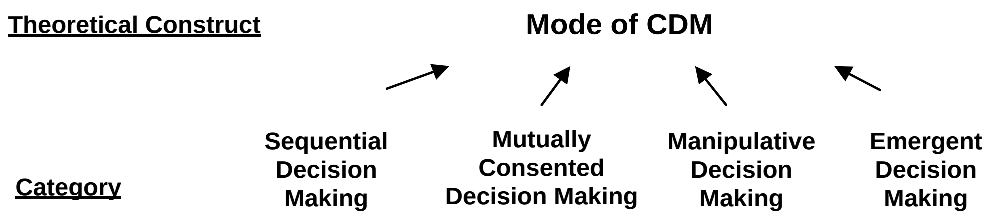


Figure 6- 10 : Modes of Undertaking Collaborative Decision Making

The emergence of these modes of undertaking CDM from the data is described below. In the figures presented, P represents personnel and D represents decision.

6.5.1. Sequential Decision Making

This mode of CDM involves personnel making decisions in response to stimuli provided by others during task performance. The stimuli were identified from the data to be information provided, actions performed and decisions made. In this mode, decision making is collaborative not in the traditional sense where personnel jointly make decisions. Instead, decisions are made individually but decision making becomes a collaborative act through the actions and interactions arising in consequence to the decision made. A decision made by one person necessitates another decision to be made in response by others undertaking the task (Figure 6- 11).

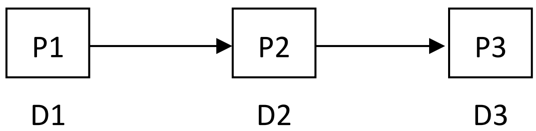


Figure 6- 11 : Diagrammatic Representation of Sequential Decision Making Activity

The data shows that during task performance the stimuli for *sequential decision making* are provided by two main communication acts: *notifying* and *requesting* (Figure 6- 12). *Notifying* occurs to inform others about one's status in task performance (such as decision made, action completed, action intended to be performed, and action required to be performed by others). It also occurs to provide information required by other personnel involved in task performance. In the studied work setting, *notifying* takes place verbally over the telephone and non-verbally through various information representation and dissemination artefacts.

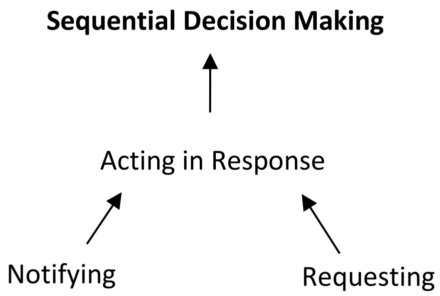


Figure 6- 12 : Related Categories of Theoretical Construct: Sequential Decision Making

Another stimulus for *sequential decision making* is *requesting* other personnel to provide assistance during task performance. Explicit verbal requests are made for necessary actions to be performed by others. Consequentially, they in turn have to make decisions in order to provide the required assistance.

The distribution of work activities across different work units and the ensuing stratification in the work process bestows personnel with certain authority in task performance. Nevertheless, their work activities are interconnected. Hence, they need to request permission from each other to perform certain actions during task performance. The two forms of stimuli - *notifying* and *requesting* - lead to personnel *acting in response* by making decisions reciprocal to that made by others during task performance. Figure 6- 13 presents the codes and sub-categories related to *sequential decision making* generated during data analysis.

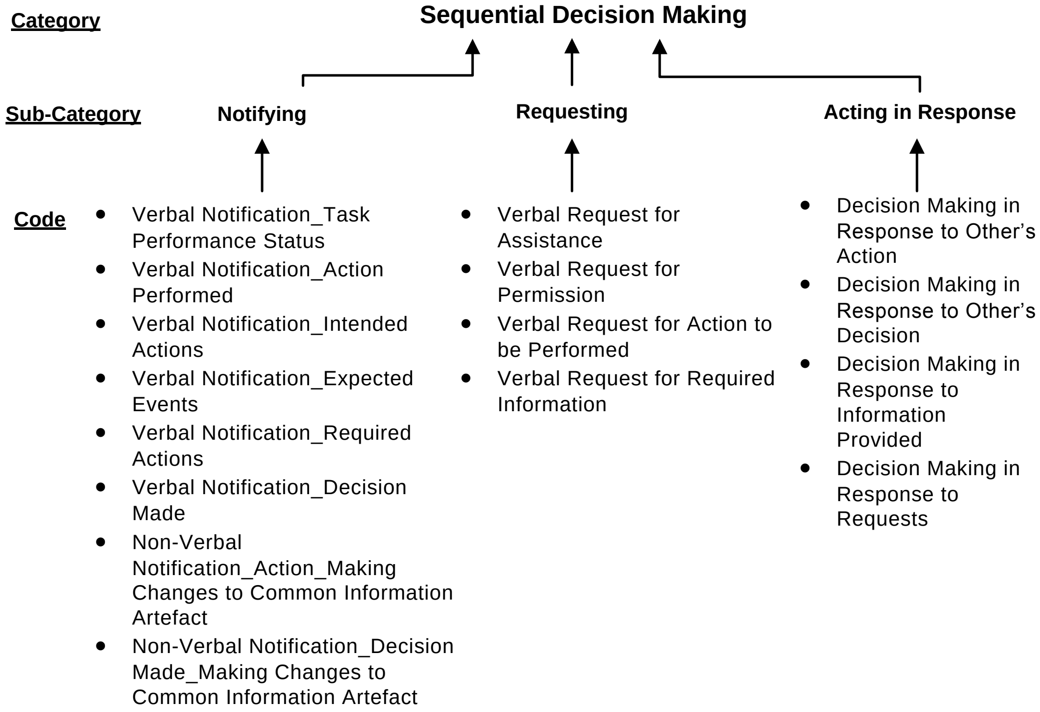


Figure 6- 13 : Codes and Categories of Theoretical Construct: Sequential Decision Making

Although this form of decision making involves making various decisions at separate points in time by different individuals, the decisions are accumulated and brought together through the actions and interactions taking place between personnel in the course of task performance. The following scenario obtained from one of the observation sessions conducted during the field studies in the Control Tower illustrates the sequential mode of CDM.

> *While making the routine weather observation, the Assistant notices that the temperature indicator was not giving proper reading. So she called the workshop and notified them. They sent their engineers to check the temperature sensor near the runway. The engineer calls the tower controller to give him the reading from the sensor. (Typically the engineer should call the Assistant but he could not get through to the Assistant's telephone. So calls the tower controller on his frequency). The tower controller passes it onto to assistant and asks her to make a comparison between the readings from the sensor and that displayed by the digital temperature indicator. The TC then passes on this information back to the engineer.*

In the above scenario, when a problem (system failure) arises during task performance (weather observation), a decision (D1) to notify the workshop personnel is made by the Assistant (P1) in an attempt to solve the problem. So, P1 notifies the workshop engineers about the problem. This causes involvement of the engineer (P2) from the workshop. In consequence, a decision (D2) has to be made by the Engineer (P2) to solve the problem. This requires him to interact with the Assistant in the Control Tower. However, he is not able to get through to the Assistant on her telephone line. So he decides to call the Tower Controller (TC) on his telephone frequency. The decision made by P2 causes involvement of the TC (P3) who mediates the interaction between P1 and P2.

In this example, a decision made by P1 causes involvement of P2 whose decision in turn causes involvement of P3 in undertaking the task. Joint involvement takes place as a consequence of the decision made by each personnel. CDM in this case does not involve personnel coming together to arrive at a decision in consultation with each other. Instead, decisions are made individually without consultation with others involved in the task performance but gains implicit acceptance by others, who by performing the necessary consequential actions indicate they acknowledge and conform to the decision. Moreover, the decision made is not explicitly communicated to other personnel. Instead, it is embedded in the information transferred when *notifying* and *requesting*.

P1, P2 and P3 are dependent on each other to rectify the problem with the temperature indicator. This involves P1, P2, and P3 *aligning work activities* by synchronizing their actions, decision making and perception to manage arising dependencies. *Managing interdependencies* structures action and interaction between P1, P2 and P3 which leads to decision making becoming a collaborative act of a sequential form. The above scenario illustrates how the sequential mode of CDM emerges in consequence to *managing interdependencies* between personnels work activities and demonstrates the relationships presented in the conceptual framework of CDM depicted in Figure 4-1.

6.5.2. Mutually Consented Decision Making

In mutually consented form of CDM, personnel from different work units jointly make decisions during task performance (Figure 6- 14). This takes place overtly or tacitly. Overtly, *mutually consented decision making* takes place through verbal interaction during which one individual takes the initiative by either proposing his or her intended decision to others or places request for necessary decisions to be made to undertake the task. This entails *discussion* between involved personnel and the proposed decision is either accepted, rejected, changed, or a new decision is made. Alternatively, this takes place tacitly by personnel acknowledging decisions made by others and displaying their agreement by performing the necessary consequential actions.

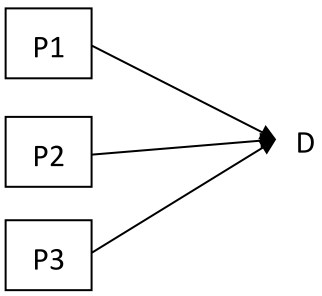


Figure 6- 14 : Representation of Mutually Consented Decision Making Activity

It emerged from the data that mutual consent of decision is established by *getting approval* from others for decision made or action to be taken, *confirming* decision made or intended action with others, and "*working things between*" each other in order to arrive at a decision (Figure 6- 15).

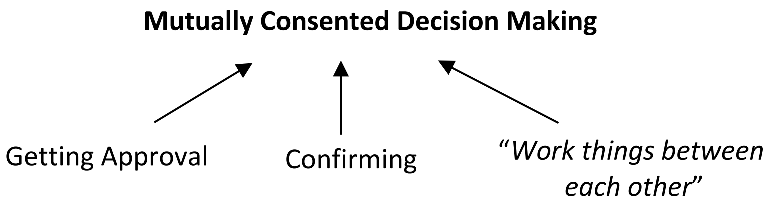


Figure 6- 15 : Related Categories of Mutually Consented Decision Making Activity

The codes and sub-categories generated during analysis in relation to *mutually consented decision making* are presented in Figure 6- 16 : .

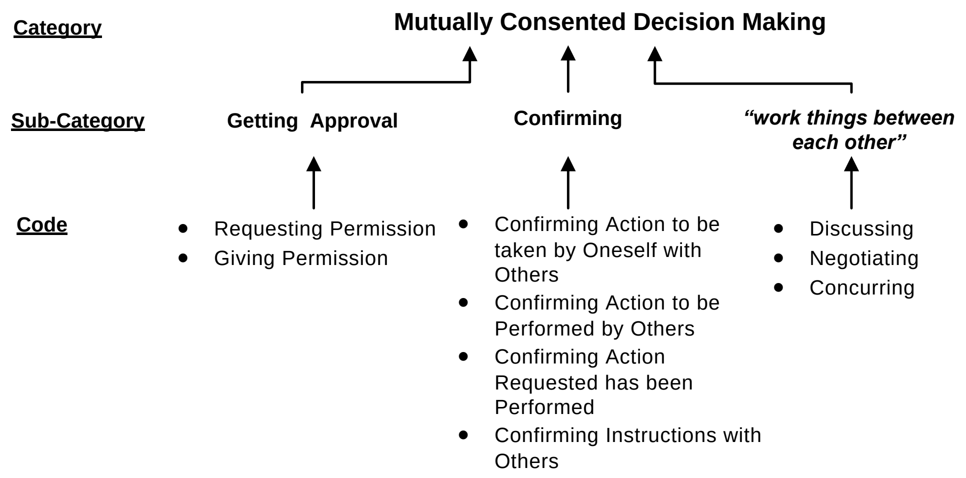


Figure 6- 16 : Codes and Categories of Theoretical Construct: Mutually Consented Decision Making

Establishing mutual consent by *getting approval* and c*onfirming* is a straightforward process of verbally verifying decision or action to be taken with other personnel. This is primarily undertaken because of the protocol arising from the stratification in the work process and takes place through standardized communication. The stratification is embedded in the work procedure to be followed during task performance. This includes *requesting permission* from other personnel to implement decisions made, who then demonstrate their consent by *giving permission*. This process of establishing mutual consent transpires from individuals *exercising authority* during task performance. A scenario obtained from the data illustrating this process of establishing mutual consent is presented below. The transcript is obtained from an interview conducted with the Ground Controller (GC) in the Control Tower.

GC *If they want any maintenance work to be done they need the permission of the Apron Control first. The airline operator or the maintenance operator will call the Apron Control. Say for example if that aircraft want to do a 'compass swing' and they say 'yeah'. There is no booking time for the compass swing and they say 'yeah, you can do it at that time. Giving you permission'.*

According to the standard procedure, when the decision is made to perform maintenance work on an aircraft, the associated airlines 'handling agent' has to first obtain permission from the GC in the Control Tower. They need to provide information about what kind of maintenance work needs to be done (such as 'compass swing') and when they would like to do it. The GC then decides if it is permissible depending on the location in the airport where the maintenance work will be performed and the traffic moving on the Taxiways. The GC grants permission once he determines that it is permissible to do. This process establishes mutual consent on the decision to conduct maintenance work on the aircraft.

Another means of obtaining mutual consent is by personnel *confirming* decision taken or action to be performed with others involved in task performance. The following scenario presents an illustration of personnel indirectly *confirming* decision made by others when performing the task of guiding the landing of an aircraft approaching the airport. The transcript is obtained from an interview conducted with the Tower Controller (TC) in the Control Tower.

TC *When we haven't got the Instrument Landing Systems operating, we have to have the ILS beam operating, poor weather when they don't have normal visual range. We normally get a call on the telephone at about 4 miles, and you tell them that the runway is clear to land and if its not you give a missed approach for it, if it is getting close Radar might call up on the priority line. But that's just a case of getting the Radar of calling us and finding out if the runway is clear or not. The Radar control is going to have faith in the Tower Controller to make sure the runway is clear. He can see what is coming*

> *down in the Approach. That's why coordination is difficult, because you are dealing with an aircraft that is landing on my runway and he is sitting in a Radar centre that is 20 miles away. So that's why you have to play by the rules.*

According to the standard procedure the TC in the Control Tower decides whether to give clearance to the approaching aircraft pilot to land on the runway or give a "missed approach" if it is not permissible. However, the above situation is an exception as there is insufficient time for the Radar Controller (RC) in the Approach Control to transfer control of aircraft to the TC in the Control Tower. Therefore, the RC decides to guide the aircraft landing. He calls the TC on the priority telephone line to confirm if the Runway is clear or not. Since the RC is located away from the airport and does not have a direct visual observation, he needs the TC to confirm if it is safe to land the aircraft on the Runway. When the TC confirms that it is clear he has given his consent to the decision made by the RC.

A more elaborate process for establishing mutual consent is depicted by the category "*work things between each other*" which includes *concurring*, *discussing* and *negotiating* decisions or actions to be taken. This is particularly a complex process when there are problems to be addressed during task performance or when optimizing it. An example of personnel *working things between each other* to optimize task performance is presented in the following scenario. The transcript is obtained from the field-notes taken during the observation sessions conducted in the Control Tower.

> *There is a light aircraft waiting to take off at holding point C1* (see Figure 6- 17) *and a police helicopter at holding point B1. Also, there is an approaching aircraft on runway 08. The TC (exclaiming "This is going to be a good one!") wants to send these two VFR flights and land the approaching aircraft at the same time. He can allow the two flights to take-off at the same time because they take different departure routes*

once they take-off. He calls the Approach Control and asks them to slow the approaching aircraft so that he can get these two aircraft to take-off and manages to do all three within a minute. Approach Control agrees.

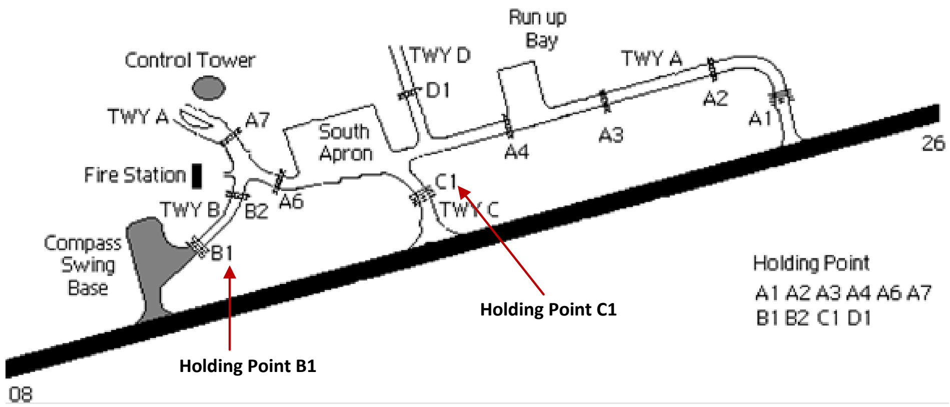


Figure 6- 17 : Diagrammatic Represented of Airport Taxiway and Runway

Here, P1 (TC) requires P2 (Approach Controller) to make a decision in order to optimize P1's performance in undertaking the task. P1 makes a decision to optimize the task performance by simultaneously allowing landing of an approaching aircraft and take-off of a helicopter and an aircraft on the Runway. Since P1 needs to arrange the time gap to schedule the three operations he needs P2's assistance. So, P1 explains his intentions and requests certain action (slow approaching air traffic) to be performed by P2. Consequentially P2 has to make decisions about whether to perform the requested action or not. P2 by deciding to do as requested consents to P1's decision. The outcome is an implicit mutual consent of decision made by P1.

The above scenarios demonstrate the mutually consented mode of decision making. In each of the scenarios, personnel are dependent on each other to perform the task and *managing interdependencies* consequentially leads to the mutually consented mode of CDM. For instance, in the scenario of TC optimizing the take-off and landing of three aircraft simultaneously, he is dependent on the Approach Controller to undertake the operation. They both align their work activities by synchronizing their actions, decision making and perception. The actions and interactions taking place between them in *aligning work activities* are structured by the *dependencies* arising between their work activities. *Managing interdependencies* between the TC and Approach Controller leads to decision making becoming a collaborative act through mutual consent. The above scenarios illustrate how CDM emerges in consequence to *managing interdependencies* between personnels work activities by aligning their work activities and demonstrates the relationships presented in Figure 4-1.

6.5.3. Manipulative Decision Making

In the studied work setting, decision making is highly procedural and stratified. However, personnel device ways to work around the procedure and stratification to elicit decisions from others that would cater to their individual needs. Personnel tend to manipulate decisions made by others during task performance to fulfil their needs by influencing the context on which the decision making rests. In Figure 6- 18, P1 influences the decision made by P2 by modifying the context on which decision made by P2 emanates.

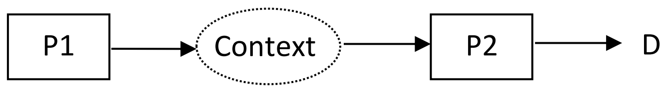


Figure 6- 18 : Representation of Manipulative Decision Making Activity

The following scenario illustrates the manipulative form of CDM. The transcript is obtained from the field-notes taken during observation sessions conducted in the Control Tower.

> *Appears that two flight plans (HCY441 and HCY441A) were filed for the same aircraft. Explanation given (by GC) was that the airline hedges their bets by filing twice to get the best route or slot or whatever, deciding later which one to use. Controller called several times to Helios 441 with no response, and then called Helios 441 alpha and got an immediate reply - so aircraft had decided which one it was.*

In this case, according to the procedure to be followed, the decision made by P1 (GC) determines the actions to be performed by the P2 (pilot) during task performance (aircraft departure). The decision to be made is the aircraft departure time and the exit route from the airport. However, P2 through his actions is *working around* authority and *bypassing standard procedure,* and thereby manipulates the decision made by P1 to suit his needs (Figure 6- 19 :). Hence, he is indirectly collaborating to make the decision.

Category — **Manipulative Decision Making**

Code
- Bypassing Standard Procedure
- Working Around Authority

Figure 6- 19 : Codes and Categories of Theoretical Construct: Manipulative Decision Making

In this scenario, P1 and P2 are dependent on each other to perform the task of aircraft departure. P1 requires the P2 to register the flight plan and P2 requires P1 to give him clearance to take-off. Managing this interdependency involves P1 and P2 aligning their work activities by synchronizing their actions and decision making. The above scenario illustrates how the manipulative mode of CDM emerges in consequence to *managing interdependencies* and demonstrates the relationships presented in the conceptual framework of CDM depicted in Figure 4-1.

6.5.4. Emergent Decision Making

In the studied work setting, actions and interactions involved in undertaking CDM vary with the changing situation of task performance. *Emergent decision making* is a category emerging from the data analysis which captures this form of CDM. The codes and sub-categories forming this category are presented in Figure 6- 20.

Category	**Emergent Decision Making**	
Sub Category	***"it purely depends on the situation"***	**Making Tactical Changes**
Code	• Deciding Course of Action_Based on Current Situation • Deciding Course of Action_Based on Expected Situation • Deciding Course of Action_Based on Time Constraint • Providing Information at the Right Time • Providing Timely Assistance	• "changing the plan quickly" • Choosing Alternative Ways of Performing Task

Figure 6- 20 : Codes and Categories of Theoretical Construct: Emergent Decision Making

CDM in the studied setting is influenced by the changes taking place in the work environment. It is based on the conditions raised by current and expected situations, including time constraints arising during task performance. For example, the following scenario presents an example of how the intensity of communication between personnel from different work units varies with change in situation during task performance. The following extract presents part of the transcript of an interview conducted with the Tower Controller (TC).

I	*How often do they* (tower controller) *have to telephone the Radar Control?*
TC	*If it's a busy day where you have got lots of inbounds and lots of outbound. You might be on the phone with them up to a few minutes. On a quiet day when there are natural gaps in traffic and if it is not too busy you might not have to phone to them.*
I	*So it depends on the situation?*
TC	*It depends purely on the situation on what's going on, how complex the traffic situation is, any instance going on. I sat in the tower position when I came in and I was there for an hour and a*

> *half and I probably spoke to the radar controller for maybe 5 times. That's all. If considering the quite bad weather, because there are hardly any inbounds there is no reason to arrange for gaps. The only thing I had to do was to arrange for one gap and that rest was to do with coordination due to deteriorating weather.*

In the above scenario, the TC in the Control Tower and Radar Controller (RC) in the Approach Control have to jointly make decisions to determine gaps between aircraft arriving into the airport in order to make space for aircraft departing from the airport. The intensity of communication taking place between them varies during 'peak' and 'non-peak' traffic hours during the day. In the above scenario the communication between the controllers in the Control Tower and Approach Control lessened considerably due to bad weather. The change in situation changes the intensity of communication taking place from every few minutes during heavy air traffic to few times, and sometimes no communication takes place between the TC and RC. Thus, actions and interactions involved in undertaking CDM vary with the changing situation type. Hence, the way decisions are made collaboratively unfolds and is altered with changing situations.

In this scenario, The TC and Radar Controller are dependent on each to manage the air traffic movement in and out of the airport. They manage the interdependencies by aligning their work activities. This involves synchronizing their actions, decision making and perception to arrange gaps between arriving aircraft to make space for departing aircraft. As illustrated in this scenario, the consequence of this process is decision making becoming a collabraotive act. This demonstrates the relationships depicted in the model of CDM presented in Figure 4-1.

The *modes of CDM* presented above help elicit the variation in the way CDM is undertaking across work units in a real world complex work setting. It is construed from the analysis of these modes that CDM is not just about personnel coming together at a particular point in time to form consensus or agreement, but is an ongoing activity taking place along a temporal continuum. This entails the convergence of decisions, actions and interaction of multiple personnel in the course of task performance. Furthermore, undertaking CDM entails accumulation of various decisions and actions of multiple personnel, thereby becoming a cumulative activity. It is also momentary as CDM is emergent with the changing dynamics of the situation of task performance. Thus, the way it is undertaken needs to be renegotiated with the changing situation and actions and interactions tailored accordingly.

6.6. SUMMARY

The chapter explains the emergence of *managing interdependencies* as the 'core category' in the Grounded Theory analysis. Also, *aligning work activities* and *keeping people in the loop* are presented as two key processes involved in managing the interdependencies arising during decision making. Different modes of undertaking CDM was identified through the analysis of data collected. An account of the way this arises in consequence to *managing interdependencies* is presented. The emergence of the theory of CDM as a process of managing dependencies by establishing relationships between these theoretical constructs through the 'Six Cs' coding family has been explicated. The next chapter discusses the key findings of this research.

CHAPTER 7

A DISCUSSION OF THE THEORY OF COLLABORATIVE DECISION MAKING

7.1. INTRODUCTION

The theory presented in this thesis explicates the occurrence of Collaborative Decision Making (CDM) in the cooperative arrangement of real world complex work settings. A reflection of the main findings of this research described in the previous three chapters is presented here. The motivation of this thesis arising from the concerns outlined in chapters 1 and 2 are revisited. The key findings and its interpretation are discussed in relation to the disparities in existing perception of CDM in complex work settings including the notions of CDM as a 'choice-point' event, a process of achieving common goals and consensual decision, and an activity of sharing information and mental models. Based on the clarifications made a new definition of CDM is derived from the developed theory. The chapter concludes with an evaluation of the Grounded Theory developed in this research.

7.2. Collaborative Decision Making (CDM) in Complex Work Settings

The cooperative arrangement of complex work settings necessitates that decision making takes place in collaboration with other personnel, which is characterized as Collaborative Decision Making (CDM) in this thesis. The findings indicate that when undertaken in the course of task performance in this arrangement, CDM does not occur as an isolated event at a particular instance when multiple personnel gather with the explicit aim of arriving at a decision. Instead, it is directed towards the task undertaken and integrated with work activities of the involved personnel. Furthermore, the theory of CDM presented in this thesis explains how undertaking CDM in the cooperative arrangement of complex work settings involves managing the distribution and interconnections in decision making in this setup. The associated conceptual framework presented in chapters 4,5 and 6 depicts this as a process of managing interdependencies.

The theory of CDM presented in this thesis explains how undertaking CDM in the cooperative arrangement of complex work settings involves managing the distribution and interconnections in decision making in this setup. The conceptual framework presented in chapters 4,5 and 6 depicts this as a process of managing interdependencies. In section 3.7. the essential elements of a theory considered for the purpose of this research were indicated to be:

- factors (variables, construct, concepts) considered to be relevant to explain the phenomenon of interest
- relationship between identified factors that delineate patterns and causal relationships

- underlying dynamics (such as psychological, economic and social) that justify the selection of factors and proposed relationships

In view of the first element mentioned above, chapters 4,5 and 6 demonstrate the emergence of concepts during data analysis which were identified to explain the occurrence of CDM in a complex work setting. The concepts include the codes and categories generated from the data through Grounded Theory Methodology (GTM). As described in chapter 3 (section 3.7.2) the theory generated through this methodology is about a concept which is the 'core variable' and its related concepts that account for the occurrence of the subject of inquiry (Glaser, 2001, pg. 199). In this thesis, the theory of CDM is positioned on the 'core category' emerging during data analysis which is managing interdependencies and its related concepts that together account for the occurrence of CDM (Figure 4- 1).

Furthermore, the second element of a theory mentioned above indicates that that it should provide relationships between identified factors. This corresponds to the desired outcome in GTM to present clear concepts and relationships explaining the matter of inquiry. The theory of CDM developed in this research presents clear relationships between the theoretical constructs formulating the conceptual framework as depicted in Figure 4- 1. The key constructs of the theory are structured by adapting the 'Six Cs' theoretical coding family prescribed in GTM which include Cause, Context, Contingency, Consequence, Covariance, and Condition. Besides, few other coding families were employed to draw relationships between the constructs as depicted in Figure 3- 14. The conceptual ideas formulated in the theory of CDM are based on the relationships drawn through these theoretical coding families. This allows plausible hypothesis to be drawn about the occurrence of CDM in the cooperative arrangement of complex work settings.

For instance, in a real world complex work setting, CDM is undertaken in constantly changing conditions. This is captured in the theory of CDM through the construct dynamics of situation which forms the Context of CDM (Figure 4- 1). Based on the relationships drawn between the constituting categories of this construct, one of the plausible grounded hypotheses emerging during data analysis is that dynamics of situation affects CDM by influencing the temporality, intensity, structure and flexibility of actions and interactions involved in undertaking decision making. Also, the mode of CDM arising during task performance is depicted to be a Consequence of managing interdependencies in the theory of CDM. Based on relationships between the categories formulating this construct, a plausible grounded hypothesis emerging during data analysis is that the way personnel manage the relational orientation emanating from the dependencies in decision making accounts for much of their social behaviour and contribution in CDM. The theory captures this through the two constructs – aligning work activities and keeping people in the loop. The data analysis also brings forth the Covariance relationship between aligning work activities and dependencies as the former takes place in response to the latter. The plausible grounded hypothesis emerging during data analysis is that the way personnel synchronise their actions, decision making and perception to align work activities is structured by the interdependencies arising between their work activities during task performance. Similarly, various plausible grounded hypotheses can be drawn at levels of detail based on the relationships drawn between the concepts formulating the theory of CDM. Hence, the conceptual framework of CDM presented in this thesis not only presents a taxonomy of factors CDM but also a set of relationships between the identified factors through which plausible hypothesis can be drawn between concepts to understand and explain the occurrence of CDM in a cooperative work arrangement.

Another essential element of a theory is that the underlying dynamics justify the selection of factors and proposed relationships. GTM is aimed at eliciting underlying social dynamics from which the relevant factors and relationships, explaining the matter of inquiry are delineated. The concepts generated through GTM represent social patterns identified in the research data and are an abstraction of time, place, and people (Glaser 2002a). The theory of CDM presented in this thesis address the social dynamics in decision making in a cooperative setup. In this study, managing interdependencies emerged as a 'core category' which accounts for the participation and contribution of personnel in undertaking decision making in this setup and their social behaviour. This is reflected in the associated concepts and relationships constituting the theory of CDM. Through the associated findings, the existing notions of CDM are clarified and extended in the ensuing sections, thereby delineating the significance of this research.

7.2.1. Impetus of CDM - Beyond 'pooling' information and decision making

The impetus of CDM is primarily considered to be decision making. This notion, widely held in CSCW, is based on studies of decision making in groups in which members assemble with the explicit aim of arriving at a decision. These studies depict the motivation for undertaking CDM to be increasing information processing capacity, and making robust and balanced decisions by 'pooling' information (DeSanctis and Gallupe 1987; Finnegan and O'Mahony 1996; Kerr and Tindale 2004; Saaty and Peniwati 2013). Such a notion stems from the approach taken to decision making as one of problem solving. Hence, members of the group are considered to go through the solution space as a collective, and discuss shared and unshared information which increases their information processing capacity. Contrary to the above viewpoint this research indicates that when CDM is undertaken during task performance in the cooperative arrangement of complex work settings, it is not approached explicitly as a problem solving process but rather as one of managing dependencies in decision making.

Unlike CDM in a group, not all members in the cooperative work arrangement are involved in making a particular decision. The distributed nature of work performance in such an arrangement entails distributed decision making. Moreover, multiple decisions are made in the course of task performance and these are carried out through the collaborative operation of different personnel at separate instances. This research shows that personnel are brought together to undertake CDM by the inherent interconnections in the cooperative arrangement which manifest in the form of *dependencies*. Therefore, when personnel participate in CDM it is not necessarily with the explicit aim of arriving at a particular decision. Instead, their focus is on managing the *dependencies* between their work activities which has relevance to decision making in task performance. On this basis, the theory developed in this research contends that if dependencies did not exist between work activities, then the need for personnel to undertake CDM does not arise.

These findings are significant because whilst the field of CSCW considers dependencies to be the crux of cooperative work arrangement in complex settings, investigations in the field generally overlook the function of dependencies in CDM. As delineated in Section 2.2.2, based on seminal research conducted in CSCW, the contention in the field is that the need to function collaboratively in complex work settings is caused by mutual dependence of tasks. Nevertheless, this relationship has not been explored in investigations of CDM. The findings of this research address the gap and explicate the role of dependencies in undertaking CDM in complex work settings. The argument put forth by researchers in the field (Schmidt and Bannon 1992; Rodden 1994;

Schmidt 1994; Schmidt and Simone 1996; Schmidt and Simone 1999) that the need for collaborative work arises due to dependencies in the work process is extended to CDM in this thesis.

7.2.2. Process of CDM – Beyond achieving 'common goals' and consensual decision

The predominant view elicited from the literature reviewed in section 2.3 is that CDM is a process of reaching goals held in 'common' between two or more individuals. Various definitions of CDM constructed over the years embody this notion (Bui and Jarke 1984; Orasanu and Salas 1993; Panzarasa, Jennings and Norman 2002; Seguy, Noyes and Clermont 2010; Kapucu and Garayev 2011; Winman and Rystedt 2012). However, such a viewpoint is contested by researchers in the field of CSCW (Bannon and Schmidt 1989; Boland et al. 1992; Bannon 1997; Cohen, Cash and Muller 2000). In particular, they argue that the notion is based on studies of CDM in groups which consists of a *relatively closed and fixed ensemble of people sharing the same 'goal' and engaged in incessant direct communication* (Bannon and Schmidt 1989). This does not reflect its occurrence in the cooperative arrangement of complex work settings which consists of large, distributed, heterogeneous and semi-autonomous ensemble of personnel with varying goals. In corroboration, the thesis contends that the notion of CDM as a process of achieving common goals is a simplistic depiction of how it actually takes place in such an arrangement of the real world.

The theory developed in this research clarifies the discrepancy by explaining that in the cooperative arrangement of complex work settings personnel are not required to undertake CDM just on the basis of common goals. In this arrangement, work activities involved in task performance are distributed across multiple personnel and work units with each having particularized roles and responsibilities. Hence, whilst personnel are working towards the common goal of successful task performance they have distinct individual goals. For example, this is illustrated in section 5.2.2 in the scenario of the controllers in the Approach Control deciding the minimum spacing between arriving aircraft in collaboration with those in the Control Tower. Although, the controllers in the Approach Control and Control Tower are working towards the common goal of safe and efficient aircraft movement in and out of the airport, they have varying individual goals stemming from the work distribution and location of their work unit. In this scenario, the Radar Controller (RC) in the Approach Control wants to reduce the spacing between aircraft arriving into the airport due to constraints presented by the situation in the location of their work unit whereas the goal of controllers in the Control Tower is to arrange sufficient gaps between arriving aircraft so that they can allow the aircraft in the airport to depart. When controllers from both work units come together to jointly undertake the decision of minimum spacing between arriving aircraft they bring with them their distinctive goals. Hence, in the cooperative work arrangement, CDM spans more than achieving common goals. Also, in order to reduce the spacing between arriving aircraft the controller in Approach Control is dependent on those in the Control Tower to guide and coordinate the movement of departing aircraft accordingly. The former makes the decision of minimum spacing in collaboration with the latter because of the dependencies between their work activities and not just because they are working towards the common goal. The findings indicate that in the distributed arrangement of cooperative settings, having a common goal alone does not bring personnel together to undertake CDM. It is the dependencies in achieving the common goal that enables this and thereby CDM becomes a process of *managing interdependencies*.

Another commonly held view in CSCW is that CDM is a process of reaching consensual decisions. This also arises from studies of decision making in groups in which the emphasis is on how group members reach consensus on action to be taken to solve a common problem (Figure 7- 1). It involves a sequential process of personnel first identifying the need to collectively solve a problem which forms their common goal. This leads them to come together to form a group, jointly reason possible solutions and form consensus on choice of action. The outcome of this process is the decision to which members commit (Karacapilidis and Papadias 2001; Panzarasa, Jennings and Norman 2002; Kapucu and Garayev 2011; Winman and Rystedt 2012). However, real world studies of decision making in the field of NDM contest the above notion of CDM as a process of forming consensus. It is argued that decision making during 'everyday' work activities is not aimed at achieving consensus through such a sequential process (Cannon-Bowers and Salas 2001; Hoffman and Yates 2005). Instead, the focus is on establishing the common understanding required for choosing a 'satisfycing' course of action by merging information (Artman 1997).

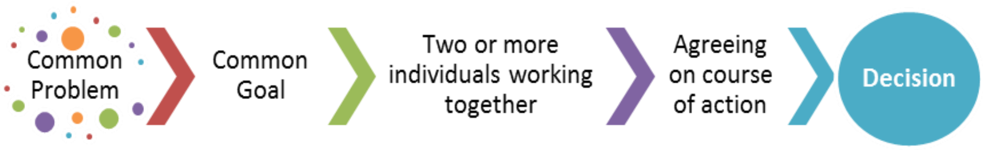


Figure 7- 1 : CDM as a Process of Achieving Common Goal and Reaching Consensus

The theory of CDM developed in this research clarifies and extends the above views by explicating that CDM is a differentiated process in the cooperative arrangement of complex work settings. Firstly, as presented above the impetus of CDM in this arrangement is *dependencies* between work activities of personnel involved in task performance and unlike in groups is not a common problem to be solved. The consequence of the distributed and interconnected nature of cooperative work arrangement is that in order to make decisions during task performance, personnel are dependent on each other for required information, necessary actions and other related decisions. In managing the interdependencies personnel come together to undertake decision making in a collaborative manner. Secondly, when CDM takes place during task performance, the focus is not just arriving at a particular decision but successful accomplishment of undertaken task and this forms the common goal of involved personnel. Thirdly, when two or more personnel come together to undertake CDM they are working towards managing the dependencies in decision making that brings them together and not necessarily forming consensus on decision. This is illustrated in section 6.4 which presents the different modes of CDM activity. Even if personnel form consensus while undertaking CDM it is encapsulated in the process of managing interdependencies. For instance, in the scenario mentioned above the controllers in the Approach Control and Control Tower are brought together to undertake the decision of minimum spacing between arriving aircraft by the dependencies in their work activities. They form consensus on the minimum spacing in the process of managing their dependencies.

7.2.3. Activity of CDM - Beyond 'choice-point' event and decision as end-point

Current conceptualizations such as the models reviewed in section 2.3.5. typically depict the activity of CDM as a 'choice-point' event which culminates at a decision (Figure 7- 1). This notion arises from the viewpoint of decision making in an organizational setting as one of choice among options. Such a stance is also reflected in the field of CSCW which addresses CDM through studies of decision making in groups. The view held is that group members come together at a particular instance in time when they identify the need to make decisions jointly (Finnegan and O'Mahony 1996). Then a choice of action to solve a problem is made through information sharing, discussion, negotiation and consensus forming (Kraemer and King 1988; Karacapilidis and Papadias 2001; Pratt et al. 2004; Wittenbaum, Hollingshead and Botero 2007; Lam and Schaubroeck 2011). Founded on this information processing view, CDM is conceptualized as an activity in which collaboration leads to a decision - the ‘end-point’.

This research presents an alternative view of CDM and explains that the activity in the cooperative arrangement of complex work settings extends beyond a ‘choice-point’ and does not necessarily culminate in a decision. The ensuing discussion elaborates the comparative view of CDM activity depicted in Figure 7- 2.

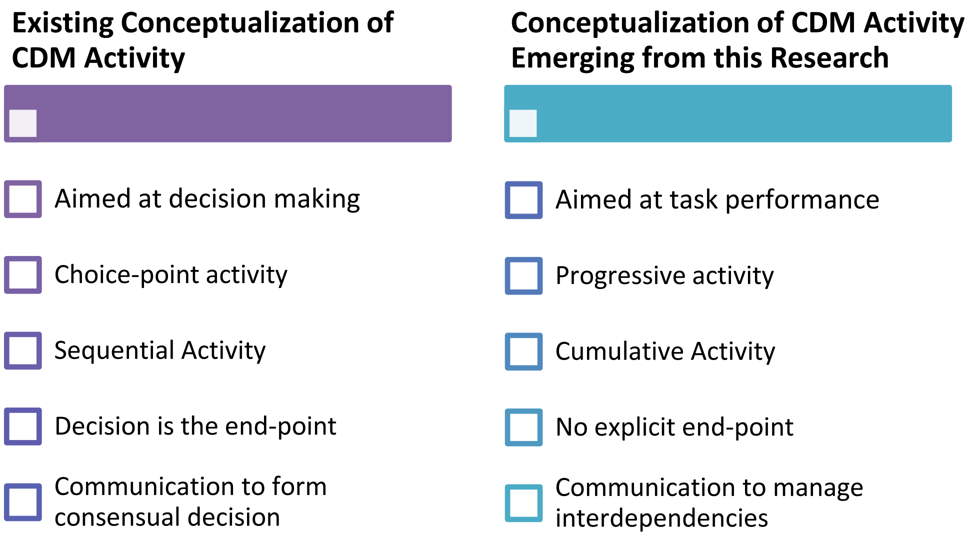


Figure 7- 2 : Comparative View of Existing and Clarified Conceptualization of CDM Activity

The inference drawn from the review of existing definitions and models of CDM in section 2.3 is that the activity is aimed at decision making. Whilst this reflects the way it takes place in an ensemble such as a group, the findings of this research show that it is not particularly so in the cooperative arrangement of a real world complex work setting. This thesis corroborates the view put forth by studies in NDM that in such settings decision making is not the explicit focus of CDM activity (Brehmer 1992); rather it is the task being performed. For instance, in the scenario of the controllers in the Approach Control and Control Tower deciding the minimum spacing between arriving aircraft, the former makes the decision in collaboration with the latter. In this case, the Radar Controller (RC) controller in the Approach Control informs the Ground Controller (GC) in the Control Tower about his need to reduce the spacing between incoming aircraft in order to manage the flow of aircraft movement in and out of the airport, to which the GC agrees. Here, when the controllers come together their focus is not decision making but performing the task in the given conditions.

This gives rise to one of the key findings of this research which is that CDM in the cooperative arrangement of complex work settings is not an activity of personnel collaborating to make a decision which is agreeable to those involved (Figure 7- 3). Instead it is more of an activity of making decisions in collaboration with others involved in task performance (Figure 7- 4). In the figures below P1, P2 and P3 represent personnel and D represents decision.

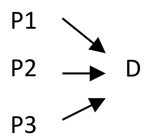


Figure 7- 3 : Diagrammatic Representation of CDM in Groups

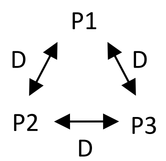


Figure 7- 4 : Diagrammatic Representation of CDM in Cooperative Work Arrangement

The different *modes of CDM activity* presented in section 6.4. illustrate this view. For instance, in the *sequential* mode, decisions are made in succession by personnel P1 (Assistant) and P2 (engineer) along a temporal continuum in response to each other's actions and decisions. In this scenario, P1 makes the decision to notify the workshop personnel that the temperature indicator in the Control Tower is not functioning. Here, P1 is dependent on P2 in the workshop to rectify the failure which necessitates involvement of the latter who in turn makes the decision to compare the reading between the sensor on the Runway and the temperature indicator in the Control Tower. In this scenario, decision making takes place in relation to each other's activities and becomes a collaborative act through the actions and interactions taking place to manage the interrelations between the work activities of the engineer, Assistant and Tower Controller (P3). Such an arrangement of CDM activity is structured by the interdependencies arising between the work activities of P1, P2 and P3. The consequence of this is that instead of being a 'choice-point' event which occurs at a particular instance to arrive at a decision, CDM is progressive with multiple personnel undertaking decision making in relation to each other's activities over a temporal continuum in the course of task performance. This differentiates CDM activity taking place in the small homogeneous ensemble of a group from that taking place in the cooperative arrangement of a complex work setting. In this arrangement, CDM activity involves actions, interactions and decisions of multiple personnel converging in the process of managing interdependencies arising during task performance. As seen in this example the actions, interactions and decisions of P1, P2 and P3 accumulate and converge in the process of managing the dependencies between their work activities. The scenarios illustrating the *sequential, mutually-consented*, *manipulative*, and *emergent* modes of CDM activity presented in section 6.4. demonstrate this aspect.

Furthermore, the models of CDM reviewed in section 2.3.5. depict decision as the termination point in the activity. Alternatively, the *modes of CDM activity* identified through this research illustrate that there is no specific instance in the activity at which a decision can be identified as end-point. In the cooperative work arrangement, decisions are not finished and final. Instead, partial decisions are made and are built upon as task performance progresses. Participation in CDM activity takes place as and when the need for managing interdependencies arises. For instance, in the example illustrating the *manipulative* mode of CDM activity depicted in section 6.4.3. decision made by personnel P1 is partial and not finished or final. Similarly, decision made by P2 is partial and not final as further decisions have to be made by other personnel in relation to this at different procedural locations along the temporal continuum of task performance. The interdependencies between work activities of P1 and P2 lead to convergence of their decisions but this does not take place explicitly. Instead, decisions made by P1 and P2 are embedded in their actions which when synchronized results in the convergence of their decisions. In this example, neither the decision made by P1 or P2 represents a final-stage or end-point of CDM activity. Instead, the decisions are embedded in their actions and interactions and the activity progresses until the completion of undertaken task. The CDM activity does not terminate at one particular decision. Instead, a number of decisions have to be made by different personnel at different instances in the course of task performance in relation to other's work activities due to the inherent interconnections in the work arrangement. These findings corroborate the argument put forth by Hoffman and Yates (2005) that decision making in the complex work settings of the real world entails a host of work activities that are interactive and parallel. Also, it is not about bringing a series of events to a point like conclusion to a decision but involves a number of decisions each of which need to be unpacked. The findings also corroborate the notions put forth by Brown (2005) who contends that instead of perceiving decisions as choice points that entail cognitive work to make a selection, it should be considered as 'social objects' that structure collaboration.

The literature reviewed in chapter 2 indicate that communication is at the crux of CDM activity as it enables inclusion of individual contribution to decision making and integrate diverse knowledge, expertise, strategies and solutions of involved personnel leading to robust and balanced decisions (Schmidt 1990; Schmidt 1994a; Jankowski et al. 1997; Cook, Gerrish and Clarke 2001; Filip 2008). This research also brings forth the importance of communication in undertaking CDM activity through the concept of *Keeping People in the*

Loop (KPIL) presented in section 6.3.2. Based on the associated findings, this research shows that unlike the portrayal of studies of decision making in groups, in the cooperative arrangement of complex work settings, communication involved in CDM activity is aimed at managing the dependencies involved and not necessarily forming consensus. The following section presents further discussion on this aspect of CDM activity.

7.2.4. Articulating CDM - Beyond sharing information and mental models

Existing studies of decision making in groups and teams, whilst recognizing that the members are interdependent in their work activities (Malone and Crowston 1990; Schmidt and Bannon 1992; Cannon-Bowers, Salas and Converse 1993; Oslon and Oslon 2000) have not placed much focus on the role of interdependencies in the occurrence of CDM. Instead, as delineated in section 2.3.3., studies in CSCW and NDM mainly approach CDM through the notion of 'sharedness' in a group or team. Particularly the focus is on sharing information and mental models. The argument put forth here is that this perspective presents a limited approach to conceptualizing the way CDM is undertaken in the cooperative arrangement of real world complex work settings. The theory of CDM presented in this thesis explicates that CDM in such settings is a complex activity which extends beyond sharing information and sharing mental models.

This research presents CDM to be fundamentally a process of *managing interdependencies*. In the field of CSCW, activities involved in managing interdependencies are known as 'articulation work'. Here, the label 'articulating' is appropriated from this notion to introduce the term 'articulating CDM' to depict the way CDM is undertaken in the process of managing interdependencies arising during task performance. The theory developed through this research explains that ‘articulating CDM’ in complex work settings involves *Aligning Work Activities* (AWA) of personnel by synchronizing their actions, decisions and perception. This is contingent on *Keeping People in the Loop* (KPIL) which takes place through various communication acts implemented as anticipatory and reactionary interactions.

Articulation work in the cooperative arrangement of complex work settings involves determining who is doing what, where, when and how in order to accomplish tasks (Fjuk and Smordal 1997; Schmidt 2010) and this extends to CDM. As shown in this research, personnel undertake CDM because they are dependent on each other during decision making for required information, performing necessary actions and making related decisions. Managing these dependencies in the constantly changing conditions of complex work settings requires personnel to establish who is doing what, where, when and how in the situations arising during task performance. The findings of this research indicate that this is achieved through explicit and implicit correlation of actions, decisions and perception of the involved personnel. This corresponds to direct and indirect articulation work portrayed in CSCW (discussed in section 2.2.3.).

Explicit correlation of actions in CDM takes place through the request-response cycle with personnel requesting others to perform actions in relation to their own. By performing actions in response to requests their actions are correlated. For instance, to perform maintenance work on aircraft, as described in section 6.3.1., the pilot of the aircraft is dependent on the decision of the Ground Controller (GC) in the Control Tower. The former needs to obtain permission from the latter to taxi the aircraft from the parking stand to the ‘compass base’ where the maintenance work will be performed. In order to do this, the actions of airline operator, aircraft pilot, GC in the Operations Centre as well as the Assistant and GC in the Control Tower need to be correlated. In the process of correlating their actions the GC in the Control Tower obtains the information required to make the decision. Alternatively, implicit correlation occurs by performing actions in response to information obtained through overhearing other's conversation and visual observation of other's activities. This is illustrated in the scenario presented in section 6.3.1. in which the GC in the Operations Centre is able to correlate his actions with that of the controllers in the Control Tower and the aircraft pilot by listening to the conversations taking place between them on the radio telephone and make corresponding decisions. Thus, decision making takes place in collaboration with other personnel through explicit and implicit correlation of their actions.

Articulating CDM in the cooperative arrangement involves correlating decisions distributed between personnel as well as bringing them together to make decisions. Similar to correlating actions, decisions made by personnel involved in task performance are also correlated through the request-response cycle. Personnel request others to make decisions in relation to their own thereby achieving correlation. In contrast, implicit correlation is achieved by embedding decisions in actions performed and information transferred. When decisions are made in response to these actions and information they are implicitly correlated. This is illustrated in the scenario presented in section 6.3.1. in which the GC in the Operations Centre embeds his decision to allow the engineer to perform maintenance work on an aircraft in the information sent to the GC in the Control Tower. When the latter makes the decision in response to this information their decisions are correlated.

Another aspect of articulating CDM involves personnel coming together to make decisions. This compares with the models reviewed in section 2.3.5. in which they assemble with the aim of making at a decision jointly. However, unlike the depiction in these models, personnel in the cooperative arrangement are brought together by the dependencies in their work activities and not necessarily the need to solve a common problem. As demonstrated earlier in this chapter, the common problem alone does not bring personnel together to undertake CDM. Instead, it is the dependencies in solving the common problem that brings them together and involved personnel are unified in the decision making. This takes place explicitly and implicitly with the former achieved through mutual decision making in which personnel make a decision jointly and the latter occurs when personnel acknowledge the decision made by others indirectly by performing related actions and decisions.

Furthermore, articulating CDM in the cooperative arrangement of complex work settings requires personnel to correlate their perception due to the differences engendered by the heterogeneous nature of work units in which personnel operate. Explicit correlation of perception is achieved by sharing information verbally or non-verbally between personnel involved in task performance. For instance, in the depiction of the use of Departure Status Information (DSI) system in section 6.3.1., perception of controllers in the Control Tower and Approach Control is correlated by means of the former sharing information about his decision and the consequent status of departure aircraft movement in the airport. Based on this information, the controller in the Approach Control makes decisions. Thus, correlating perception of personnel leads to CDM. Alternatively, implicit correlation takes place by monitoring other's work performance and making inferences out its relation to one's own activities. It is also achieved by adhering to standard procedure and work practices in task performance as not deviating from this helps avoid surprises and misunderstanding between personnel. The procedures and standard work practices act as a common frame of reference based on which personnel perceive the relation between each other's work activity in undertaking CDM. This is particularly vital for associative and temporal structuring of work activities when CDM takes place across spatially distributed work units and personnel are restricted in their means of communication.

Besides, the standard procedure in task performance delineates the depender-depended relationship between work activities of the involved personnel. It prearranges who does what, where, when and how thereby leading to planned articulation work. This helps to form expectations of requirements, possibilities and constraints in articulating CDM. However, the dynamic environment of the complex work setting requires adapting to the constantly changing conditions during CDM and entails situated articulation work. For instance, the scenario presented in section 6.4.4. describes how the intensity of communication between the controllers in the Control Tower and Approach Control varies during decision making with the changing conditions in task performance.

The findings of this research indicate that the process of *Keeping People in the Loop* (KPIL) is central to articulating CDM. This is particularly vital to synchronise work activities in the constantly changing conditions of complex work settings and across work units. It is achieved through a number of communication acts implemented as anticipatory interactions in preparation for decision making and reactionary interactions in consequence to it. The information shared through these establish the awareness and common understanding required for synchronizing work activities to undertake CDM. The premise in CSCW is that group members make better decisions by sharing information as well as their opinion and knowledge thereby integrating individual contributions. In the complex work settings however it is more about providing timely and valid information in the constantly changing conditions in order to synchronize work activities and manage interconnections in decision making. Nevertheless, studies in CSCW contend that sharing information alone is insufficient to function collaboratively and the meaning of shared information needs to be held in common (Schmidt and Bannon 1992; Bannon and Bødker 1997; Reddy, Dourish and Pratt 2001). This is enabled through the anticipatory and reactionary interactions taking place to manage the dependencies in decision making.

7.2.5. A Definition of Collaborative Decision Making

The definitions reviewed in this thesis in section 2.3.1 focus on outcomes of CDM such as reaching consensual decision and achieving common goals. As discussed above this does not necessarily reflect the way CDM is undertaken in the cooperative arrangement of complex work settings. Based on the clarifications presented in this chapter a new definition of CDM is put forth which depicts its occurrence in these settings. The definition is founded on the following assumptions:

CDM is undertaken in the course of task performance in a cooperative work arrangement.
The cooperative work arrangement is characterized by multiple individuals with specific role responsibilities, distributed work performance, dependencies between work activities and dynamic work conditions.
Personnel are dependent on each other for information, actions and decisions to undertake tasks.
Personnel participating in CDM share operational responsibility for the outcome of task performance.
Personnel have the similar goal of successful task performance but can have varying goals arising from their individual role responsibilities and location of the work units they are operating from.
Operational procedures laid down by the organization govern work activities of personnel.

Based on the above assumptions and the theory developed through this research CDM in complex work settings is defined as:

> *An ongoing activity induced and structured by dependencies in decision making, and a process of managing the interdependencies by synchronizing actions, decisions and perception of personnel through various communication acts and modes of interaction.*

Unlike other definitions, this focuses on the cooperative arrangement in complex work settings and not on the outcome of CDM.

7.3. EVALUATING GROUNDED THEORY OF COLLABORATIVE DECISION MAKING

The goal of theory development through Grounded Theory Methodology (GTM) is conceptualization of phenomenon by integration a set of plausible grounded hypothesis (Glaser and Holton 2004b). The main difference between GTM and other qualitative research approaches is in the importance given to the abstraction of time, place, and people for theory generation as opposed to the context specific description of the latter (Glaser 2001). Thus, the validity of Grounded Theory research is judged by *fit*, *relevance*, *workability*, and *modifiability* (Glaser and Strauss 1967; Glaser 1978; Holton 2008).

Fit refers to how closely the concepts relate to the phenomenon represented by them. This criteria is deemed to be most important for evaluating validity and truth of theory generated through GTM (Lomborg and Kirkevold 2003). In this research, *fit* of the theory developed was achieved by being conscious of not imposing preconceived notions from reviewed literature to influence the coding of collected data. Although the literature reviewed in chapter 2 informed the development of codes and categories, these were not forced to fit the literature. *Fit* is also achieved by undertaking data collection, analysis and theory generation jointly. 'Theoretical sampling' was employed in theory generation whereby the data directs subsequent questions to be addressed and further data collection in the development of the theory of CDM. This process ensures that the concepts comprising the theory closely relate to the way CDM is undertaken in the studied complex work setting. Besides the core concerns of studied personnel and processes involved in undertaking CDM were elicited from the data which ensured *relevance* of theory to the substantive field of study.

The next criteria is *workability* which means the theory should be able to explain and interpret the data as well as predict what will happen in the substantive field. This is achieved through the identification of the core category - *managing interdependencies* - and integrating related categories by employing the ‘Six Cs’ theoretical coding family prescribed by Glaser. The theory of CDM is founded on the core category and its systematic generation enables interpretation and explanation of what is happening in the data and the way CDM is undertaken by personnel during task performance. Furthermore, relationships drawn in the theoretical framework provide plausible propositions that predict the occurrence of CDM in the cooperative work arrangement of a complex work setting.

The fourth criteria is *modifiability*. Grounded Theory is inherently modifiable as it receptive to change with new data and ideas (Glaser 1978). Theory generation is an emergent process in GTM and is constantly modified when new relevant data is compared to existing data. This modifiability attribute of theory generated through GTM makes generalizability easily possible because theory can be applied elsewhere with emergent fit (Glaser 2001; Glaser 2002c). Conceptualization in GTM is guided by the criteria that the conceptual level of the category should be abstract enough to make the theory applicable to multiple changing situations and at the same time not lose the sensitizing aspect (Glaser and Strauss 1967, p.g. 242). The concepts formulating the theory of CDM were generated through the method of ‘constant comparison’ in all three coding phases which helps identify underlying patterns about what is happening in the data. As new data was collected, it was compared with existing codes and categories to look for similarities and differences. Categories were compared to identify relationships and formulate higher level concepts. This process of constant comparison enables the concepts developed to be abstract of time, place and people, thereby those comprising the theory of CDM are generalised. Additionally, the transparency and dependability of the process of theory generation in this research is ensured by clearly explaining the procedural application of GTM as well as by illustrating the application of its tenets in chapter 3.

7.4. SUMMARY

This chapter has presented a discussion of key findings formulating the theory of CDM described in chapters 4, 5 and 6. Its occurrence in real world complex work settings is explicated by addressing the impetus, context, process and activity of CDM in the cooperative arrangement of these settings. The findings of this research are mapped against specific notions elicited from the literature reviewed in chapter 2 and current views on CDM are clarified and extended. Specifically, the discussion presented in this chapter reveals that CDM in the cooperative arrangement of complex work settings is a differentiated process. Addressing CDM in this arrangement requires a shift in perception from considering it as an activity of collaboration leading to a decision to one of making decisions in collaboration with personnel involved in task performance. This brings forth the integrated nature of decision making and social work activities.

CHAPTER 8

A CONCEPTUAL FRAMEWORK FOR ANALYSING COLLABORATIVE DECISION MAKING IN A COMPLEX WORK SETTING

8.1. INTRODUCTION

A conceptual framework is derived from the theory emerging from this research to serve as a tool for analyzing the occurrence of CDM in a complex work setting. The chapter presents this analytical tool with the purpose of examining the usefulness of the theory in explaining how CDM transpires in the cooperative arrangement of complex work settings. It consists of 10 parameters that can be applied to characterize the particularities of CDM in such a setting. A demonstration of this is presented by analyzing an aircraft accident investigation report. This analysis also provides an initial validation of the viability of the developed framework for exploring, understanding and drawing insights about the way personnel undertake CDM during everyday work activities in the real world.

8.2. PARAMETERS OF THE ANALYTICAL FRAMEWORK

The analytical tool consists of ten parameters derived from the theoretical constructs presented in chapters 4, 5 and 6. This provides a structure to focus the analysis and allows the occurrence of CDM in a complex setting to be characterised with respect to the distribution and interconnections in its cooperative arrangement. The parameters and are as follows:

i. Type of Situation
ii. Heterogeneity of Work Units
iii. Dependencies between Work Activities
iv. Keeping Track of Changes in Work Environment
v. Keeping the Interaction Going with Each Other
vi. Avoiding Misunderstanding and Surprises
vii. Correlating Actions and Decisions
viii. Unifying Decision Making
ix. Emergent Decision Making
x. Fitness of Information Exchange

The parameters presented above highlight important conditions (i, ii, iii) , behaviour (iv, v, vi, vii, viii) and contingency factors (ix, x) to focus upon to analyse the way CDM is undertaken during task performance in a real world complex work setting. The associated propositions presented in the theory of CDM are also indicated to guide the analysis.

Type of Situation

CDM takes place in the dynamic environment of a complex work setting. Hence, it is important to understand the type of situation in which it is undertaken. This parameter focuses on the situations arising during task performance. For example, it can be characterised through varying degrees of criticality and predictability as presented in chapter 5. The theory of

CDM explains that the type of situation arising during task performance affects participation in CDM with respect to the temporality, structure, intensity and flexibility of interaction taking place between personnel involved.

Proposition: Type of situation arising during task performance presents possibilities and constraints in undertaking CDM.

Heterogeneity of Work Units

Task performance in the cooperative arrangement of complex work settings requires involvement of multiple work units. When CDM is undertaken during task performance differences between the work units of involved personnel influences their goals, requirements, participation and contribution.

Proposition: Heterogeneity of work units involved in undertaking the task presents possibilities and constraints in undertaking CDM between personnel operating from these units.

Dependencies between Work Activities

To undertake decision making in the cooperative arrangement of complex work settings personnel are dependent on each other for obtaining required information, performing necessary actions and making related decisions. This arises from the distributed and interconnected nature of the cooperative arrangement of such settings. Managing the relational orientation emanating from the dependencies leads to and structures participation in CDM.

Proposition: Dependencies cause the need for personnel to undertake decision making in a collaborative manner as well as structure participation and contribution in CDM.

Keeping Track of Changes in Situation

In complex work settings, the dynamic environment gives rise to variation in the type of situation arising during task performance. Hence, undertaking CDM requires personnel to keep track of changes taking place in the work setting.

Proposition: Keeping track of changes in situation of task performance facilitates adapting CDM to changing requirements in the dynamic environment.

Keeping the Interaction Going between Each Other

Undertaking CDM in the varying situation of task performance requires keeping the interaction going between personnel undertaking the task in order to determine the requirements to be fulfilled, establish required common understanding and make informed decisions. This takes place through interaction undertaken in anticipation or response to occurrences in the work environment.

Proposition: Keeping the interaction going with personnel during task performance helps synchronize actions, decisions and perceptions required to undertake CDM.

Avoiding Misunderstandings and Surprises

Performing CDM across heterogeneous work units and in the constantly changing situation of task performance is facilitated by avoiding misunderstandings between personnel involved and avoiding surprises. This is enabled by adhering to standard procedure for undertaking tasks and standard work practices in the setting.

Proposition: Establishing the common understanding required for undertaking CDM involves integrating viewpoints of personnel involved in task performance by sharing information as well as avoiding misunderstanding and surprises by adhering to standard operational procedures and work practices.

Correlating Actions and Decisions

CDM in the cooperative arrangement of complex work settings involves correlating actions and decisions of personnel performing the task. This is achieved through implicit and explicit orientation. Explicit orientation takes place through by individuals requesting actions and decisions to be taken by others who then respond accordingly. Implicit orientation takes place by individuals embedding decisions in actions and information transferred between those involved in task performance. When personnel perform actions and decisions in response their actions and decisions are correlated through implicit orientation.

Proposition: Undertaking CDM in complex work settings requires managing the distribution and interconnections in decision making in the cooperative arrangement by correlating actions and decision of personnel undertaking the task.

Cohering Decision Making

During task performance, personnel are brought together to undertake CDM through mutual and complimentary means. Decision making of multiple personnel is unified through mutual means by making decisions jointly. Alternatively, this takes place through complimentary means when personnel make decisions in causal or reciprocal relation to that made by others.

Proposition: Unifying decision making of multiple personnel undertaking the task in the distributed and interconnected setup of the cooperative work arrangement is achieved through mutual and complimentary decision making.

Emergent Decision Making

Undertaking CDM in complex work settings is emergent because it needs to be adapted to the constantly changing conditions arising during task performance.

Proposition: Participation and contribution is CDM needs to be adapted to the varying conditions brought forth by the changing situations of task performance.

Fitness of Information Transmission

Fitness of information exchanged between personnel during task performance is an important factor affecting CDM. It is determined through the form of information transfer such as standard and non-standard forms; medium through which information transfer takes place such as verbal and non-verbal; and timing of information transfer such as periodical and ad-hoc.

Proposition: The form, medium and timing of information exchange taking place during task performance influences the ability of personnel to align work activities required for undertaking CDM.

The application of the analytical tool is presented next by employing the parameters to analyse an aircraft accident report and drawing insights about the way CDM in undertaken during airport air traffic control operations.

8.3. ANALYZING COLLABORATIVE DECISION MAKING IN ATC WORK SETTING

The aircraft accident report selected for this study is that of the Singapore Airlines (SIA) Flight SQ006 which crashed on a partially closed runway in Chiang Kai-Shek (CSK) Airport, Taiwan on October 31, 2000 (Aircraft Accident Report ASC-ARR-02-04-001, Aviation Safety Council, Taiwan, Republic of China). A number of accident reports were reviewed and this was considered to be particularly suitable for the purpose of the study as it provides detailed description of the state of the work setting and Air Traffic Control (ATC) operations at the time of occurrence of the accident. The report focuses on operations taking place during the departure of Singapore Airlines (SIA) Flight SQ006 from CSK Airport. It also presents the collaborative functioning of personnel from different work units and decision making involved. This section of the chapter describes the use of the parameters presented above to analyse CDM occurring during aircraft departure from the airport. This is purely a theoretical exercise to demonstrate the plausible applicability of the theory emerging from this research to analyze CDM in complex work settings.

The aircraft crashed on a partially closed Runway during takeoff. It collided with construction equipment and pits on the Runway and was destroyed in post crash fire. This took place on a portion of the Runway which had been closed to for maintenance at the CSK airport. The following analysis is structured through the parameters and propositions presented above.

Type of Situation

Weather condition at the time of aircraft departure from the Airport was poor as heavy rain and strong winds from typhoon “Xangsane” prevailed. During takeoff the Runway was slippery with strong crosswind and low visibility. While occurrence of the typhoon was known in advance the severity of its effect at the time of aircraft takeoff was unexpected. Here, the type of situation arising during task performance was critical and unanticipated. According to the accident investigation, these conditions subtly influenced the flight crew’s decision making and situation awareness. However, this analysis reveals that low visibility also influenced the situation awareness of the controllers in the Control Tower.

The type of situation by limiting the ability of flight crew members and controllers in the Control Tower in establishing required situation awareness arising during the aircraft departure presented constraints in undertaking CDM. Consequentially, this constraints the interaction taking place between them to undertake CDM. Due to the lapse in situation awareness neither did the controllers provide progressive instructions nor did the flight crew deem necessary to request it. Hence, the latter made the assumption that they were on the correct runway and made the decision to takeoff.

Heterogeneity of Work Units

At the time of aircraft departure, there were four controllers functioning in the CSK Airport Control Tower: Local Controller, Ground Controller, flight Data Controller, and Clearance Delivery Controller. The flight crew members in the aircraft consisted of three pilots who are represented in the accident report as Crew Members 1, 2, and 3 (CM1, CM2, and CM3). Besides, there are individuals from a number of other work units who are involved such as: Airport Infrastructure Management, Maintenance and Engineering Unit, SIA Contract Dispatchers, Airport Management, Airport Rescue and Fire Fighting (ARPF) personnel, medical personnel, Civil Aeronautics Administration, (CAA) of Republic of China (ROC), and International Civil Aviation Authority.

Heterogeneity between work units involved in performing the task of aircraft departure elicited from the report is as follows. In terms of responsibilities of personnel, the pilots are responsible for flying the aircraft from departing to destination airport. The controllers in the Control Tower are responsible for providing guidance and instructions to the pilots in the aircraft to move it from the parking stand in the airport, movement on the taxiway and takeoff from the runway. Maintenance and Engineering unit is in charge of lights in the airport including the taxiways and runways. CAA of ROC is responsible for issuing Notice to Airmen (NOTAM) while the SIA contract dispatchers provide dispatch documents in advance to the flight crew which provide important information flight preparation. Based on their responsibilities, personnel from these work units are placed at different procedural location in the process of performing the task of aircraft departure.

In terms of spatial location, the flight crew are in the aircraft as it departs from the airport. Hence, they are in constant motion. The Controllers in the Control Tower are located near the Runway and Taxiways whilst the SIA Contract Dispatcher is located in the Airline Hanger. Other units located in the airport are Maintenance and Engineering Unit, Airport Management, Airport Rescue and Fire Fighting (ARPF) personnel, and medical personnel. In terms of resources, Automatic Terminal Information Service (ATIS) is available to the controllers in the Control Tower and flight crew whereas Notice to Airmen (NOTAM) is available to Control Tower, Maintenance and Engineering Section, Flight Operating System (FOS) and flight crew. However, only the flight crew have the Para-Visual Display (PVD).

Whilst the report establishes the differences between the work units there is insufficient information to determine the influence of all the above on CDM. However, it shows that the difference in spatial location of the flight crew and the controllers in the Control Tower constrained their ability to undertake CDM during the aircraft departure. The controllers could not visually monitor the movement of the aircraft. Moreover, whilst the flight crew members could see the Taxiway and Runway lighting, the controllers in the Control Tower could not. This influenced their participation and contribution in making the takeoff decision.

Dependencies between Work Activities

Dependencies were identified between work activities of a number of personnel involved in the departure of the aircraft. In the report this was mainly presented in relation to the activities of the flight crew members. Specifically, they are dependent on the controllers in the Control Tower for guidance and clearance instructions during their movement from the parking bay to the Runway, SIA contract dispatchers for pre-flight information, CSK airport infrastructure management personnel for placement of warnings and indicators on the Taxiways and Runway, medical coordinator/interim coordinator for medical treatment and rescue, and airport rescue and fire fighting personnel during emergencies.

These dependencies brought together personnel from different work units at different instances in the course of performing the task of aircraft departure. For instance, the flight crew members and the dispatchers had a briefing the day before the flight whereas the flight crew members and the controllers in the Control Tower were brought together to undertake decision making during the movement of the aircraft from the parking gate to the Runway. Whilst the dispatchers and the flight crew members do not jointly make decisions, the former has participated in the decision making by providing required information. The decision made by the flight crew members during takeoff was influenced by the information given by the dispatchers. Similarly, the decision to takeoff was also based on the clearance obtained from the controllers in the Control Tower at the time of departure. Thus, the dependencies between their work activities structured the participation of personnel in CDM.

Keeping Track of Changes in Situation

The flight crew of the aircraft departing from the airport was aware that a portion of the Runway 05R was closed and that it was only available for taxiing. They were informed that typhoon “Xangsane” was approaching CKS airport during the dispatch briefing that took place the previous day. The flight crew members also read the NOTAM and Internal Notice to Airmen (INTAM) regarding partial closure of Runway 05R between Taxiway N4 and N5. For example, the report states that CM1 recounted that he told himself to be more alert than usual and to be especially aware of the situation.

CM1 continued to visually monitor the weather on ATIS. He also kept track of the situation by overhearing the controller in the Control Tower giving weather information to two other flights that were departing around the same time. Keeping track of changes in the situation by visually monitoring the physical environment was challenging because of reduced visibility caused by the darkness and heavy rain. Nevertheless, this did not prohibit the flight crew members from seeing the Taxiway and Runway lighting, makings, and signage. The report states that CM1's actions were founded on visual observation of centreline and green Taxiway lights which he followed to manoeuvre the aircraft onto Runway 05R. Similarly, CM2 relied on the green centreline lights for navigation because of poor visibility.

With respect to the controllers in the Control Tower, the Local Controller (LC) could not visually observe the movement of the aircraft on the Taxiway and Runway as low visibility prevented him from seeing the aircraft line up for takeoff. This restricted his ability to keep track of changes in situation. The report states that the LC could not visually observe the aircraft after it commenced taxing. He could also not see the centreline lights and edge lights on the Runway 05R or between the Control Tower and Runway 05L. However, the LC was aware of planned conversion of Runway 05R to Taxiway. Furthermore, the report states that if the controllers in the Control Tower had verbally issued 'progressive instructions' to the flight crew, then it would have enhanced their ability to keep track of their position while turning onto the wrong Runway. Although, the flight crew were keeping track of changes in the situation of task performance through certain means, they failed to adapt CDM involved in task performance accordingly.

Keeping the Interaction Going

Prior to aircraft departure from the Airport, the Civil Aeronautics Administration (CAA) of Republic of China (ROC) issued NOTAM indicating that a portion of the runway 05R was closed due to work in progress. At the airport, NOTAMs are issued by Flight Information Service station and before publication it is coordinated between Maintenance and Engineering Section, Flight Operating System (FOS) and Control Tower. The flight crew members were also informed through NOTAM that a portion of the Runway 05R was closed and was only available for taxi.

Hence, related personnel were keeping the interaction going prior to the departure and information about the Runway closure was shared between them through the NOTAM.

At the time of aircraft departure from the airport the LC issued takeoff clearance along with wind direction. However, at the time of aircraft departure from the airport the flight crew members and the controllers in the Control Tower did not keep the interaction going with each other. Consequently they failed to synchronize their perception which was required for undertaking CDM. For instance, the report states that *information was shared and crosschecked between crew members as the taxi progressed, until the most critical point during the taxi from Taxiway NP through Taxiway N1 and onto Runway 05R*. Also, neither did the flight crew request progressive taxi instructions from the LC in the Control Tower nor did the latter issue progressive taxi/ground movement instructions to the flight crew members. The report states that if the Ground Controller had informed the pilots that the controllers could not visually observe their movement from the Control Tower, CM1 would have been more aware of the aircraft's location as he then would not have been under the false impression that the controllers in the Tower were able to see the aircraft movement on the taxiway and were acknowledging his decision to takeoff from the Runway.

Avoiding Misunderstandings and Surprises

One of the main factors affecting CDM in this case is the inability of collaborating personnel to avoid misunderstanding and surprises. Even when the flight crew employed the procedures for undertaking the aircraft departure in accordance with the SIA Operations manual, it did not avoid misunderstandings and surprises during the aircraft departure. This was because at the time of departure, the flight crew members and controllers in the Control Tower did not share information and hence could not integrate their viewpoints. For instance, the controllers did not share the information that they could not visibly monitor the movement of the aircraft on the Runway due to poor visibility. So, when CM1 confirmed takeoff clearance with the Tower Controller he assumed that they were under visual observation

Also, misunderstandings and surprises could not be avoided as the airport infrastructure management did not share the correct information with the flight crew members by not lighting the Runway and Taxiways as required. Flight crew members CM2 and CM3 also mistook the Runway based on the lighting on it. CM2 expected a closed runway to be "black" and have no lights, and any work in progress on the aerodrome should have warning lights. Similar to CM1 he misinterpreted the saliency of lights leading onto Runway 05R. He said the Runway picture was "correct" because the lights down the middle of the runway were very bright and there were no visible obstructions ahead of the aircraft. The taxi lights led into the Runway and he did not notice any other lights or identification signboard or marking. He said the visual cues indicated that the aircraft was on an active Runway. CM3 also considered Runway 05R to be correct runway because the centerline of the runway had bright lights similar to a "typical" runway. Since, lighting on Runway 05R did not 'stick to standard'[22] this led to

[22] *At the time of the incident, there were a number of items of CKS airport infrastructure (lighting on runway and taxiways) that did not meet the level of internationally accepted standards and recommended practices, in particular lighting on the Runway, Taxiway centerline marking, Runway guard lights and stop bars, guidance signs installed on the left*

misinterpretation and misunderstandings of flight crew who had a "typical" view of an active runway. Hence, the common understanding required for undertaking CDM was not established.

Correlating Actions and Decisions

Performing the task of aircraft departure from the airport requires establishment of orderly connection between actions and decisions of personnel from different work units. In the course of manoeuvring the aircraft from the parking stand to the runway, actions and decisions taken by Ground Controller, Local Controller, and Flight Crew members are explicitly correlated. For instance, the flight crew members and Ground Controller established this by the former verbally requesting clearance from the latter on the telephone who then responds by giving clearance to commence taxiing. Consequentially, CM2 acknowledges clearance and starts taxiing thereby undertaking CDM. Decision to depart the aircraft from the runway emanates from an explicit correlation of multiple decisions of different personnel at different points in time during the movement of aircraft from the parking stand to the runway.

Cohering Decision Making

Decision making involved in departing the aircraft from the Runway is taken collaboratively by the controllers in the Control Tower and flight crew in the aircraft. Decisions of personnel from both work units are integrated through the process of flight crew requesting and receiving clearance from the controllers. For instance, after pushback from the parking bay, the flight crew requested and received clearance from the Ground Controller in the Control Tower to commence taxiing. Also, when the flight crew positioned the aircraft on Runway and were ready to takeoff, CM1 instructed CM2 to

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and right sides of Taxiway, and monitoring mechanisms of airfield lighting system. Appropriate attention given to these items could have enhanced the situational awareness of flight crew while taxiing to Runway 05L.

inform the controllers that they were ready. Then the Tower Controller transmitted clearance to takeoff. Thus, decisions made by personnel in both work units are brought together through complimentary decision making by controllers in Control Tower making decisions in response to flight crew's action and decision.

Emergent Decision Making

The flight crew members were under moderate time pressure as they wanted to takeoff from the Airport before the typhoon came closer to CKS Airport. However, there was no undue organizational pressure from Singapore Airlines (SIA) placed upon the crew to takeoff on the evening of the accident. CM1 reported that he felt no time pressure on the evening of the accident. According to CM1 the crew had sufficient time to complete the checklist and prepare for departure. However, the report states that because the flight crew tried to avoid the typhoon this hastened their departure without appropriate attention to information that would have helped them to correctly identify and confirm the correct takeoff runway. Also, the timing of receiving clearances from Controllers in the Control Tower gave CM1 the impression that they were on the correct runway and that the Tower Controller could visually observe their position resulting in the decision to takeoff. Here, participation and contribution to CDM by the flight crew members and controllers in the Control Tower is not adapted to the changing conditions of the situation

Fitness of Information Transmission

The SIA contract dispatchers gave the flight crew in advance information about expected environmental conditions during takeoff from the Runway. This was done non-verbally and in standard form with appropriate and complete dispatch documents. They also highlighted parts of the operational documentation to help summarize important information for the flight crew. However, the report states that extracting key information from these documents is difficult because of the format and the flight crew could have been unable to detect information about Runway 05R lighting. In addition, the dispatcher's procedure of highlighting information they consider as vital could have taken away the flight crew's attention from the lighting data.

Verbally exchange of ATC clearance given to the flight crew before aircraft departure clearly states that Runway 05L is in use and that Runway 05R between N4 and N5 is closed due to work in progress. However, neither ATIS nor the Tower Controller provided specific information on the runway surface conditions to the flight crew. The Local Controller did not use low visibility standard phraseology to inform the flight crew to slow down during taxi. The Duty Controller gave only routine instructions to the flight crew to move from terminal apron to Runway 05L and did not use the standard phraseology to provide progressive instructions to the flight crew. Nevertheless, the report states that the flight crew were not mislead during takeoff by ATC taxi instructions and takeoff clearance.

Additionally, from an infrastructure perspective, lack of adequate warnings at the entrance of Runway 05R did not provide a potential last minute defence to prevent the flight crew from mistakenly entering Runway 05R. This is because there are no clear International Civil Aviation Organization (ICAO) regulations for placement of warnings on temporarily closed runways that are also used for taxi operations. The green centreline lights leading from taxiway onto Runway 05R were more visible than those of taxiway centreline lights leading towards Runway 05L because they were more densely spaced. Runway guard lights and stop bars were not provided at the CKS Airport.

The report shows that fitness of information transferred to flight crew members by other personnel such as SIA dispatchers and controllers in the Control Tower was correct in terms of timing of information. However, it was incorrect in terms of the form in which information was transferred. For instance, information extraction from the operational documents provided by SIA contract dispatchers to the flight crew is difficult. Hence, the dispatchers highlight what they consider as vital. But, this diverted flight crew's attention from lighting data. Controllers in the Control Tower on the other hand did not use standard phraseology to provide instructions to flight crew members. Although, this did not mislead flight crew during takeoff it reduced their awareness required for making informed decisions. Furthermore, fitness of information provided by the airport infrastructure management was incorrect in terms of all three factors of form, medium, and timing. For instance, the latter did not place warning signs at the entrance of Runway 05R, did not provide runway guard lights and stop-bars, and did not provide appropriate lighting arrangement to indicate the correct Runway to be used for takeoff. Hence, the fitness of information exchanged during task performance was insufficient. Consequently, personnel could not align their work activities for undertaking CDM.

8.4. REFLECTION

In summation, during aircraft departure from the Runway, CDM was undertaken in critical and unanticipated conditions between heterogeneous work units with high degree of interdependencies between personnel's work activities. The situation at the time of aircraft departure constrained the ability of personnel in establishing the awareness required for undertaking CDM. The heterogeneity of work units also influenced their participation and contribution in making the takeoff decision. To perform the task of aircraft departure, dependencies between work activities necessitates that the flight crew members undertake decision making in collaboration with others. The mode of participation of in CDM was complimentary with entailing actions and decisions being correlated explicitly. However, personnel failed to keep track of changes taking place in the work environment at the time aircraft departure. They also failed to keep the interaction going with each other near takeoff. Furthermore, fitness of information exchanged between personnel was insufficient. While the medium and timing of information transferred was appropriate the form was not. This in combination with personnel having different perception of occurrences in the work environment during aircraft departure resulted in them being unable to avoid misunderstandings and surprises which would have enabled appropriate participation in CDM.

The aim of this exercise is to demonstrate the plausible application of the theory of CDM developed in this research. The parameters derived from the proposition presented in the theory are intended to serve as an analytical tool to provide insights into the way personnel undertake CDM in a particular work setting. It provides a map of important aspects to consider in a work setting in order to comprehend and explain personnel's behaviour and mode of participation in CDM. In this sense the parameters provide a conceptual framework for analysing CDM in complex work settings. This appears to be a useful framework as it can help sensitise the analysis to key elements in work performance. It is at a high-level and open ended thereby allowing unique attributes of the studied setting to emerge but this could also be a limitation as it requires considerable creative interpretive effort. Moreover, the application of the framework was undertaken by its developer which could moderate comments about its usefulness. Hence, the usefulness of the framework needs to be tested by others. This is yet to be undertaken.

8.5. SUMMARY

A conceptual framework is derived from the theory developed in this research to analyze the occurrence of CDM in a particular setting. The parameters constituting this framework are described along with the related propositions presented in the theory. Its application has been demonstrated by analysing an aircraft accident report to draw insights about the occurrence of CDM during task performance in the air traffic control setting. The parameters structured the analysis by directing the focus on the conditions, behavior and contingency factors to be considered. The process of analysis is presented along with the insights drawn. Through this, the chapter has put forth a plausible application of the theory of CDM developed in this research. Also, the limitation of the conceptual framework as an analytical tool has been considered.

CHAPTER 9

CONCLUSION

9.1. SUMMARY OF RESEARCH

The purpose of this research is to develop a theory of Collaborative Decision Making (CDM) founded on studies of work performance in a real world complex setting. The need for such an undertaking arose from the disparity identified between the existing theoretical conceptualizations of CDM and its occurrence in the real world.

It was ascertained from the literature reviewed in chapter 2 that the current view of CDM is founded on a number of notions. Firstly, decision making is generally considered to be a mental process separate from the physical actions. However, there is a growing realization for the need to address the integrated nature of cognitive processes and physical actions in decision making. Secondly, the primary focus of CDM is regarded as decision making. Nevertheless, literature stipulates that in the real world, decision making is the means to achieving the goals of the undertaken task. Hence, the focus of CDM is the latter. Thirdly, CDM is considered to be a process of achieving common goals. This view is contested in the literature with the argument that in the work settings of the real world goals of personnel participating in CDM can be of different scope and nature. Fourthly, models depict CDM as a process of forming consensus which culminates in a decision. This stems from the approach taken by studies of CDM which consider it to occur at a particular instance, during task performance, whereupon a choice of action has to be made. Nonetheless, in the real world, decision making is not an isolated activity, but is interlaced with other entailing task performance activities. Hence, there is certain inconsistency between the theory and practice of CDM in real world complex work settings.

This research aims to address the gap in knowledge and understanding of the occurrence of CDM in the real world by addressing the question – *how do people in a complex heterogeneous working environment make decisions collaboratively?* The process of answering the question led to the development of the theory of CDM presented in this thesis. Taking a qualitative approach, the study explored, analysed and conceptualized behaviour of personnel operating in their natural work environment in the airport Air Traffic Control (ATC) work setting. Theory development was founded on Grounded Theory Methodology (GTM). Chapter 3 describes the methodology and application of its guiding principles in this study as well as the data collection and analysis techniques used. The chapter also describes the work setting of the airport in which the field studies informing this research were undertaken. The studies focused on developing a deeper understanding of the way personnel from different work units undertake CDM in the course of performing air traffic control operations. It also aimed at constructing a theoretical framework to explain the occurrence of CDM in the conditions of a complex work setting.

In this thesis, analysis of study findings through GTM led to the development of the theory of CDM *as a process of managing interdependencies*. The emergence of entailing codes, categories and relationships are described in chapters 4, 5 and 6. The theory explains the occurrence of CDM by delineating influential conditions as well as the strategies, means and mechanisms employed by personnel to undertake CDM in the course of task performance. This theory is centred on the core concern of personnel in undertaking CDM which emerged from the findings to be managing the dependencies in decision making. The differentiated nature of CDM in the cooperative arrangement of complex work settings is explicated through the developed theory.

The findings of this research not only clarify, but also extend our understanding of the way CDM is undertaken in the complex work settings of the real world. This is described in chapter 7 which discusses the key findings in relation to the limitations of existing notions of CDM identified in the literature. The discussion of key findings brings forth the need to consider the characteristics of cooperative arrangement in complex work settings and to take a broader perspective in conceptualizing the occurrence of CDM in these settings. Whilst, personnel come together in order to jointly make a decision that is agreeable to those involved, CDM is not limited to this setup. During task performance in the cooperative work arrangement different personnel make different decisions at various instances. They contributed to each other's decision making by providing required information, performing necessary actions or making related decisions. Hence, CDM also takes place by personnel synchronizing their work activities so as to aid each other's decision making. This requires approaching CDM as an activity of making decisions in collaboration with others involved in task performance instead of viewing it as personnel collaborating with the aim to arrive at a decision. Such a shift in perception brings forth the situated and embedded nature of decision making in the work activities of task performance. The theory generated in this research is then evaluated by providing evidence that it meets the proposed criteria for validating a Grounded Theory which includes fit, relevance, workability and modifiability.

Based on the developed theoretical framework of CDM a list of ten parameters is derived which can be applied in conjunction to analyse and characterise the occurrence of CDM in a particular setting. This is intended to serve as an analytical tool for exploring, understanding and drawing insights about the way CDM is undertaken during everyday work activities of a complex work setting. Chapter 8 demonstrates the application of these parameters to analyse an aircraft accident report and characterise CDM occurring in the course of performing the task of aircraft departure from the airport. The parameters are found to provide a structure for analysis and a set of concepts of explaining the influential conditions and behaviour of personnel in undertaking CDM.

The main contributions of this thesis are demarcated next and its significance delineated by presenting the implications of the findings of this research in the fields of CSCW, NDM and Decision Theory. The contributions are then placed within the limitations of the study. Finally, the chapter concludes the thesis with directions for future work.

9.2. RESEARCH CONTRIBUTIONS AND SIGNIFICANCE

The contribution and significance of this thesis are primarily in the field of Computer Supported Cooperative Work (CSCW) and to some extent in Naturalistic Decision Making (NDM). Specifically, the thesis makes two main contributions:

- A theory of CDM as a process of managing interdependencies which presents a new take on the occurrence of CDM during work performance.
- A framework for analysing and characterising CDM taking place in a complex work setting.

The field studies undertaken to inform this research makes certain key contributions in the field of CSCW. It contributes to the repertoire of workplace studies which are prominent in this field. These are particularly useful for extracting descriptions of work performance and its organization in a setting. Whilst collaborative work performance has been investigated by a number of such studies, those particularly addressing CDM are limited. The field studies undertaken to inform this research contribute to narrowing the gap.

Moreover, the existing workplace studies in CSCW are aimed at drawing requirements for design and development of technological artefacts to facilitate CDM with focus on information sharing through these artefacts. Alternatively, the studies of this research have demonstrated the intricacies involved in undertaking CDM in the cooperative arrangement of complex work settings and help gain a better understanding. It has raised awareness about important aspects to consider in the cooperative work arrangement to conceptualise the occurrence of CDM in a complex work setting. Also, employing GTM to guide the studies helped to go beyond mere descriptions of the way personnel undertake CDM to abstracting concepts from the data. The relationships drawn between these concepts constitute the theoretical understanding of CDM elicited in this thesis and contribute to the development of the conceptual foundation of CDM in the field of CSCW.

The theory generated through GTM is about a concept which is the 'core variable' and its related concepts that account for the occurrence of the subject of inquiry. The concepts generated through GTM represent social patterns identified in the research data. In the theory of CDM developed, the 'core variable' emerged to be managing interdependencies. The social patterns involved in CDM were identified in the research data to be centred on managing the interdependencies arising between personnel's work activities in the course of task performance. The associated conceptual framework presented in chapters 4,5 and 6 explain how CDM is articulated during every day work activities in the process of managing interdependencies. In CSCW, while interdependencies is considered to be the crux of the cooperative arrangement in complex work settings, studies of CDM have overlooked the role of dependencies in decision making. Alternatively, this research uncovers the role of dependencies in undertaking CDM and makes key contributions to the way CDM is perceived in not only the field of CSCW but also in others studying decision making. The conceptual framework of CDM presented in this thesis shows that interdependencies between work activities of personnel structures participation and contribution to decision making in the course of task performance resulting in CDM becoming a process of managing interdependencies. This is a new perspective on how decision making in a cooperative work arrangement become a collaborative act.

Furthermore, in the field of CSCW, existing research typically explores articulation work with respect to collaboration. This thesis contributes to the field by demonstrating the nature of articulation work involved in undertaking decision making in the cooperative setup of a work setting. This research explains that undertaking CDM in the dynamic conditions and cooperative arrangement of complex work settings requires establishing who does what, where, when and how. Hence, there is a need to address how it is articulated in the course of task performance. In doing so, this research has revealed that there are varied modes of undertaking CDM. This demonstrates that the way personnel undertake CDM is not limited to the typical sequential depiction of the process in the field of CSCW based on studies of group decision making.

The typical view in CSCW research is that group members assemble with the explicit aim of making a decision that is agreeable to all and the focus is on information sharing between group members. Most models depict CDM as a sequential process of collaboration leading to a decision which takes place at a particular instance when a choice of action has to be made.

Alternatively, this research demonstrates that when CDM is undertaken during task performance in the conditions of real world complex work settings, it is a cumulative activity of actions, interactions and decisions of multiple personnel converging at different instances. This is structured by the configuration of dependencies arising during task performance. Thus, depictions need to extend beyond the sequential model and capture the non-linear approach as well as the different modes of undertaking CDM exhibited in the real world. The conceptual framework of CDM presented in this thesis steps from the predominantly existing sequential models identified in the literature which present a narrow simplistic depiction. On the other hand, this framework has identified important aspects of the cooperative work arrangement influencing decision making and the intricacies in undertaking decision making in such a collaborative setup. It explains the embedded nature of decision making within the ecology of social interactions and provides a new lens through which the sociality in decision making can be explored.

The conceptual framework of CDM presented in this thesis demonstrates that CDM takes place in a differentiated manner in real world complex work setting. In these settings, it occurs in a cooperative arrangement which influences the way CDM is undertaken. Hence, the characteristics of this arrangement need to be factored in the conceptualizations of CDM. It also brings forth the integrated nature of decision making in task performance activities. This calls for studies in CSCW to look beyond the means and mechanisms of information sharing in CDM and address the larger context of this setup. Furthermore, studies in CSCW have refrained from addressing decision making directly as it is considered to be the realm of cognitive science. This thesis has demonstrated how decision making can be a direct subject of study in a field that primarily focuses on the social processes in work performance. In doing so, it has developed a conceptual framework of

CDM from CSCW perspective that expounds the influence of social arrangement of complex work settings on decision making.

Furthermore, this research holds significance in the field of NDM as it also investigates decision making in the natural setting of the real world. The difference however is in the approach taken to the investigation. NDM research focusses on the cognitive aspects of decision making whereas this research addresses the sociality involved. Although not directly addressed as CDM, studies in NDM investigate decision making in teams. The focus here is on 'sharedness' of individual cognition which is captured in concepts such as shared situation awareness and shared mental models. According to these notions, communication between team members is aimed at sharing information to establish a collective understanding of the situation of task performance and similarity of member's declarative, procedural and strategic knowledge. Based on this understanding, team members assess the situation of task performance and decide the course of. Such a perception led to collective decision making in a team to be considered as a variant of individual decision making.

Nevertheless, the perception has shifted with the realization that members do not work autonomously in complex work settings, but are dependent on each other, which requires them to cooperate with others in the team. Whilst the need to explore decision making in the social context of complex work settings is acknowledged in the field, studies addressing this need are limited. This research addresses the gap and provides a new approach for NDM studies to include the sociality involved in decision making. The theory of CDM developed in this research addresses the social structure between personnel involved in task performance through the dependencies between their work activities. Although, NDM research considers team members to be interdependent in their work activities, the role of interdependencies in decision making has not been explored. Alternatively, the theory developed in this research explains how decision making is organized across personnel undertaking tasks in the process of managing the dependencies between their work activities. By incorporating the notions put forth by this theory in studies of NDM, decision making can be explored in a wider social context. Furthermore, the theoretical framework developed in this research can be employed as an analytical lens through which studies in NDM can explicate the way personnel articulate decision making in a naturalistic work environment.

9.3. LIMITATIONS OF STUDY

Three main limitations can be identified. Firstly, this research addresses the sociality of decision making. In this sense, the limitation of the study is that it concentrates on the actions and interactions between personnel involved in task performance and the cooperative work arrangement in which it is performed. Consequentially, the cognitive processes involved in CDM are overlooked. Whilst the findings bring forth the interleaved nature of decision making and collaborative activities, the focus is on social processes and entailing cognitive processes are not addressed.

Secondly, this research takes a qualitative approach as described in chapter 3. Associated field studies were undertaken in a domain which was viewed to be representative of complex work settings. The study was undertaken in the setting of two work units in an airport – Control Tower and Operations Centre. Work performance of personnel from other work units was studied in relation to the work activities taking place in these two centres of operation. This limits the findings towards the concerns of personnel and work activities taking place in these two centres. The study could have benefited from incorporating perspectives from other related work units involved in airport ATC operations.

Qualitative data are considered to be less precise than that collected through quantitative methods. This is because data collected through qualitative methods such as field studies, particularly steered by GTM, which advocates ‘emergence’, does not control the variables studied in the setting. Nevertheless, such an approach is particularly suitable for obtaining a fresh perspective on work performance in a natural work setting by not restricting studies to preconceived notions and variables to be addressed. This enables a comprehensive study on the occurrence of CDM during everyday work activities by considering a wide range of factors and concerns that arise in the context of natural work settings. The third limitation here is the issue of generalizability that arises with any qualitative research. In this research, data collection and analysis is founded on GTM. The emerging theory is based on field studies undertaken from one particular airport setting (known as ‘substantive’ case in GTM) and is considered to be a ‘substantive theory’. For the theory to become generalizable, a ‘formal theory’ needs to be generated through comparative analysis of different kind of substantive cases.

9.4. Directions for Future Research

There are a number of avenues for furthering this research work. Directions for future research are derived from the three elements of work presented in this thesis: approach taken towards investigating CDM, number and range of settings examined in developing the theory, and validating and refining the analytical framework of CDM. Existing studies typically address either the cognitive or social aspects even though both are interleaved in undertaking CDM. Whilst this research contends the need to address both aspects in conjunction, it focuses on the sociality of decision making. Hence, further research needs to be carried out to extend the theory presented in this thesis to include the cognitive aspects of decision making.

A new approach to perceiving CDM is presented in this thesis and is a first undertaking to conceptualise it as a process of managing interdependencies.

However, this theory is founded on studies of a particular work setting. Comparable studies can be carried out in other complex work settings to explore similarities and differences in articulating CDM. This would strengthen and extend the constructs comprising the ‘substantive theory’ of CDM presented in this thesis and contribute to developing a ‘formal theory’. A possible direction would be to study CDM in the complex work setting of a different domain such as a hospital or business organization. This could also include wider and diverse work units in the setting. Further research can also validate the theory of CDM presented in this thesis through quantitative methods. The findings of this study can be verified or falsified through quantitative studies by drawing hypothesis from the relationships between constructs presented in the theory.

The applicability of the analytical framework developed from the theory of CDM was evaluated by its developer. Further validation needs to be undertaken by other researchers and practitioners in the field to evaluate its usability and usefulness in analysing CDM in a complex work setting. Also, its suitability as an analytical tool to inform the design and development of technology aimed at facilitating CDM is yet to be explored. Hence, there is much scope for furthering this research work.

9.5. CONCLUDING REMARKS

The aim of this research was to gain a deeper understanding of the occurrence of CDM in complex work settings. The exploration has brought forth the differentiated nature of the way CDM is undertaken in the cooperative arrangement of these settings.

The theory of CDM developed through this research explains how decision making is articulated during everyday work activities in the process of managing the interdependencies arising during task performance. It explains the embedded nature of decision making within the ecology of social interactions and provides a lens through which the sociality in decision making can be explored. Moreover, the findings of this research have not only clarified existing notions but also extended our understanding of the way personnel undertake CDM in complex work settings.

BIBLIOGRAPHY

Ackerman, Mark. S., and C.A. Halverson. 1998. "Considering an Organization's Memory." Pp. 39-48 in *ACM Conference on Computer Supported Cooperative Work (CSCW '98)*. New York: ACM.

Adler, Bernd-Mathias., Walter. Baets, and Reinhard. Konig. 2011. "A complexity perspective on collaborative decision making in organizations:The ecology of group-performance." *Information & Management* 48:157-165.

Alby, Francesca., and Cristina. Zucchermaglio. 2006. "'Afterwards we can understand what went wrong, but now let's fix it': How Situated Work Practices Shape Group Decision Making." *Organization Studies* 27:943–966.

Aldiabat , M. Khaldoun. , and Carole-Lynne. Le Navenec. 2011. "Philosophical Roots of Classical Grounded Theory: Its Foundations in Symbolic Interactionism " *The Qualitative Report* 16:1063-1080.

Aldunate, R. G., F. Pena-Mora, and G. E. Robinson. 2005. "Distributed decision making for large scale disaster relief operations: Drawing analogies from robust natural systems." *Complexity* 11:28–38.

Ambert, A.-M., P. A. Adler, P. Adler, and D. F. Detzner. 1995. "Understanding and evaluating qualitative research." *Journal of Marriage and the Family* 57:879–893.

Amy, R., N. Dahlbäck, and J. Lundberg. 2013. " A case study of factor influencing role improvisation in crisis response teams." *Cognition, technology & work* 15:79-93.

Andersen, Hans, H. K. 1997. "Cooperative Documentation Production in Engineering Design. The 'Mechanisms of Interaction' Perspective." in *Maersk Mc-Kinney Institute for Production Technology*. Taastrup, Denmark: Danish Technological University.

Andres, P. Hayward. 2002. "A comparison of face-to-face and virtual software development teams." *Team Performance Management: An International Journal* 8:39-48.

Ariely, Dan., and Dan. Zakay. 2001. "A Timely Account of the Role of Duration in Decision Making." *Acta Psychologica* 108:187-207.

Armstrong, D. J., and P. Cole. 2002. "Managing distances and differences in geographically distributed work groups." Pp. 167-186 in *Distributed Work,* edited by P. J. Hinds and S. Kiesler. Cambridge, MA: MIT Press.

Artman, H. 1997. "Team Situation Awareness and Technology Architectures." in *Proceedings of European Conference on Cognitive Science*. Manchester. U.K.

Babchuk, W. A. 1996. "Glaser or Strauss? Grounded theory and adult education " in *Midwest Research-to-Practice Conference in Adult, Continuing and Community Education*. Michigan State University.

Baker, C., J. Wuest, and P. N. Stern. 1992. "Method slurring: The grounded theory/phenomenology example." *Journal of Advanced Nursing* 17:1355 - 60.

Bannon, L. J, and S Bødker. 1997. "Constructing common information spaces." Pp. 81-96 in *Proceedings of the Fifth European Conference on Computer-Supported Cooperative Work*. Lancaster, U.K: Kluwer Academic Publishers.

Bannon, Liam. 1997. "CSCW - A challenge to certain (G)DSS perspectives on the role of decisions, information, and technology in organizations." in *Decision Support in Organizational Transformation*, edited by P.Humphreys., A.McCosh., and B.Mayon-White. London: Chapman & Hall.

Bannon, Liam., and Kjeld. Schmidt. 1989. "CSCW: Four Characters in Search of a Context." Pp. 358-372 in *First European Conference on Computer Supported Cooperative Work, UK*.

Bardram, E. Jakob. 1998. "Designing for the Dynamics of Cooperative Work Activities." Pp. 89-98 in *Computer-Supported Cooperative Work*. Seattle, Washington, United States: ACM Press.

Bardram, E. Jakob., and Claus. Bossen. 2005. "A Web of Coordinative Artifacts: Collaborative Work at a Hospital Ward." in *GROUP'05*. Sanibel Island, Florida, USA.

Bardram, J., and T. Hansen. 2010. "Why the Plan Doesn't Hold – a Study of Situated Planning, Articulation and Coordination Work in a Surgical Ward." Pp. 331-340 in *ACM Conference on Computer Supported Cooperative Work (CSCW'10)*. Savannah, Georgia, USA.

Barry, A. Cristine. 1998. "Choosing Qualitative Data Analysis Software: Atlas/ti and Nudist Compared." *Sociology Research Online* 3.

Bearman, Christopher., B. F. Susannah. Paletz, Judith. Orasanu, and J. W. Mathew. Thomas. 2010. "The Breakdown of Coordinated Decision Making in Distributed Systems." *Human Factors: The Journal of the Human Factors and Ergonomics Society* 52:173-188.

Bentley, A., et al. 1992. "Ethnographically-informed systems design for air traffic control." Pp. 123-129 in *Computer Supported Cooperative Work (CSCW'92)*. Toronto, Canada: ACM Press.

Berg, M., and G. Bowker. 1997. "The Multiple Bodies of the Medical Record: Toward a Sociology of an Artifact." *The Sociological Quarterly* 38:511-535.

Berndtsson, Johan., and Maria. Normark. 1999. "Coordination in Air Traffic Control Work - The Copenhagen Fieldstudies." Pp. 101–110 in *ACM SIGGROUP Conference on Supporting Group Work*. Phoenix, Arizona, US.

Blomberg, Jeanette. , and Helena. Karasti. 2013. "Reflections on 25 Years of Ethnography in CSCW." *Computer Supported Cooperative Work (CSCW)* 22:373-423.

Blumer, Herbert. 1986. "The Methodological Position of Symbolic Interactionism." in *Symbolic Interactionism. Perspective and Method*, edited by Herbert. Blumer. London, England: University of California Press, Ltd.

Blumer, Herbert. 2005. "Society as Symbolic Interaction." in *Contemporary Sociological Thought. Themes and Theories*, edited by P. Sean. Hier. Toronto, Ontario: Canadian Scholar's Press Inc.

Boden, Alexander. , Bernhard. Nett, and Volker . Wulf. 2008. "Articulation work in small-scale offshore software development projects." Pp. 21-24 in *International Conference on Software Engineering*: ACM New York, USA.

Bødker, S. 1989. "A human activity approach to user interfaces." *Human-Computer Interaction* 4:171– 195.

Boiney, Lindsley. 2004. "Team Decision Making in Complex, Time-Sensitive Environments." in *FY04 Air Force Mission Oriented Investigation and Experimentation (MOIE)*: The MITRE Corporation.

Boland, J , Richard, Jr., K Anil Maheshawarl, Dov Te'eni, G David Schwartz, and V Ramakrishnan Tenkasi. 1992. "Sharing Perspectives in Distributed Decision Making." Pp. 303-313 in *ACM conference on Computer-supported cooperative work (CSCW '92)*. New York, NY, USA ACM

Bolman, L. 1979. "Aviation accidents and the “theory of the situation“." Pp. 31-58 in *Resource Management on the flight deck: Proceedings of a NASA/Industry Workshop*, edited by G.E. Cooper, M.D. White, and J.K. Lauber. Moffett Field, CA: NASA Ames Research Center.

Bowers, A.Victoria., and L. Harry. Snyder. 1990. "Concurrent versus Retrospective Verbal Protocol for Comparing Window Usability." *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* 34:1270-1274.

Bowker, G., and Leigh. Susan. Star. 1991. "Situations vs Standards in Long Term, Wide-Scale Decision Making: The Case of the International Classification of Diseases." Pp. 73-81 in *Twenty Fourth Annual Hawaii International*

Conference on System Sciences, edited by F. J. Nunamaker and H. R. Sprague. Kauai, Hawaii: IEEE Computer Society Press.

Brehmer, B. 1992. "Dynamic decision making: Human control of complex systems." *Acta Psychologica* 81:211-241.

Brehmer, B. 2000. "Dynamic Decision Making in Command and Control." Pp. 233-248 in *The human in command: exploring the modern military experience*, edited by C. McCann and R. Pigeau. New York: Kluwer Academic/Plenum Publishers.

Brown, Barry. 2005. "Choice and Mobility: decision making on the move." in *Draft, presented at SASE panel on Mobile Geographies*. Budapest.

Bui, X. T., and M. Jarke. 1984. "A DSS for Cooperative Multiple Criteria Group Decision Making." Pp. 101-113 in *5th International Conference on Information Systems*. Tucson, AZ.

Busemeyer, J. R., R. K. Jessup, and E. Dimperio. 2009. "The dynamic interactions between situations and decisions." Pp. 307–321 in *The Cambridge Handbook of Situation Cognition*, edited by P. Robbins and M. Aydede. New York: Cambridge University Press.

Cabello, Francisco. , and Denis. O´Hora. 2002. "Addressing the Limitations of Protocol Analysis in the Study of Complex Human Behavior." *International Journal of Psychology and Psychological Therapy* 2:115-130.

Campanella, G., A. Pereira, Rita. A. Ribeiro, and Leonilde. R. Varela. 2012. "Collaborative Dynamic Decision Making: A Case Study from B2B Supplier Selection." *Decision Support Systems–Collaborative Models and Approaches in Real Environments*:88-102.

Cannon-Bowers, J. A, Eduardo Salas, and S Converse. 1993. "Shared mental models in expert decision making." Pp. 221-246 in *Individual and group decision making: current issues*, edited by N.J Castellan. Hillsdale, NJ: Erlbaum.

Cannon-Bowers, J. A., and E. Salas. 2001. "Reflections on shared cognition." *Journal of Organizational Behavior* 22:195–202.

Carmel, E., and R. Agarwal. 2001. "Tactical Approaches for Alleviating Distance in Global Software Development." *Software, IEEE* 8:22-29.

Carpenter, Sandra., et al. 2008. "Studying team shared mental models." Pp. 41-48 in *3rd International Conference on the Pragmatic Web*, edited by ACM. Uppsala, Sweden.

Carstensen, H. Peter., and Kjeld. Schmidt. 1998. "Computer Supported Cooperative Work: New Challenges to Systems Design." *Handbook of Human Factors*.

Carstensen, H. Peter., and Kjeld. Schmidt. 1999. "Computer Supported Cooperative Work: New Challenges to Systems Design." Pp. 619-636 in *Handbook of Human Factors,* edited by K. Itoh. Tokyo.

Carstensen, Peter. H. , and C. Sorensen. 1996. "From the social to the systematic. Mechanisms supporting coordination in design, Computer Supported Cooperative Work." *Computer Supported Cooperative Work* 5:387-413.

Cartensen, Peter. 1994. "The Bug Report Form." Pp. 187-219 in *Social Mechanisms of Interaction.* , edited by K. Schmidt. Lancaster, UK: Computing Department, Lancaster University.

Carvalhoa, V. R. Paulo., .L. Isaac. dos Santosa, and C.R. Mario. Vidalb. 2005. "Nuclear power plant shift supervisor's decision making during microincidents." *International Journal of Industrial Ergonomics* 35: 619–644.

Charmaz, Kathy. 2006. *Constructing Grounded Theory: A Practical Guide through Qualitative Analysis* London, U.K.: Sage Publications Inc.

Chatman, A. Jennifer., and J. Francis. Flynn. 2001. "The Influence of Demographic Heterogeneity on the Emergence and Consequence of Cooperative Norms in Work Teams." *Academy of Management Journal* 44:956-974.

Christensen, Caryn., and R. James. Larson JR. 1993. "Collaborative Medical Decision Making." *Medical Decision Making* 13:339-346.

Christian, K. Caprice , et al. 2006. "A prospective study of patient safety in the operating room." *Surgery* 139:159–173.

Cilliers, Paul. 1998. *Complexity and Post-Modernism. Understanding Complex Systems*. London, UK: Routledge.

Clark, H.H. 1996. *Using Language*. Cambridge: Cambridge University Press.

Clark, H.H., and S.E. Brennan. 1991. "Grounding in communication." in *Perspectives on socially shared cognition,* edited by L.B. Resnick, J.M. Levine, and S.D. Teasley. Washington, D.C.: American Psychological Association.

Clarke, A. 2005. *Situational analysis: Grounded theory after the postmodern turn*. Thousand Oaks, CA: Sage.

Clement, Andew., and Ina. Wagner. 1995. "Fragmentation Exchange: Disarticulation and the Need for Regionalized Communication Spaces." Pp. 33-49 in *Fourth European Conference on Computer-Supported Cooperative Work,* edited by H. Marmolin, Y. Sundblad, and K Schmidt. Stockholm, Sweden: Kluwer Academic Publishers, Norwell, MA.

Cohen, A.L., D. Cash, and M. J. Muller. 2000. "Designing to Support Adversarial Collaboration." Pp. 31-39 in *2000 ACM conference on Computer supported cooperative work (CSCW '00)* New York, NY, USA: ACM.

Cohen, G.Susan., and E Bailey, Diane. 1997. "What Makes Teams Work: Group Effectiveness Research from the Shop Floor to the Executive Suite." *Journal of Management* 23:239-290.

Converse, S.A., J. A Cannon-Bowers, and E. Salas. 1991. "Team member shared mental models: a theory and some methodological issues." Pp. 1417-1421 in *Human Factors Society 35th Annual Meeting*.

Cook, Glenda., Kate. Gerrish, and Charlotte. Clarke. 2001. "Decision-making in teams: issues arising from two UK evaluations." *Journal of Interprofessional care* 15:141-151.

Cooke, W.G., E. Salas, J. A. Cannon-Bowers, and R Stout, J. 2000. "Measuring Team Knowledge." *Human Factors* 42:151-173.

Corley, K. G., and D. A. Gioia. 2004. "Identity Ambiguity and Change in the Wake of a Corporate Spin-off." *Administrative Science Quarterly* 49:173–208.

Coyne, T. Imelda. 1997. "Sampling in qualitative research. Purposeful and theoretical sampling; merging or clear boundaries?" *Journal of Advanced Nursing* 26:623–630.

Cramton, C. D. 2001. "The mutual knowledge problem and its consequences for dispersed collaboration." *Organization Science* 12:346-371.

Creswell, J. W. 2007, pg. 37. *Qualitative inquiry and research design*. Thousand Oaks, CA: Sage Publications, Inc.

Creswell, J.W. 1998. *Qualitative inquiry and research design: Choose among five traditions*. London: Sage.

Degani, Asaf., and L. Earl. Wiener. 1990. "Human Factors of Flight-Deck Checklists: The Normal Checklist." Moffet Field, California: National Aeronautics and Space Administration. Ames Research Centre.

Dekker, S., J. Bergstro¨m, I. Amer-Wa˚hlin, and P. Cilliers. 2013. "Complicated, complex and compliant: Best practices in obstretics." *Cognition, Technology & Work* 15:189-195.

DeSanctis, G., and B. Gallupe. 1987. "A foundation for the study of group decision support systems." *Management Science* 33:1589-1609.

Dey, A.K., G.D. Abowd, and Daniel. Salber. 2001. "A conceptual framework and a toolkit for supporting rapid prototyping of context-aware applications." *Human-Computer Interactions (HCI) Journal* 16:97-166.

Dourish, P., A. Adler, V. Bellotti, and A. Henderson. 1996. "Your place or mine? Learning from long-term use of audio–video communication." *Computer-Supported Cooperative Work* 5:33–62.

Dourish, P., and V. Belotti. 1992. "Awareness and Coordination in Shared Workspaces." Pp. 107–114 in *Conference on Computer-Supported Cooperative Work (CSCW'92)*. Toronto, Canada: ACM.

Dourish, Paul. 2004. "What We Talk About When We Talk About Context." *Journal of Personal & Ubiquitous Computing* 8:19-30.

Durfee, H. Edmund., R. Victor. Lesser, and D. Daniel. Corkill. 1989. "Trends in Cooperative Distributed Problem Solving." *IEEE Transactions on Knowledge and Data Engineering* 1:63-89.

Egger, Edeltraud., and I. Wagner. 1993. "Negotiating Temporal Orders: The Case of Collaborative Time Management in a Surgery Clinic." *Computer Supported Cooperative Work (CSCW). An International Journal* 1:255-275.

Ehrhart, Scott, Lee., and J. Anthony. Bigbee. 1999. "Co-Evolving C2 Organizational Processes, Decision Support Technology, and Education/Training: The Role of Evaluation in Cognitive Systems Engineering." in *Paper presented at the RTO SAS Symposium OR "Modelling and Analysis of Command and Control"*. Issy les Moulineaux, France: published in RTO MP-38.

Ellingsen, K., and E. Mathisen. 2011. "Decision making and information. Conjoined twins?" in *Norsk konferanse for organisasjoners bruk av informasjonsteknologi(NOKOBIT 2011)*. Universitetet i Tromsø: Tapir Akademisk Forlag.

Elliott, Taryn. 2005. "Expert Decision-Making in Naturalistic Environments: A Summary of Research." Edinburgh South Australia: DSTO System Sciences Laboratory.

Endsley, M. R. 1995. "Measurement of situation awareness in dynamic systems." *Human Factors* 37:65-84.

Endsley, M. R. 2003. "Supporting Situation Awareness for Multiple Operators." in *Designing for Situation Awareness: An Approach to User-Centered Design*, edited by M. R Endsley, B. Bolte, and D.G. Jones. New York: Taylor & Francis.

Endsley, R.Mica. 2000. "Theoretical Underpinnings of Situation Awareness: A Critical Review." in *Situation Awareness Analysis and Measurement*, edited by M.R. Endsley and D.J. Garland. Mahwah, NJ: Lawrence Erlbaum Associates.

Engeström, Y. 1999. "Activity theory and individual and social transformation." Pp. 19-38 in *Perspectives on activity theory*, edited by Y. Engeström., R.

Miettinen., and R.-L. Punamäki. Cambridge, UK: Cambridge University Press.

Entin, E., and E. Entin. 2000. "Assessing Team Situation Awareness in Simulated Military Missions." *Ergonomics for the New Millennium. In: Proceedings of the XIVth Triennial Congress of the International Ergonomics Association and 44th Annual Meeting of the Human Factors and Ergonomics Society. San Diego, California* 1:73–76.

Erickson, Thomas. 1993. "From Interface to Interplace: The Spatial Environment as a Medium for Interaction." in *Conference on Spatial Information Theory*.

Ericsson, A., and H.A. Simon. 1993. *Protocol Analysis: Verbal Reports as Data* Cambridge, MA: MIT Press.

Ericsson, K.A. 2006. "Protocol analysis and expert thought: Concurrent verbalizations of thinking during experts' performance on representative tasks." Pp. 223–241 in *Handbook of expertise and expert performance*, edited by K. A. Ericsson, N. Charness, P. J. Feltovich, and R. Hoffman. New York: Cambridge University Press.

Ericsson, K.A., and H.A. Simon. 1980. "Verbal reports as data." *Psychological Review* 87:215-251.

Eriksson, Joakim. 2009. "Collaborative Product Development: A Collaborative Decision Making Approach." in *School of Innovation, Design and Engineering*. Eskilstuna, Sweden: Mälardalen University.

Faergemann, Louise., Teresa. Schilder-Knudsen, and H. Peter. Carstensen. 2005. "The Duality of Articulation Work in Large Heterogeneous Settings - a Study in Health Care." Pp. 163-183 in *Ninth European Conference on Computer-Supported Cooperative Work (ECSCW'05)*, edited by H.Gellersen et al. Paris, France: Springer.

Fairburn, C., P. Wright, and R. Fields. 1999. "Air traffic control as distributed joint activity. Using Clark's theory of language to understand collaborative working in ATC." in *European Conference on Cognitive Science*. Siena.

Fields, B, P Amaldi, and A Tassi. 2004. "Representing Collaborative Work: The Airport as Common Information Space." *Cognition, Technology and Work*.

Filip, F.G. 2008. "Decision support and control for large-scale complex systems." *Annual Reviews in Control* 32:61-70.

Finnegan, Pat., and Lynda. O'Mahony. 1996. "Group problem solving and decision making: an investigation of the process and the supporting technology." *Journal of Information Technology* 11:211-221.

Fiore, S.M., E. Salas, H.M. Cuevas, and C.A. Bowers. 2003. "Distributed coordination space: toward a theory of distributed team process and performance." *Theoretical Issues in Ergonomics Science* 4:340–364.

Fitzpatrick, Geraldine. , and Gunnar. Ellingsen. 2013. "A Review of 25 Years of CSCW Research in Healthcare: Contributions, Challenges and Future Agendas." *Computer Supported Cooperative Work (CSCW)* 22:609-665.

Fjuk, Annita., and Ole. Smordal. 1997. "Taking Articulation Work Seriously - an activity theory approach." Turku Centre for Computer Science.

Fonteyn, M., and A. Fisher. 1995. "Use of think aloud method to study nurses' reasoning and decision making in clinical practice settings." *Journal of Neuroscience Nursing* 27:124-128.

Furuta, Kazuo. , and Yufei. Shu. 2004. "Team Situation Awareness and Its Assessment." in *Advancement on Operation & Maintenance for Nuclear Power Plant*. The Seminar of JSPS-KOSEF Core University Program on Energy Science & Technology Subtask CR04-2-2, Tohoku University, Sendai, Japan.

Garbis, Christer., and Henrik. Artman. 2006. "Team situation awareness as communicative practice." in *A cognitive approach to situation awareness: theory and application*, edited by S. Banbury and S. Tremblay. Aldershot, UK: Ashgate & Town.

Gaver, W. 1991. "Sound Support for Collaboration." Pp. 293-308 in *Second European Conference on Computer Supported Cooperative Work (ECSCW '91)*: ACM Press.

Glaser, B. G. 1978. *Theoretical Sensitivity. Advances in the Methodology of Grounded Theory*. Mill Valley, California: The Sociology Press.

Glaser, B. G. 1992. *Basics of Grounded Theory Analysis: Emergence vs. Forcing*. Mill Valley, California: Sociology Press.

Glaser, B. G, and A Strauss. 1967. *The Discovery of Grounded Theory: Strategies for Qualitative Research*: Aldine New York.

Glaser, B. G. 2001. *The Grounded Theory Perspective: Conceptualization Contrasted With Description*: Sociology Press.

Glaser, B. G. 2002a. "Conceptualization: On Theory and Theorizing Using Grounded Theory." *International Journal of Qualitative Methods* 1:23-38.

Glaser, B. G. 2002b. "Constructivist Grounded Theory?" in *Forum Qualitative Sozialforschung / Forum: Qualitative Social Research*. North America.

Glaser, Barney G., and Judith Holton. 2004a. "Remodeling Grounded Theory." in *Forum Qualitative Sozialforschung / Forum: Qualitative Social Research*. North America, 5.

Glaser, G.Barney. 2002c. "Conceptualization: On Theory and Theorizing Using Grounded Theory." *International Journal of Qualitative Methods* 1.

Glaser, G.Barney., and Judith. Holton. 2004b. "Remodelling Grounded Theory." *Forum: Qualitative Social Research* 5.

Goel, Lakshmi., Iris. Junglas, Blake. Ives, and Norman. Johnson. 2012. "Decision-making in-socio and in-situ: Facilitation in virtual worlds." *Decision Support Systems* 52:342-352.

Goncalves, Pina Nuno, and Pedro Antunes. 2000. "An Information Systems Approach to Support Decision Makers Selecting Group Decision Processes." in *Proceedings of the 6th International Workshop on Groupware (CRIWG'00).*

Gonzalez, Cleotilde. 2005. "Decision support for real-time, dynamic decision-making tasks." *Organizational Behavior and Human Decision Processes* 96:142–154.

Gore, Julie., Adrian. Banks, Lynne. Millward, and Olivia. Kyriakidou. 2006. "Naturalistic Decision Making and Organizations: Reviewing Pragmatic Science." *Organization Studies* 27:925–942.

Gorman, J. C., N. J. Cooke, and J. L. Winner. 2006. "Measuring team situation awareness in decentralized command and control environments." *Ergonomics* 49:1312–1325.

Goulding, C. 1998. "Grounded theory: the missing methodology in interpretivist agenda." *Qualitative Market Research: An International Journal* 1:50-57.

Goulding, Christina. 1999. "Grounded Theory: some reflections on paradigms, procedures and misconceptions." Wolverhampton Business School, Management Research Centre, University of Wolverhampton.

Grinter, R. E., J. D. Hersleb, and D. E. Perry. 1999. "The Geography of Coordination: Dealing with Distance in R & D Work." Pp. 306-315 in *GROUP'99 - International ACM SIGGROUP Conference on Supporting Group Work ACM*, edited by S. Hayne. Phoenix, Arizona.

Grudin, J. 1994. "Computer-supported cooperative work: History and focus." *Computer* 27:19-26.

Gutwin, Carl., and Saul. Greenberg. 2002. "A Descriptive Framework of Workspace Awareness for Real-Time Groupware." *Computer Supported Cooperative Work* 11:411–446.

Harper, R., A. John. Hughes, and Dan.Z. Shapira. 1989. "The Functionality of Flight Strips in ATC Work." Lancaster Sociotechnics Group, Department of Sociology, Lancaster University.

Harper, Richard H. R., and A. John Hughes. 1992. "What a f-ing system! Send 'em all to the same place and then expect us to stop 'em hitting. Managing technology work in air traffic control." Pp. 127-144 in *Technology in Working Order. Studies of work, interaction, and technology,* edited by G. Button. London and New York: Routledge.

Harper, Richard H. R., and A. John Hughes. 1993. "What a f-ing system! Send 'em all to the same place and then expect us to stop 'em hitting. Managing technology work in air traffic control." Pp. 127-144 in *Technology in Working Order. Studies of work, interaction, and technology,* edited by G. Button. London and New York: Routledge.

Harrison, S., and Paul Dourish. 1996. "Re-Place-ing Space: The Roles of Place and Space in Collaborative Systems." Pp. 67-76 in *Computer Supported Cooperative Work*: ACM Press.

Heath, C., P. Luff, and A. Sellen. 1995. "Reconsidering the Virtual Workplace: Flexible support for Collaborative Activity." Pp. 83-95 in *ECSCW '95*. Stockholm: Kluwer Academic Publishers.

Heath, Christian., Hubert. Knoblauch, and Paul. Luff. 2000. "Technology and social interaction: the emergence of 'workplace studies'." *British Journal of Sociology* 51:299-320.

Heath, Christian., and Paul Luff. 1991. "Collaborative activity and technological design: Task coordination in London Underground control rooms." Pp. 65-80 in *European Conference on Computer Supported Cooperative Work (ECSCW'91)*. Dordrecht, The Netherlands: Kluwer Academic Publishers.

Heath, Christian., and Paul. Luff. 1992. "Collaboration and Control. Crisis Management and Multimedia Technology in London Underground Control Rooms." *Computer Supported Cooperative Work (CSCW): An International Journal* 1:69-94.

Herbert, Simon A, and Associates. 1986. "Decision Making and Problem Solving." in *Reprinted with permission from Research Briefings 1986: Report of the Research Briefing Panel on Decision Making and Problem Solving © 1986 by the National Academy of Sciences*: Published by National Academy Press, Washington, DC.

Herbsleb, J.D., and A. Mockus. 2003. "An empirical study of speed and communication in globally distributed software development." *IEEE Transactions on Software Engineering* 29.

Herbsleb, J.D., A. Mockus, T.A. Finholt, and R.E Grinter. 2000. "Distance, Dependencies, and Delay in a Global Collaboration." Pp. 319-328 in *CSCW*. Philadelphia, PA.

Hermann, F., N. Rummel, and H. Spada. 2001. "Solving the case together: The challenge of net-based interdisciplinary collaboration." Pp. 293-300 in *First European Conference on Computer Supported Collaborative*

Learning, edited by P. Dillenbourg, A. Eurelings, and K. Hakkarainen. Maastricht.

Herrera-Viedma, Enrique., Francisco. Herrera, and Francisco. Chiclana. 2002. "A Consensus Model for Multiperson Decision Making With Different Preference Structures." *IEEE Transactions on Systems, Man and Cybernetics-Part A: Systems and Humans* 32:394-402.

Hertzum, M. 1999. "Six roles of documents in professional's work." Pp. 41-60 in *Sixth European Conference on Computer-Supported Cooperative Work*, edited by S. Boedker, M. Kyng, and K. Schmidt. Netherland: Kluwer Academic Publishers.

Hilburn, B. . 2004. "Cognitive Complexity in Air Traffic Control A Literature Review." in *Project COCA - COmplexity and CApacity*. Brussels: Eurocontrol Experimental Centre.

Hinsz, B. Verlin., and R. Scott. Tindale. 1997. "The Emerging Conceptualization of Groups as Information Processors." *Psychological Bulletin* 121:43-64.

Hirokawa, Y. Randy. 1990. "The Role of Communication in Group Decision-Making Efficacy : A Task-Contingency Perspective." *Small Group Research* 21:190-204.

Hoffman, R. R., and J. F. Yates. 2005. "Decision(?)Making(?)." *IEEE Intelligent Systems* 20:76 - 83.

Hollnagel, E. . 2012. "Coping with Complexity: past, present and future." *Cognition, Technology & Work* 14:199-205.

Holton, A. Judith. 2008. "Grounded Theory as a General Research Methodology." *Grounded Theory Review. An International Journal* 7:67-93.

Huberman, A. M. , and M. B. Miles. 1994. "Data Management and Analysis Methods." in *Handbook of Qualitative Research*, edited by N. Denzin and Y. S. Lincoln. Thousand Oaks: Sage Publications.

Hughes, A. John., Dave. Randall, and Dan. Shapiro. 1999. "From Ethnographic Record to System Design Some experiences from the field." *Computer Supported Cooperative Work* 1:123-141.

Hughes, A. John., David. Randall, and Dan. Shapira. 1992. "Faltering from ethnography to Design." in *Computer-Supported Coopertative Work (CSCW 92)*, edited by John. Turner and Robert. Kraut. Toronto, Canada: ACM.

Hutchins, Edwin. 1995. "How a cockpit remembers its speeds." *Cognitive Science* 19:265-288.

Hutchins, G. Susan., and Tony. Kendall. 2009. "Analysis of Team Collaboration across Decision-Making Domains to Empirically Evaluate a Model of

Team Collaboration." in *14th International Command and Control Research and Technology Symposium (ICCRTS)*. Washington, DC.

Iversen, Buschmann. Tobias., Line. Melby, Dypvik Landmark, Andreas., and Pieter. Toussaint. 2013. "Managing variations from surgical care plans: Challenges for coordination." *International Journal of Medical Informatics* 82:47-57.

Jankovic, M. 2006. "Prise des decisions collaboratives dans le processus de conception de nouveaux produits. Application a l'automobile." *Laboratoire de Génie Industriel. École Centrale des Arts et Manufactures Paris*.

Jankowski, Piotr., L. Timothy. Nyerges, Alan. Smith, J. T. Moore, and Emory. Horvath. 1997. "Spatial group choice: a SDSS tool for collaborative spatial deicison-making." *International Journal of Geographical Information Science* 11:577-602.

Johnson, D. W., and R. T. Johnson. 1992. "Key to effective cooperation." Pp. 174−199 in *Interaction in cooperative groups: The theoretical anatomy in group learning*, edited by R. Hertz-Lazarowitz. and N. Miller. New York: Cambridge University Press.

Jones, H. Peter., and P. Christopher. Nemeth. 2005. "Cognitive Artifacts in Complex Work." *Ambient Intelligence for Scientific Discovery*:152–183.

Jones, P.E., and P. Roelofsma. 2000. "The potential for social contextual and group biases in team decision-making: biases, conditions, and psychological mechanisms." *Ergonomics* 43:1129-1152.

Kameda, T., R. S. Tindale, and J. H. Davis. 2002. "Cognitions, Preferences, and Social Sharedness: Past, Present, and Future Directions in Group Decision-Making." in *Emerging perspectives on judgment and decision research*, edited by S.L. Schneider and J. Shanteau. Cambridge, UK: Cambridge University Press.

Kane, Bridget., Pieter. Toussaint, and Saturnino. Luz. 2013. "Shared Decision Making Needs a Communication Record." Pp. 79-90 in *CSCW '13*. San Antonio, Texas, USA: ACM.

Kapucu, N., M. E. Augustin, and V. Garayev. 2009. "Interstate partnerships in emergency management: Emergency Management Assistance Compact (EMAC) in response to catastrophic disasters." *Public Administration Review* 69:297–313.

Kapucu, N., and M. VanWart. 2006. "The emerging role of the public sector in managing extreme events: Lessons learned." *Administration & Society* 3:279–308.

Kapucu, Naim., and Vener. Garayev. 2011. "Collaborative Decision-Making in Emergency and Disaster Management." *International Journal of Public Administration* 34:366–375.

Karacapilidis, Nikos., and Dimitris. Papadias. 2001. "Computer supported argumentation and collaborative decision making: the HERMES system." *Information Systems Journal* 26.

Kasbi, Catherine., and Maurice de. Montmollin. 1991. "Activity Without Decision and Responsibility: The Case of Nuclear Power Plants." Pp. 275-283 in *Distributed Decision Making. Cognitive Models for Cooperative Work*, edited by J. Rasmussen, B. Brehmer, and J. Leplat. Chichester: John Wiley & Sons.

Kerr, L.Norbert., and Scott. R. Tindale. 2004. "Group Performance and Decision Making." *Annu. Rev. Psychol* 55:623–655.

Kerstholt, J. H., and J.G.W. Raaijmakers. 1997. "Decision making in dynamic task environments." Pp. 205-217 in *Decision making: Cognitive models and explanations*, edited by R. Ranyard, R. W. Crozier, and O. Svenson. London: Routledge.

Kim, S. Y., A. Godbole, R. Huang, R. Panchadhar, and W. W. Smari. 2004. "Toward an integrated human-centered knowledge-based collaborative decision making system. In *Information Reuse and Integration, 2004. IRI 2004*." Pp. 394-401 in *2004 IEEE International Conference*.

Klein, A. Gary., Judith. Orasanu, Roberta. Calderwood, and C. Zsambok (Eds.). 1993. *Decision making in action: models and methods*. Norwood, CT: Ablex.

Klein, A. Gary., et al. 2003. "Macrocognition." *Intelligent Systems, IEEE* 18:81- 85

Klein, Gary. 1997. "The Recognition-Primed Decision (RPD) Model: Looking Back, Looking Forward." Pp. 285-292 in *Naturalistic Decision Making*, edited by E. Caroline Zsambok and Gary Klein. Mahwah, New Jersey: Lawrence Erlbaum Associates.

Klein, Gary. 2008. "Naturalistic Decision Making." *Human Factors: The Journal of the Human Factors and Ergonomics Society* 50:456-460.

Klein, Gary, J. Paul. Feltovich, M. Jeffrey. Bradshaw, and D. David. Woods. 2005. "Common ground and coordination in joint activity." *Organizational simulation*:139-184.

Klimosky, R., and S. Mohammed. 1994. "Team mental model: Construct of metaphor?" *Journal of Management* 20:403-437.

Kofod-Petersen, A., and J. Cassens. 2005. "Using Activity Theory to Model Context Awareness." Pp. 1-17 in *Modeling and Retrieval of Context (MRC2005)*. Edinburgh, UK.

Kolbe, Michaela., and Margarate. Boos. 2009. "Facilitating Group Decision Making: Facilitator's Subjective Theories on Group Coordination." *Forum Qualitative Sozialforschung/ Forum: Qualitative Social Research* 10.

Koros, Anton. , S. Pamela. Della Rocco, Gulshan. Panjwani, Victor . Ingurgio, and Jean-François. D'Arcy. 2003. "Complexity in Air Traffic Control Towers: A Field Study. Part 1. Complexity Factors." Washington, DC: Federal Aviation Administration (FAA) - ACB-220.

Koslowski, S.W. J., and D. R. lgen. 2006. "Enhancing the effectiveness of work groups and teams." *Psychological Science in the Public Interest* 7:77-124.

Kozlowski, S. W. J., and B. S. Bell. 2003. "Work groups and teams in organizations." in *Handbook of psychology (Vol. 12): Industrial and Organizational Psychology*, edited by W. C. Borman, D. R. Ilgen, and R. J. Klimoski. New York: Wiley-Blackwell.

Kraemer, Kenneth., and Leslie King, John. 1988. "Computer-Based Systems for Cooperative Work and Group Decision Making." *ACM Computing Surveys* 20:115 - 146

Kraut, R. E., S. R. Fussell, S. E. Brennan, and J. Siegel. 2002. "Understanding effects of proximity on collaboration: Implications for technologies to support remote collaborative work." Pp. 137-162 in *Distributed work*, edited by P. Hinds and S. Kiesler. Cambridge, MA: MIT Press.

Kraut, R. E., and L. A. Streeter. 1995. "Coordination in Software Development." *Communications of the ACM* 38:69-81.

Kuutti, Kari. 1991. "The concept of activity as a basic unit of analysis for CSCW research." Pp. 249 - 264 in *Second conference on European Conference on Computer-Supported Cooperative Work (ECSCW 91)*, edited by Liam J. Bannon, M. Robinson, and K. Schmidt. Amsterdam, The Netherlands: Kluwer Academic Publishers Norwell, MA, USA.

Lam, S. K. Simon., and John. Schaubroeck. 2011. "Information sharing and group efficacy influences on communication and decision quality." *Asia Pac J Manag* 28:509–528.

Larossa, Ralph. 2005. "Grounded Theory Research and Qualitative Family Research." *Journal of Marriage and Family 67*:837–857.

Larson, J. R., C. Christensen, T. M. Franz, and A. S. Abbott. 1998. "The pooling, management, and impact of shared and unshared case information in team-based medical decision making." *Journal of Personality and Social Psychology* 75:93−108.

Larson, R. James., G Foster-Fishman, Pennie., and B. Christopher. Keys. 1994. "Discussion of Shared and Unshared Information in Decision-Making Groups." *Journal of Personality and Social Psychology* 67:446-461.

Lave, J. 1988. *Cognition in Practice*. Cambridge Cambridge University Press.

Lave, J., and E. Wenger. 1991. *Situated Learning: Legitimate Peripheral Participation*. Camridge: Cambridge University Press.

Leont'ev, A. 1974. "The problem of activity in psychology." *Soviet Psychology* 13:4–33.

Lipshitz, R. 1994. "Decision Making in Three Modes." *Journal for the Theory of Social Behavior* 24:47-65.

Lipshitz, Raanan, Gary Klein, Judith Orasanu, and Eduardo Salas. 2001. "Focus Article: Taking Stock of Naturalistic Decision Making." *Journal of Behavioral Decision Making* 14:331-352.

Liu, Z. Geoffrey. 2010. "Spontaneous Group Decision Making in Distributed Collaborative Learning: Toward a New Research Direction " *MERLOT Journal of Online Learning and Teaching* 6:279-296.

Lomborg, K., and M. Kirkevold. 2003. "Truth and validity in grounded theory—A reconsidered realist interpretation of the criteria: Fit, work, relevance and modifiability." *Nursing Philosophy* 4:189-200.

Luff, P., J. Hindmarsh, and C. Heath. 2000. *Workplaces Studies: Recovering Work Practice and Informing System*. Cambridge: Cambridge University Press.

Lundberg, Nina., and L. Tone. Sandahl. 2000. "What do Artefacts Mean to Us in Work." Pp. 363–372 in *22nd Information Systems Research Seminar in Scandinavia (IRIS 22): Enterprise Architectures for Virtual Organizations*. Keuruu, Finland.

Malone, T., and K. Crowston. 1994. "The Interdisciplinary Study of Coordination." *ACM Computing Surveys* 26:87-119.

Malone, W. Thomas., and Kevin. Crowston. 1990. "What is Coordination Theory and How Can It Help Design Cooperative Work Systems." Pp. 357-370 in *Conference on Computer Supported Cooperative Work*. Los Angeles, California: ACM Press, New York.

Mark, Gloria. 2002. "Conventions and Commitments in Distributed CSCW Groups." *Computer Supported Cooperative Work* 11:349–387.

Mays, Nicholas. , and Catherine. Pope. 1995. "Qualitative Research: Rigour and qualitative research." *British Medical Journal* 311:109-112.

McCallin, M. Antoinette. 2003. "Designing a grounded theory study: some practicalities." *Nursing in Critical Care* 8:203-208.

McClennan, Jim., M.Alina. Holgate, M.Mary. Omodei, and J.Alexander. Wearing. 2006. "Decision Making Effectiveness in Wildfire Incident Management Teams." *Journal of Contingencies and Crisis Management* 14:27-37.

Mcintyre, R.M., and Eduardo Salas. 1995. "Measuring and managing for team performance: emerging principles from complex environments." Pp. 149-

203 in *Team effectiveness and decision making in organizations*, edited by R. Guzzo and E. Salas. San Fracisco: Jossey-Bass.

McLeod, Lauretta. Poppy. 1992. "An Assessment of the Experimental Literature on Electronic Support of Group Work: Results of a Meta-Analysis " *Human Computer Interaction* 7:257-280.

Mi, Peiwei. , and Scacchi. Walt. 1991. "Modeling articulation work in software engineering processes." Pp. 188–201 in *First International Conference on the Software Process*, edited by Mark. Dowson. California: IEEE Computer Society Press.

Mohammed, Susan., and C. Brad. Dumville. 2001. "Team mental models in a team knowledge framework: expanding theory and measurement across disciplinary boundaries." *Journal of Organizational Behaviour. Special Issue: Shared Cognition* 22:89-106.

Mohammed, Susan., and Erika. Ringseis. 2001. "Cognitive Diversity and Consensus in Group Decision Making: The Role of Inputs, Processes, and Outcomes." *Organizational Behavior and Human Decision Processes* 85:310-335.

Mongford, H.R., A.J. Guttman, L.S. Morrow, and P. Kopardekar. 1995. "The Complexity Construct in Air Traffic Control: A Review and Synthesis of the Literature." Washington, DC: US Department of Aviation, Federal Aviation Administration (FAA).

Moon, B.M. . 2002. "Naturalistic Decision Making: Establishing a Naturalistic Perspective in Judgment and Decision Making Research." in *19th Qualitative Analysis Conference. Prepared in part through participation in the Advanced Decision Architectures Collaborative Technology Alliance cooperative agreement DAAD19-01-2-0009, US Army Research Laboratory, 2002, http://arlada.info/uploads/62/286/KLEIN_Report_-_101402.doc. .*

Mosier, L. Kathleen., and M. Ute. Fischer. 2010. "Judgment and Decision Making by Individuals and Teams: Issues, Models, and Applications." *Reviews of Human Factors and Ergonomics* 6:198-256.

Munkvold, Glenn, and Gunnar Ellingsen. 2007. "Common Information Spaces along the illness trajectories of chronic patients." Pp. 291-310 in *Proceedings of the Tenth European Conference on Computer Supported Cooperative Work*. Limerick, Ireland: Springer 2007.

Nakakawa, Agnes. , van Patrick. Bommel, and Erik. Proper. 2010. "Towards a Theory on Collaborative Decision Making in Enterprise Architecture. Global Perspectives on Design Science Research." *LNCS 6105*:538 – 541.

Nardi, B. A. 1996. *Context and Conciousness*. Cambridge, Massachusetts, London, England: The MIT Press.

Nova, N. 2005. "A Review of How Space Affords Socio-Cognitive Processes during Collaboration " *PsychNology Journal* 3:118 – 148.

Nova, Nicolas. 2003. "Socio-cognitive functions of space in collaborative settings : a literature review about Space, Cognition and Collaboration."

Nova, Nicolas., Mirweis. Sangin, and Pierre. Dillenbourg. 2008. "Reconsidering Clark’s Theory in CSCW." in *8th International Conference on the Design of Cooperative Systems (COOP'08)*.

Obradovich, Heintz. Jodi., and J. Philip. Smith. 2003. "Design Concepts for Distributed Work Systems: An Empirical Investigation Into Distributed Teams in Complex Domains." Pp. 354-358 in *Human Factors and Ergonomics Society 7th Annual Meeting*

Orasanu, Judith, and T Connolly. 1993. "The reinvention of decision making." Pp. 3-20 in *Decision Making in Action: Models and Methods*, edited by G.A Klein, Judith Orasanu, R Calderwood, and Zsambok: Norwood, CT: Ablex.

Orasanu, Judith. 1990. "Shared mental models and crew decision making." Princeton, NJ.: Princeton University, Cognitive Science Laboratory.

Orasanu, Judith., and E. Salas. 1993. "Team decision-making in complex environments." Pp. 158-171 in *Decision Making in Action: Models and Methods*, edited by G. Klein, J. Orasanu, R. Calderwood, and C. E. Zsambok. Ablex: Norwood.

Oslon, G.M., and J.S. Oslon. 2000. "Distance Matters." *Human Computer Interaction Special Issue: New agendas for human-computer interaction* 15:139-178.

Oslon, M. Gary., and S. Judith. Oslon. 2002. "Distance Matters." Pp. 407 in *Human Computer Interaction in the New Millennium*, edited by M. John. Carroll. New York: ACM Press.

Panzarasa, Pietro, R. Nicholas Jennings, and J. Timothy Norman. 2002. "Formalizing Collaborative Decision-Making and Practical Reasoning in Multi-agent Systems." *Journal of Logic and Computation* 12:55-117.

Patton, Michael. Quinn. 1999. "Enhancing the Quality and Credibility of Qualitative Analysis." *HSR: Health Services Research: Part II* 34:1189-1208.

Perry, L. Walter., and James. Moffat. 2004. "Information Sharing Among Military Headquarters. The Effects on Decisionmaking." CA, USA: RAND.

Pettigrew, F. Simone. 2000. "Ethnography and Grounded Theory: a Happy Marriage?" *Advances in Consumer Research* 27:256-260.

Plowman, Lydia., Yvonne. Rogers, and Magnus. Ramage. 1995. "What are Workplace Studies for?" Pp. 309-324 in *Fourth European Conference on Computer-Supported Cooperative Work*, edited by H. Marmolm, Y. Sundblad, and K. Schmidt. Stockholm, Sweden: Kluwer Academic Publishers.

Pohl, Jens. 2006. "Elements of Human Decision-Making." Pp. 1-20 in *18th International Conference on Systems Research, Informatics and Cybernetics (InterSymp-2006)*. Baden-Baden, Germany.

Pohl, Jens. 2008. "Cognitive Elements of Human Decision Making." *Studies in Computational Intelligence (SCI)* 97:41-76.

Pratt, Wanda, Madhu C. Reddy., David W. McDoanld., Peter Tarczy-Hornoch., and John H. Gemari. 2004. "Incorporating ideas from computer-supported cooperative work." *Journal of Biomedical Informatics* 37:128-137.

Reddy, M., P Dourish, and W Pratt. 2001. "Coordinating Heterogeneous Work: Information and Representation in Medical Care." Pp. 239-258 in *Proceedings of the Seventh European Conference on Computer Supported Cooperative Work*. Bonn, Germany: Kluwer Academic Publishers.

Robertson, T. 1997. "Cooperative work and lived cognition: A taxonomy of embodied actions." Pp. 205-220 in *Fifth European Conference on Computer-Supported Cooperative Work*. Lancaster, UK: Kluwer Academic Publishers.

Robrecht, L. C. 1995. "Grounded Theory: Evolving Methods." *Qualitative Health Research* 5.

Rosen, A. Michael., M. Stephen. Fiore, Eduardo. Salas, Michael. Letsky, and Norman. Warner. 2008. "Tightly Coupling Cognition: Understanding How Communication and Awareness Drive Coordination in Teams." *Special Issues: Awareness. The International C2 Journal* 2:1-30.

Rouse, W.B., J. A Cannon-Bowers, and E. Salas. 1992. "The role of mental models in team performance in complex systems." *IEEE Transactions on Systems, Man, and Cybernetics* 22:1296-1308.

Saaty, L. Thomas., and Kirti. Peniwati. 2013. "The Need for a Structured Approach." in *Group Decision Making: Drawing Out and Reconciling Differences*: RWS Publications.

Salas, Eduardo, C Prince, D.P. Baker, and L. Shreshta. 1995. "Situation awareness in team performance: implications for measurement and training." *Human Factors* 37:123-136.

Salas, Eduardo., J. Nancy. Cooke, and A. Michael. Rosen. 2008. "On Teams, Teamwork, and Team Performance: Discoveries and Developments." *Human Factors: The Journal of the Human Factors and Ergonomics Society* 50:540-547.

Salas, Eduardo., D. E. Sims, and C. S. Burke. 2005. "Is there a big five in team-work?" *Small Group Research* 36:555-599.

Salas, Eduardo., K.C. Stagl, C.S. Burke, and G. F. Goodwin. 2007. "Fostering team effectiveness in organizations: Toward an intergrative theoretical framework of team performance." *Modeling complex systems: Motivation, cognition and social processes, Nebraska Symposium of Motivation* 51:185-243.

Salmon, P. , et al. 2007. "“What is really going on? Review, Critique and Extension of Situation Awareness Theory”." *Psychol. and Cog. Ergonomics. HCII 2007* LNAI 4562:407–416.

Schatzman, L. 1991. "Dimensional analysis: Notes on alternative approaches to the grounding of theory in qualitative research." Pp. 303 - 314 in *Social organization and social process: Essays in honour of Anslem Strauss*, edited by D.R. Maines. New Yor: Aldine de Gruyter.

Schmidt, K. 1998a. "The Critical Role of Workplace Studies in CSCW." Pp. 1-12 in *Workplace Studies: Recovering Work Practice and Informing Design*, edited by Christian Heath, Jon Hindmarsh, and Paul Luff. New York: Cambridge University Press.

Schmidt, K, and L Bannon. 1992. "Taking CSCW Seriously: Supporting Articulation Work." *Computer Supported Cooperative Work (CSCW): An International Journal* 1:7-40.

Schmidt, K. 1994a. "Cooperative Work and its Articulation: Requirements for Computer Support." *Invited Paper for special issue on Le Travail Collectif, Travail Humain* 57:345-366.

Schmidt, K. 2002a. "The Problem with 'Awareness'. Introductory Remarks on 'Awareness in CSCW'." *Computer Supported Cooperative Work* 11:285-298.

Schmidt, K., and L. Bannon. 1991a. "CSCW, or What's in a Name?" in *Manuscript, Risø National Laboratory*.

Schmidt, K., and L. Bannon. 1991b. "CSCW: Four Characters in Search of a Context." in *Studies in Computer Supported Cooperative Work: Theory, Practice and Design. North-Holland Human Factors In Information Technology Series, Vol. 8.*, edited by M. John. Bowers and D. Steven. Benford. Amsterdam, The Netherlands, The Netherlands 3-16: North-Holland Publishing Co.

Schmidt, K., and I. Wagner. 2002. "Coordinative artifacts in architectural practice." Pp. 257-274 in *Fifth International Conference on the Design of Cooperative Systems (COOP 2002)*. Saint Raphaël, France: IOS Press, Amsterdam.

Schmidt, Kjeld. 1990. "Analysis of Cooperative Work. A Conceptual Framework ". DK-4000 Roskilde, Denmark: Riso National Laboratory.

Schmidt, Kjeld. 1991a. "Cognitive Work. A Conceptual Framework." *Distributed Decision Making. Cognitive Models for Cooperative Work*:75-109.

Schmidt, Kjeld. 1991b. "Riding a Tiger, or Computer Supported Cooperative Work." Pp. 1-16 in *ECSCW'91, Second European Conference on Computer-Supported Cooperative Work*, edited by L.Bannon., N.Robinson., and K.Schmidt. Amsterdam: Kluwer Academic Publishers.

Schmidt, Kjeld. 1993. "Modes and Mechanisms of Interaction in Cooperative Work. Outline of a Conceptual Framework." Pp. pp. 21-104 in *Computational Mechanisms of Interaction for CSCW*, edited by Carla. Simone and Kjeld. Schmidt. Lancaster, England: University of Lancaster.

Schmidt, Kjeld. 1994b. "Modes and Mechanisms of Interaction in Cooperative Work. Outline of a Conceptual Framework." Risø National Laboratory.

Schmidt, Kjeld. 1998b. "Some notes on mutual awareness." in *Copenhagen, Denmark: COTCOS, CTI, DTU*.

Schmidt, Kjeld. 2002b. "Remarks on the complexity of cooperative work." *Cooperation and Complexity in Sociotechnical Systems, [special issue of] Revue des sciences et technologies de l'information (RSTI), série RAI* 16:443-483.

Schmidt, Kjeld. 2009. "Divided by a common acronym: On the fragmentation of CSCW." Pp. 223-242 in *11th European Conference on Computer Supported Cooperative Work (ECSCW'09)*, edited by I. Wagner, H. Tellioglu, E. Balka, and L. Ciolfi. Vienna, Austria: Springer.

Schmidt, Kjeld. 2011. "The Concept of 'Work' in CSCW." *Computer Supported Cooperative Work (CSCW)* 20:431-401.

Schmidt, Kjeld., and Liam. Bannon. 2013. "Constructing CSCW: The First Quarter Century." *Computer Supported Cooperative Work (CSCW)* 22:345–372.

Schmidt, Kjeld., and Tom. Rodden. 1996. "Putting it all together: Requirements for a CSCW platform." Pp. 157-176 in *The Design of Computer-Supported Cooperative Work and Groupware Systems*, edited by Dan. Shapiro, Michael. Tauber, and Roland. Traunmüller. North-Holland Elsevier, Amsterdam.

Schmidt, Kjeld., and Carla . Simone. 2000. "Mind the gap! Towards a unified view of CSCW." in *In The Fourth International Conference on the Design of Cooperative Systems (COOP2000)* Sophia Antipolis, France.

Schmidt, Kjeld., and Carla. Simone. 1996. "Coordination Mechanisms: Towards a conceptual foundation of CSCW systems design." *Computer Supported*

Cooperative Work: The Journal of Collaborative Computing. Special Issue: 'The Design of Cooperative Systems' 5:155-200.

Schmidt, Kjeld., and Carla. Simone. 1998. "Cooperative work is seamless."

Schmidt, Kjeld., and Ina. Wagner. 2004. "Ordering systems. Coordinative practices and artifacts in architectural design and planning." *Computer Supported Cooperative Work. The Journal of Collaborative Computing.* 13:349-408.

Schmidt, Kjield. 2010. "'Keep Up the Good Work!': The Concept of 'Work' in CSCW." Pp. 265-285 in *Proceedings of COOP 2010, Computer Supported Cooperative Work*, edited by M. Lewkowicz, et al. : Springer-Verlag, London, UK.

Schraagen, Maarten, Jan., G. Laura. Militello, Tom. Ormerod, and Raanan. Lipshitz (Eds.). 2008. *Naturalistic Decision Making and Macrocognition*. Hampshire, England: Ashgate Publishing Limited.

Schwartz, D. 1990. "Training for situational awareness." Houston, TX: Flight Safety International.

Seguy, Anne., Daniel. Noyes, and Philippe. Clermont. 2010. "Characterisation of collaborative decision making processes." *International Journal of Computer Integrated Manufacturing* 23:1046–1058.

Shattuck, G. Lawrence., and Lewis Miller, Nita. 2006. "Extending Naturalistic Decision Making to Complex Organizations: A Dynamic Model of Situated Cognition." *Organization Studies* 27:989-1009.

Simone, C., and K. Schmidt. 1993. "The COMIC Project - Computational Mechanisms of Interaction for CSCW." Milan, Italy: Department of Information Science, University of Milan and Cognitive Systems Group, Risoe National Laboratory.

Simone, Carla., Monica. Diviniti, and Kjeld. Schmidt. 1995. "A notation for malleable and interoperable coordination mechanism for CSCW systems." in *COOCS' 95, Conference on Organizational Computing Systems*. Milpitas, California.

Smith-Jentsch, A. Kimberly., P. David. Baker, Eduard. Salas, and A. Janis. Cannon-Bowers. 2001. "Uncovering Differences in Team Competency Requirements: The Case of Air Traffic Control Teams." in *Improving TeamWork in Organizations. Applications of Resource Management Training*, edited by Eduardo. Salas, A. Clint. Bowers, and Eleana. Eden. Mahwah, New Jersey: Lawrence Erlbaum Associates.

Smith, K., and P.A. Hancock. 1995. "Situation awareness in adaptive, externally directed conciousness." *Human Factors* 37:137-148.

Soubie, Jean-Luc., and Pascale. Zarate'. 2005. "Distributed Decision Making: A Proposal of Support Through Cooperative Systems." *Group Decision and Negotiation* 14:147–158.

Stankovic, J.A. et al. 1996. "Strategic Directions in Real-Time and Embedded Systems." *ACM Computing Surveys* 28.

Stasser, Garold., and William. Titus. 1985. "Pooling of Unshared Information in Group Decision Making: Biased Information Sampling During Discussion." *Journal of Personality and Social Psychology* 48:1467-147.

Stout, R, J., J. A Cannon-Bowers, and E. Salas. 1990. "The role of shared mental models in developing team situation awareness: Implications for training." *Training Research Journal* 2:86-116.

Stout, R.J., J.A. Cannon-Bowers, E. Salas, and D. Milanovich. 1999. "Planning, shared mental models, and coordinated performance: an empirical link is established." *Human Factors* 41:61-71.

Straus, G. Susan., and E. Joseph. McGrath. 1994. "Does the Medium Matter? The Interaction of Task Type and Technology on Group Performance and Member Reactions." *Journal of Applied Psychology* 79:87-97.

Strauss, A. 1987. *Qualitative Analysis for Social Scientists.* New York: Cambridge University Press.

Strauss, A. 1988. "The Articulation of Project Work: An Organizational Process." *The Sociological Quarterly* 29:163 - 178.

Strauss, A, Anselm. 1985. "Work and Division of Labor." *The Sociological Quarterly* 26:1-19.

Strauss, A, and J Corbin. 1998. *Basics of Qualitative Research: Techniques and Procedures for Developing Grounded Theory*. Thousand Oaks, California: Sage Publications.

Strauss, A., and J. Corbin (Eds.). 1990. *Basics of Qualitative Research: grounded theory procedures and techniques*. London: Sage.

Strauss, A., S. Fagerhaugh, B. Suczek, and C. Wiener. 1985. *Social Organizations of Medical Work*. Chicago: The University of Chicago Press.

Suchman, A. Lucy. 1983. "Office Procedures as Practical Action: Models of work and system design." *ACM Transactions on Office Information Systems* 1:320-328.

Suchman, A. Lucy. 1987. *Plans and Situated Actions. The problem of human machine communication*: Cambridge University Press.

Suchman, L.A., and Eleanor. Wynn. 1984. "Procedures and Problems in Office." *Office: Technology and People* 2:133-154.

Sullivan, D. G., A. Glass, B. J. Grosz, and S. Kraus. 1999. "Intention Reconciliation in the Context of Team Work: An Inital Empirical Investigation." *Cooperative Information Agents III* Lecture Notes in AI, Vol 1652:149-162.

Sundstrom, E. , K.P. DeMeuse, and D. Furtell. 1990. "Work teams: Applications and effectiveness." *American Psychologist* 45:120-133.

Thomas, C. David. 1999. "Cultural Diversity and Work Group Effectiveness : An Experimental Study." *Journal of Cross-Cultural Psychology* 30:242-263.

Tindale, R. S., T. Kameda, and V. B. Hinsz. 2003. "Group decision making." Pp. 381–403 in *Sage handbook of social psychology*, edited by M. A. Hogg and J. Cooper. London: Sage.

Vanharanta, Markus. 2009. "Social Structure in Naturalistic Decision Making." Pp. 401-405 in *Social Structure in Naturalistic Decision Making (NDM9)*. London, UK: British Computer Society.

Wellens, Rodney, A. 1993. "Group Situation Awareness and Distributed Decision Making: From Military to Civil Aapplications." Pp. 267-292 in *Individual and Group Decision Making. Current Issues*, edited by John Castellan, N. Jr. Hillsdale, New Jersey: Lawrence Erlbaum Associates.

Whetten, A. David. 1989. "What Contitutes a Theoretical Contribution?" *Academy of Management Review* 14:490-495.

Wilson, T.D. 2002. "Philosophical foundations and research relevance: issues for information research." in *Keynote address delivered to CoLIS4 to the Fourth International Conference on Conceptions of Library and Information Science: Emerging Frameworks and Method*. University of Washington, Seattle, USA.

Winman, Thomas., and Hans. Rystedt. 2012. "Electronic Patient Records in Interprofessional Decision Making: Standardized Categories and Local Use." *Human Technology. An Interdisciplinary Journal on Humans in ICT Environments* 8:46–64.

Wittenbaum, M. Gwen., B. Andrea. Hollingshead, and C. Isabel Botero. 2007. "From cooperative to motivated information sharing in groups: moving beyond the hidden profile paradigm." *Communication Monographs* 71:286-310.

Wynn, Eleanor. 1991. "Taking Practice Seriously." Pp. 45-64 in *Design at Work: Cooeprative Design of Computer Systems*, edited by J. Greenbaum and M. Kyng. Hillsdale, New Jersey: Lawrence Erlbaum.

Yang, Hongmei. , J. Chimay. Anumba, M. John. Kamara, and Patricia. Carrillo. 2001. "A fuzzy-based analytic approach to collaborative decision making for construction teams." *Logistics Information Management* 14:344 - 355.

Yen, John., et al. 2003. "Implementing Shared Mental Models for Collaborative Teamwork." Pp. 115-126 in *Workshop on Collaboration Agents:Autonomous Agents for Collaborative Environments in the IEEE/WIC Intelligent Agent Technology Conference*. Halifax, Canada.

Yen, John., Xiaocong. Fan, Shuang. Sun, Timothy. Hanratty, and John. Dumer. 2006. "Agents with shared mental models for enhancing team decision makings." *Decision Support Systems* 41:634-653.

Young, A. Kirsty. 2005. "Direct from the source: the value of ‘think-aloud’ data in understanding learning." *Journal of Educational Enquiry* 6:19-33.

Zachary, W., J. Ryder, and J. Hicinbothom. 1998. "Cognitive Task Analysis and Modeling of Decision Making in Complex Environments." Pp. 315-344 in *Making Decisions Under Stress: Implications for Training and Simulation*, edited by J. Cannon-Bowers. and E. Salas. Washington, DC: American Psychological Asssociation.

APPENDICES

APPENDIX 1

WORK UNITS, WORK ACTIVITIES AND TECHNOLOGICAL ARTEFACTS INVOLVED IN AIRPORT ATC OPERATIONS

Work activities involved in ATC operations at the Airport is distributed among various work units, each of which is responsible for particular aspects of the work process. This creates clear division and organization of work activities among personnel operating in different work units, and allows for clear distinction of actions and decisions that can be taken by these personnel. The work activities are supported by various technologies and artefacts which act as information representation, communication and coordination devices which assist both individual and collective work of personnel. Also, some of the artefacts are interconnected with information from one artefact being passed onto another.

Control Tower

The Control Tower is located near the runway and is higher than all the other buildings in the airport (Figure 1). It is surrounded with glass windows to allow visual surveillance of the surrounding area, both on land and airspace.

Figure 1 Luton Airport Control Tower

Personnel working in the Control Tower are air traffic controllers who are responsible for controlling aircraft movement from ground level at the Airport up to 2500 feet in air and 2.0-2.5 nautical miles surrounding the Airport. Their primary function is to maintain safety of aircraft and efficiency of traffic movement in and around the airport by giving instructions and providing information through radio to the Pilots. Besides issuing instructions they are also responsible for recording information related to traffic management, problems encountered during work activities, and changes in environmental conditions. Further, they issue clearance and guide other vehicles that need to use the taxiway, runway, and some of the Apron areas.

There are three air traffic controller positions in the Control Tower: Tower Controller (TC), Ground Controller (GC), and Ground Planner (GP) (Figure 2, Figure 3). Each controller is responsible for particular aspects of aircraft movement. Besides the three controllers, there is another position called as the Assistant.

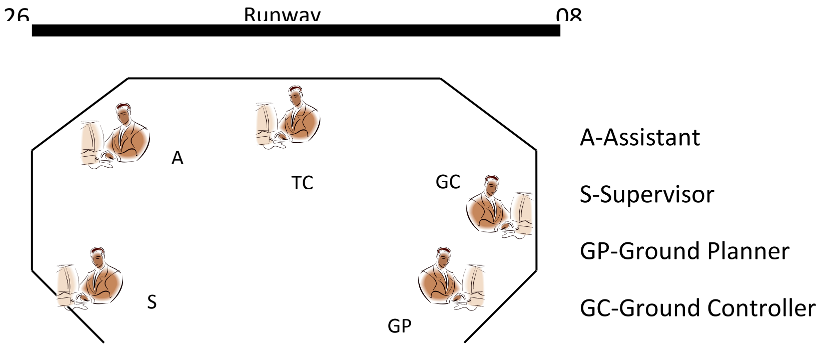


Figure 2 Arrangement of Personnel Working in the Control Tower

The primary function of the Assistant is to ensure that safety of the aircraft is maintained by providing information about arriving and departing aircraft to the controllers in the Control Tower by printing them on the FPS. The Assistant has to coordinate various activities with other agencies in the airport such as the accident services, maintenance services, weather office, operations centre, approach control, aircraft pilots, and accounts department. The Assistant plays a supporting role and does not hold the responsibility of controlling aircraft movement.

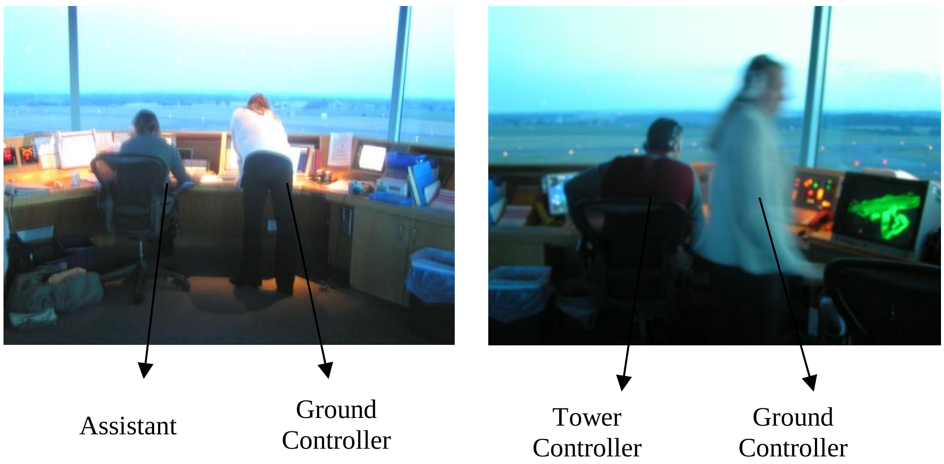


Figure 3 Air Traffic Controllers in the Control Tower

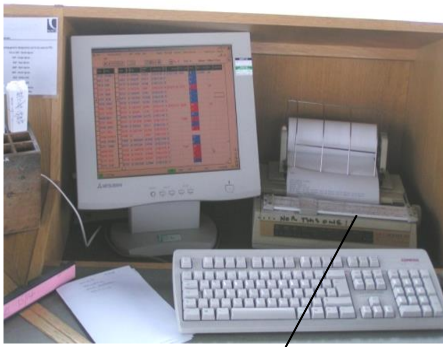
The Tower Controller (TC) controls the movement of departing and arriving aircraft on the runway and airspace surrounding the airport. Their main role is to issue clearance and instructions to aircraft pilots during take-off and landing on the runway, and to ground vehicles requiring movement on the runway. TC in required to liaise with the GC in the Control Tower and controllers at the LTCC to control movement of aircraft during landing and departing on the runway.

The role of the Ground Controller (GC) is to control the aircraft and other vehicle movement on the Taxiways and Apron area. They issue clearance and instructions to arriving and departing aircraft during their movement between the stand in the Apron area and the Runway as well as to ground vehicles requiring movement on the Taxiways. The Ground Planner (GP) is positioned next to the GC and is the first point of contact for pilots of departing aircraft. GP position is active in the Control Tower only during peak hours in the morning, between 6.30 a.m. and 8.30 a.m., to assist the GC to plan and execute the departure sequence.

The Assistant, TC, and GC are equipped with various information representation and dissemination artefacts that help them to conduct their work. Some of the artefacts are for individual purpose, while some are jointly used by the people working in the Control Room such as the Flight Progress Strip (FPS), Ground Radar, and Weather Report.

One of the main systems required for performing the Assistant's role is the Copperchase ATIS (Air Traffic Information System) computer system (Figure 4). This system provides applications to perform various functions. The applications provided in the computer system allow the Assistant to perform various functions for recording aircraft arrival and departure information and weather information, printing FPS and weather report, communicating with other airports, airport authority and the billing department.

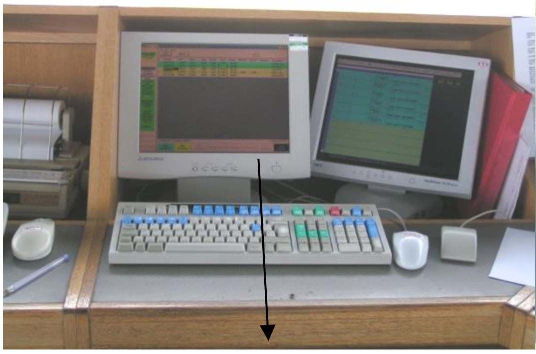
FPS Printer



Weather Report Printer

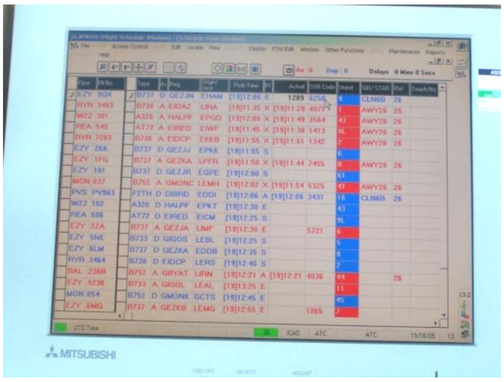
Weather Report

Printed Flight Progress Strips



Copperchase Computer System (ATIS)

Ground Radar



AMOS Flight Schedule Window

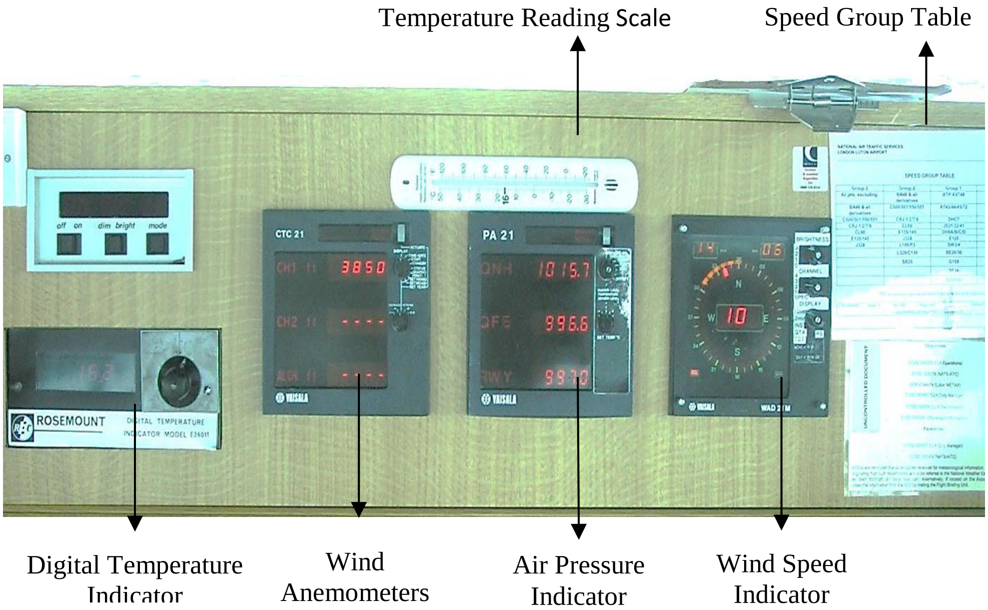
Touch Screen Telephone

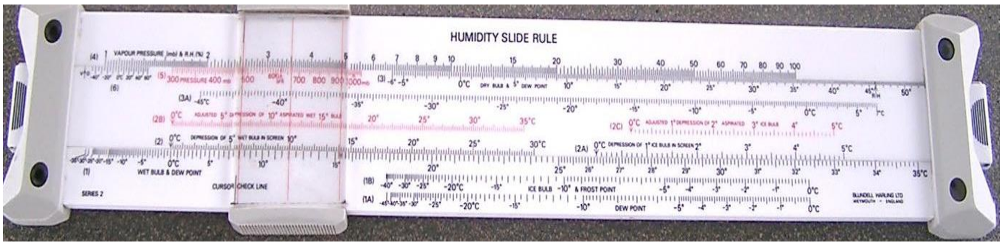
Aircraft Flight Display Information System (AFDIS)

Omni Crash Telephone

Figure 4 Artefacts Assisting Control Tower Operations

One of the roles of the Assistant is to make routine weather observations and enter the information (time the observation was made, wind speed, wind direction, visibility, cloud density, temperature around the airport, and air pressure) into the Weather Editor of the Copperchase ATIS computer system (Figure 5). This is a software application through which weather information is sent to the Tower Controller in the Control Tower, Weather Office, LTCC, Operations Centre, and other aircraft through ATIS frequency. In order to make these weather measurements the Assistant is provided with various other tools such as the *Digital Temperature Indicator*, *Cloud Base Recorder*, *Air Pressure Indicator*, and *Wind Speed Indicator*. Information obtained from these artefacts has to be entered into the *Copperchase Weather Editor* (Figure 5). The Met office also sends the weather forecast report every six hours directly to the printer at the Assistant's desk. The Assistant then has to place it near the TC from where both controllers can access it.





Humidity Slide Rule


Computerized Wind Speed Indicator

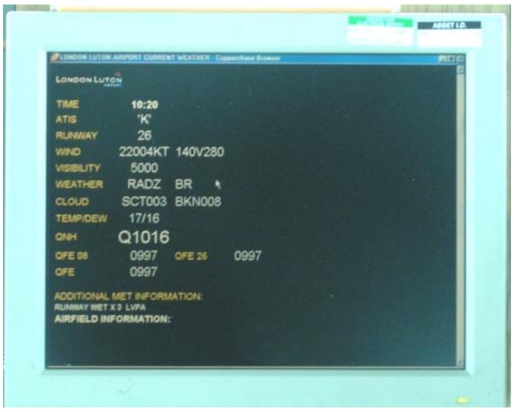

Copperchase Weather Monitor

Figure 5 Weather Observation Systems

Another important function facilitated by *Copperchase* ATIS system is that the flight information required by the controllers in the Control Tower is sent to this system from the central flight information database. The Assistant prints the information on the FPS, places it in a strip holder, and hands it over to the TC and GC in the Control Tower. The stand information for arriving and departing aircraft is sent from the Operations Centre to this system (*Flight Schedule Window*) from where the Assistant view it and then writes this information by hand on the FPS before giving it to the controllers. The Assistant also uses the *Flight Schedule Window* to send aircraft arrival and departure information to the Accounts Department. Once the controllers have finished utilizing the FPS they are thrown into a blue box place on the floor. The Assistant periodically takes these strips and enters the information represented (e.g. parking stand number, SID) in them into the *Flight Schedule Window* of *Copperchase* ATIS system which is then sent to the Accounts Department. The *Message Editor* of *Copperchase* ATIS system is used to send messages to various personnel at the Airport and to other airports.

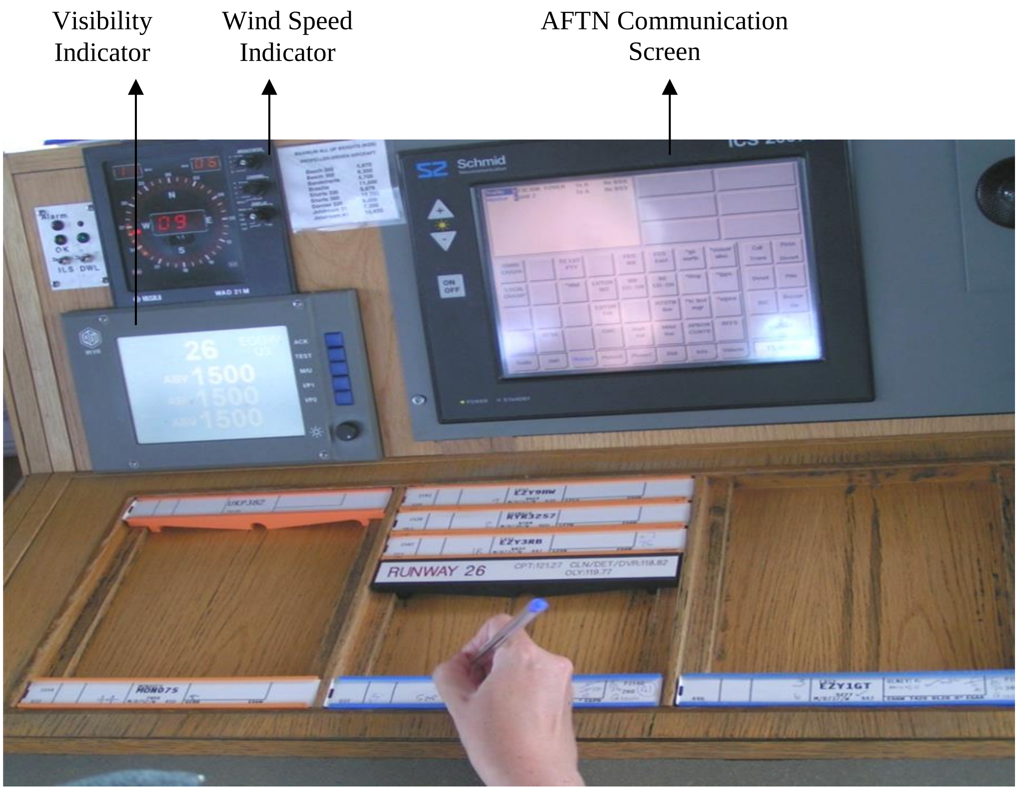
The Aircraft Flight Display System (AFDS) is used to edit flight strips, create new strips, reprint strip, change the list of strips displayed, change the colour code of the displayed strips, set the status of the flight strips to ‘delay’, ‘active’, ‘cleared too take-off’, and ‘air-borne’. This system is used to set the status of departing aircraft in coordination with the actions taken by the GC. The Assistant is also provided with a speed dial panel for telephone numbers to reduce the time taken to dial the numbers of people who have to be contacted frequently.

The main artefacts used by the Tower Controller (TC) (Figure 6) in the Control Tower are the Flight Progress Strip (FPS), Blocking Strips, Aerodrome Radar, Wind Speed Indicator, Visibility Indicator, and AFTN Communication Network. The FPS represents movement of aircraft and ground vehicles on the Runway and Taxiways. The Aerodrome Radar is used to represent and view movement of aircraft in the airspace surrounding the airport. The TC uses the AFTN communication screen to talk to personnel from other work communities particularly the Radar Controller at the Approach Control to arrange for gaps between incoming aircraft in order to be able to depart aircraft out of the Airport. The Visibility Indicator is used give Runway visual range information to incoming aircraft Pilots during poor visibility and to make decisions about lighting on the Runway and Taxiways. The Wind Speed Indicator is used to give surface wind speed information to the Pilots of landing aircraft.

The Ground Controller (GC) is equipped with various artefacts (Figure 7) to control the movement of aircraft from the standing gate to the Taxiway and movement of other ground vehicles in the Apron area. The Departure Slot Monitor provides information about aircraft departing from the Airport so that the GC can schedule departing aircraft traffic. The information arrives from the host computer at London Area Terminal Control Centre (LATCC). Aeronautical Fixed Telecommunication Network (AFTN) is the linking communication system through which information is exchanged between the various agencies involved in ATC. The Lighting Panel is used to control lighting on the taxiways and runway. This is used by the GC during poor visibility and to give aircraft and ground vehicle routes by highlighting Taxiway routes. The Lighting Display is connected to the Lighting Panel and reflects the lights selected on the runway and taxiways. The arrangement of FPS on the Strip Holding Bay reflects the movement of aircraft between the taxiways and the stand. Besides the FPS strips used for departing and arriving aircraft, the GC also uses various blocking strips to represent other actions such as the ground vehicle and helicopter movement.

Aerodrome Radar

Complete View of Artefacts used by TC in Control Tower



Strip Holding Bay, AFTN, Wind Speed Indicator, Visibility Indicator in TC's Position

Movement of FPS on Strip Holding Bay Representing Movement of Incoming and Outgoing Aircraft

Runway and Taxiway during Poor Visibility-View from the Control Tower

Figure 6 Artefacts Used by Tower Controller in the Control Tower

Departure Slot Monitor

Ground Radar

Wind Speed Indicator

Visibility Indicator

AFTN

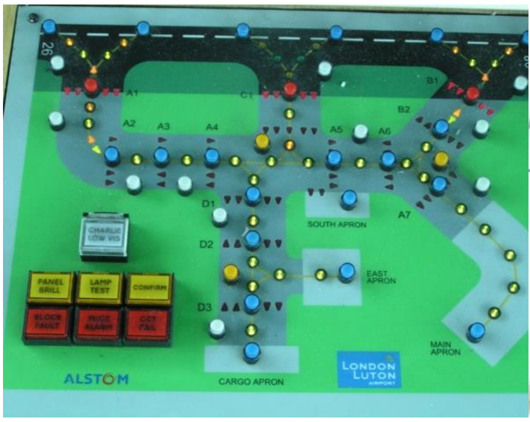
Departure Flight Strips Bay (Yet to Contact)

Departure Flight Strips Bay (After First Contact)

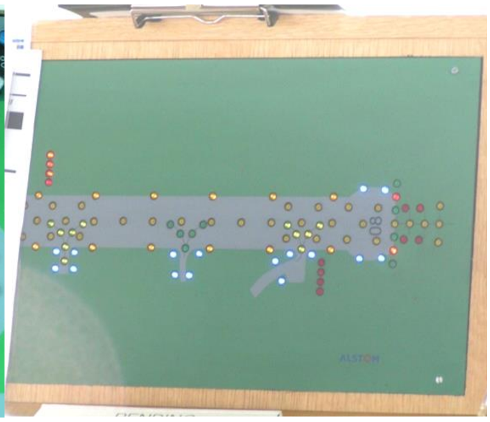
Runway 26 Bay (Moving to Runway)

Lighting Knobs

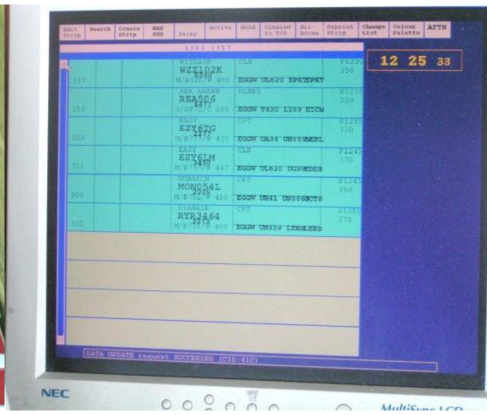
FPS Bays and Other Artefacts in Ground Controller Position in Control Tower



Lighting Panel


Lighting Display

Blocking Strips



Computerised Flight Strip Display

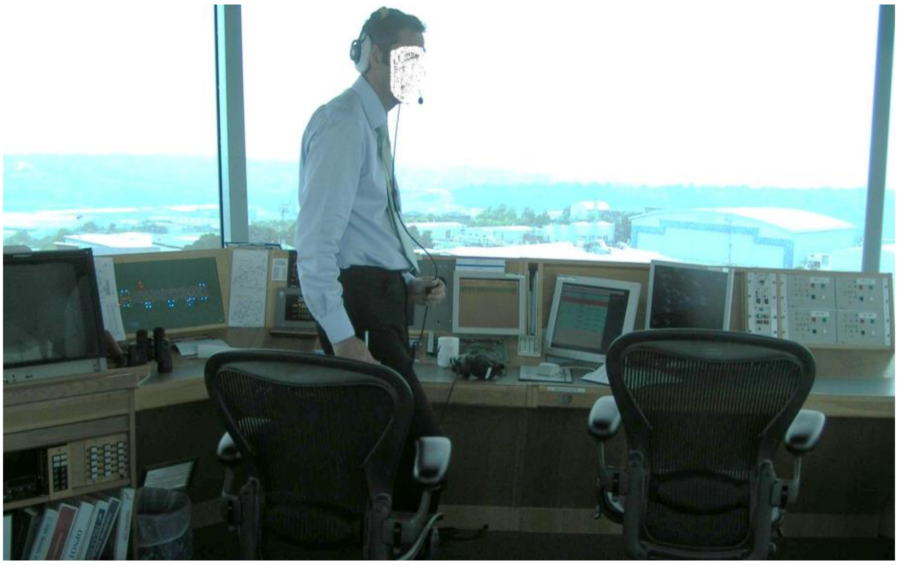

Complete View of Artefacts Used by Ground Controller in the Control Tower

Figure 7 Artefacts Used by Ground Controller in the Control Tower

During the third phase of studies, the FPS were changed to Electronic Flight Progress Strips (EFPS) at Luton and Heathrow airports. Hence, this phase of the study was intended to be conducted only at the Operations Centre at the airport but because of the move to EFPS in both Control Tower and Operations Centre and the interrelation between systems used at both centres, studies were conducted at the Control Tower to study the use of EFPS by the controllers to carry out their operations.

The Electronic Flight Progress Strip (EFPS) is a computer system designed to replace FPS holding bay on the controller’s table. The screen is designed to replicate the layout of the holding bay and is divided into three columns vertically with each column divided into two horizontally. The information in the EFPS arrives directly from the central database at the LTCC. The EFPS gives air traffic information in the form of flight strips displayed on the screen for 40 min traffic and 4 hour traffic. Besides updating the aircraft departing and arriving aircraft slot time instantly, EFPS also contains weather forecast information which is updated every half hour and status of air traffic.

All new strips being generated get ordered bottom up on the display. The controllers can physically change the order. The strips are colour coded for departing and arriving aircraft just like the paper strips and includes colour codes for setting reminders and blocking strips. However, the choice of colours is limited and there is a high chance of more than one strip having the same colour.

Before the move to EFPS the TC could turn and look at the arrangement in the strip holding bay on the GC’s table. However, with the new layout the GC is positioned higher than the TC and GC’s EFPS system is not within the visual range of the TC. The GC on the other hand has an advantage to look down at the strip arrangement on TC’s EFPS system. The GC and GP each have their own EFPS system. The working of personnel in the Control Tower with the EFPS system was studies only with respect to how their interaction with other personnel is mediated by EFPS system.

Operations Centre

In the airport, the Operations Centre (Figure 8) is located next to the Control Tower and Apron area. It was set up to integrate various operational facilities such as apron management and control, security, public information services, and passenger transportation into a single facility to improve operational services. These facilities until then were distributed around the Airport and had been operating separately, leading to various problems in communication between them. The physical distance slowed information flow as they relied only on telephone for communication between them. Bringing personnel from different work units together into one facility made managing operational functions simple and easier.

The Operations Centre is an important control centre, which is responsible for various functions involved in day-to-day operations in the Airport. They consider themselves to be the "information hub"[23] of the Airport as any information related to ATC arriving and transmitted from the airport has to go through them. They monitor all airport activities on the terminal side, airside, and landside as well as coordinate the activities of the various agencies in the Airport.

There are three positions in the Operations Centre: Assistant, Arrivals Controller, and Departure Controller. All operations controllers have the same expertise. During the day there are three controllers working in the Operations Centre and in the night it is staffed by two controllers.

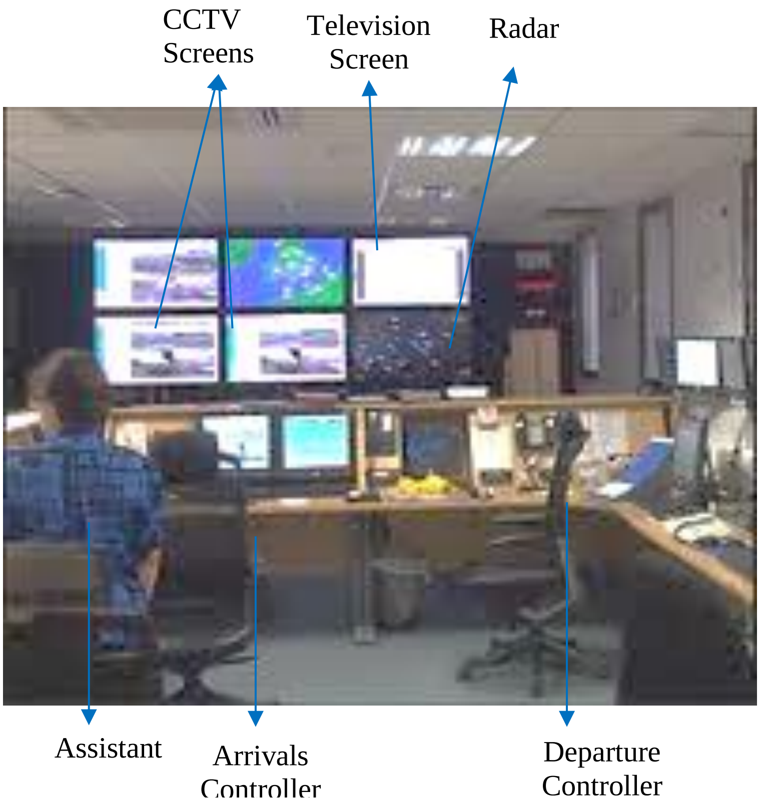


Figure 8 Operations Centre[24]

The Assistant is positioned at the switch board position. Their primary functions is to receive information and pass it to concerned people within the airport and outside, answer queries about airport operations both from the general public and people operating in the airport, and maintain records of day-to-day events occurring in the airport. They perform various other functions in the Operations Centre such as updating weather information, attending to customer complaints, assisting controllers in the arrivals and departures position, managing access control, coordinating with security and emergency services, manage access, fire, and security control systems, updating information to be displayed in the airport website, make boarding calls, security messages, and ad hoc announcements for passengers in the terminal.

24 http://guohengiv.com/business_airports_luton.htm

Unlike the role of the Assistant in the Control Tower, the Assistant in the Operations Centre is also a controller. So, they take on the controller role when they shift to the positions of Arrivals Controller or Departure Controller.

The Arrivals Controller (AC) working in the arrivals position is mainly concerned with allocating the parking stand for inbound aircraft. Another responsibility of AC is to record information about aircraft flight status, such as aircraft estimated and actual landing time, flight cancellation, technical problems, change in aircraft, and delay. This information is required by the airport management, accounts department for billing, and for displaying information in the Airport terminal.

The Departure Controller (DC) is positioned in the departures section and manages the preparation required for departing aircraft such as checking the departure slot, verifying aircraft is departing on time, and updating information about stand occupancy. DC is responsible for recording the estimated and actual aircraft departure time in a computer system which will be used for billing and displaying flight information in the displays located in the Airport terminal. Another responsibility of DC is to coordinate with ground staff and handling agents for movement of aircraft in the Apron area.

The Operations Centre is facilitated with a number of technological artefacts. When the researcher obtained permission to conduct the field studies in the Operations Centre she was not granted permission to take photographs. Hence, in this section, description of the tools utilised by personnel functioning in the Operations Centre cannot be illustrated through pictures obtained from the field.

There are some tools that are used in common between personnel in the Operations Centre, such as, the Radio, CCTV displays, Stand Plan, Maps of the Airport, Visibility Indicator, and Aerodrome Radar. Stand

Plan is printed from the Chrome stand planning software. There is a glass film on top of the paper on which the controllers can write information about aircraft departing from the parking stand and arriving to the parking stand. Radio on which the controllers in the Operations Centre listen to "ground frequency" (radio frequency on which ground staff communicate) to know when aircraft pushback and can also listen to conversation between controllers in the Control Tower and ground vehicle drivers.

The fire control system and security system are the big display screens behind the desk which are being constantly monitored by the Assistant. Aerodrome Radar is placed between the AC and DC so that they both can monitor the movement of air traffic in the airspace around the Airport. Since, the Operations Centre is in an enclosed building, in order to help the controllers monitor occurrences at different places in the Airport CCTV displays present information from various cameras installed at various locations in the Airport. The controllers also use a weather monitoring system which presents readings taken from the runway so that they can make decisions to deal with weather changes such as anti-icing and de-icing in winter months.

Because the Assistant performs diverse functions, he/she is supported with various artefacts. The main tasks to be performed by the Assistant is answering queries through telephone, recording day-to-day actions[25] taking place in the Airport, and passing required information to personnel. The fire control system and security system screens are the big display screens behind the desk which are being constantly monitored by the Assistant. In case any problem arises in relation to these two, the Assistant uses a system called "Mission Mode" which can be used to activate various messages and sent to those personnel

25 Example: Passenger figures, fire arms tested, primitive road, low visibility, strong wind warning, spill, track open, broken down vehicle, etc.

who need to know about it through the internet. It is used a day-to-day activity log and a notification system. Personnel will receive a text message, or a voice mail call, phone call or email depending on their preferences. The Assistant monitors the CCTV screens and handles phone calls from personnel from other work communities such as the Airlines, Handling Agents, Airport Operations Management, and IT support. The Assistant also carries out stand planning and any changes that have to be made to previously made plans by using the Chrome Stand Planning Software package. The AVIVOx (Artifical Voice Works) is used to make announcements in the terminal area.

The Arrivals Controller (AC) has to manually enter information about incoming flights into the AMOSS system. The required flight information is sent to the Operations Centre by the Airline Handling Agents through e-mail or fax. The AC also refers to the EFPS to enter aircraft information to be sent to the accounts department for billing airlines for the use of Airport facilities. The AC moves between the EFPS and AMOS system during task performance by using information presented in EFPS system to manually updating information (e.g. landing time and estimated arrival times) in the AMOSS system, which is then reflected in the information displays in the Airport terminal area. The AC also listens to the ground frequency on Radio and updates information in the EFPS which is then reflected in the EFPS system in the Control Tower. The AC also visually monitors the Aerodrome Radar.

The GC has to enter the stand number for arriving aircraft into the AMOS flight information system by referring to the stand plan and changes made on the glass surface on top of the printed paper stand plan. The GC enters the time of departing aircraft pushback from the stand into the AMOSS system. This is reflected in the AMOSS flight information system in the Control Tower. The GC also enters aircraft departure time in the system which gets reflected in the information displays in the Airport terminal area.

The Information Technology systems used in the Operations Centre are linked. For example, EFPS and AMOSS, Chrome – AMOSS, AMOSS-Flight Information Displays. This is because information is being constantly updated as events take place in the work **environment.**

Other Work Communities

Besides the above mentioned work communities personnel from other work communities involved in ATC operations at the Airport were also studied. They are the London Terminal Control Centre (LTCC), Pilots, Airlines, Handling Agents, Maintenance Engineers, and Ground Service Agents. However, the activities of people belonging to these work communities were studied only in relation to the operations being undertaken by the Control Tower and Operations Centre.

- The London Terminal Control Centre (LTCC) is one of the two control centres from where NATS provides air traffic control services to flights flying in UK Flight Information Regions (FIR). The sectors controlled by LTCC are divided into three types: Terminal Sectors, Approach Sectors, and En-Route Sectors all of which fall under the LTMA. Each of the divisions consists of a number of sectors as shown in (Figure 9).

Air traffic controllers working in the sectors of these divisions are responsible for controlling and guiding air traffic arriving and departing from six London airports including Luton Airport. The Terminal Sectors consist of three controllers: Radar Controller (RC), Coordinator, and Assistant. RC is responsible for air traffic movement in the respective sector and arranges the sequences of air traffic flowing into and out of London airports in the airspace of the sector. The role of the Coordinator is to assist the RC by arranging the Flight Progress Strips

(FPS) and liaise with other sectors and units, while the Assistant provides assistance with flight information, operating computer systems, and prepares the FPS for the controllers.

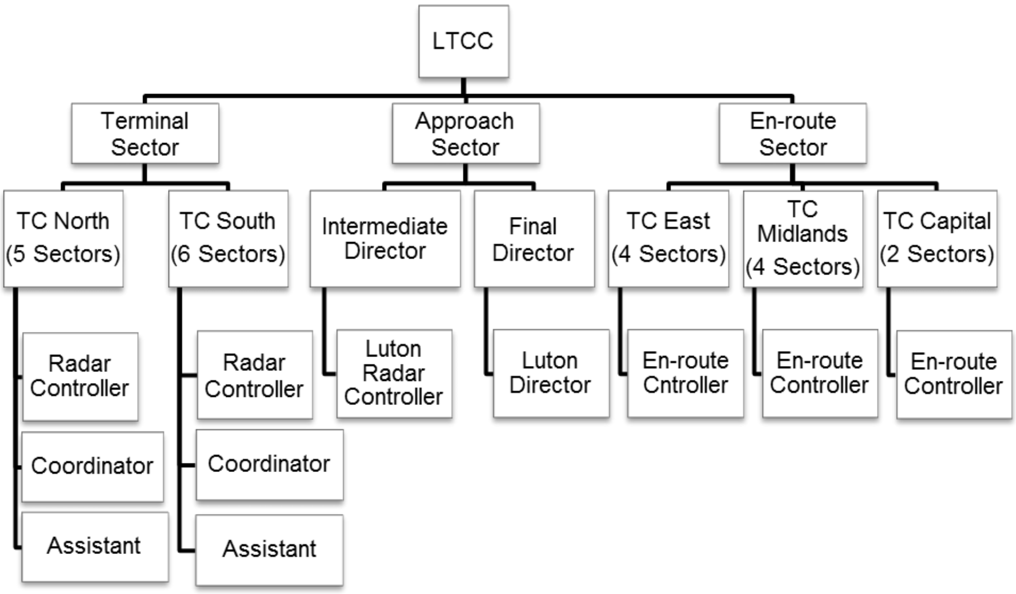


Figure 9 LTCC Sectors and Controllers

The air traffic controllers (Radar Controller and Director) of the Approach Control sequence and guide air traffic approaching the London airports to order them for landing at the airport. Radar Controller is responsible for the initial approach sequence while the Director is responsible for the final approach sequence. They also manage some of the departing aircraft from the airport that might conflict with the approaching air traffic.

A number of en-route sectors also are under the responsibility of LTCC. These sectors are the lower level of the airspace and above the LTMA and are divided into three: TC East, TC Midlands, and TC Capital. The controllers responsible for TC Midlands besides guiding air traffic in the airways also have to interact with controllers in the Control Tower of the Airport and Pilots of aircraft departing from the airport.

- The Pilot arriving and departing aircraft has to perform various checks before landing and take-off. The Pilots flying the aircraft are required to communicate with the air traffic controllers during the various phases of flight from the source to the destination airport.

- Every aircraft using Luton Airport services has a Handling Agent to which the airlines subcontracts ground handling of its aircraft at the airport. The Handling Agents take care of the service requirements for the aircraft at the airport. In Luton airport, the Handling Agents have to collaborate with personnel in the Operations Centre to perform their services such as maintenance of aircraft, filing the flight plan, and delay in aircraft departure.

- There are two types of Engineers at the Airport: Air Traffic Control Engineer and Aircraft Maintenance Engineer. The former are employed by NATS and are responsible for correct functioning of equipment installed by NATS at the airport. They are located near the Control Tower in the Airport and provide maintenance services such as installation of new systems, maintenance and repair of equipment and computer systems in the airport including the Control Tower and Operations Centre. On the other hand the Aircraft Maintenance Engineers employed by the airlines are responsible for maintenance of aircraft in the Airport.

- The Ground Service Agents are personnel operating on the ground area. They include people such as Ramp Agents who perform various functions on the airport ramp like pushback for departing aircraft from the terminal gate, guiding arrival aircraft with hand signals and flash lights to position it in the gate, chock the wheels of the plane after it halts, and guiding jetbridge to the aircraft door, towing aircraft on the airport to and from the gate and parking area, and baggage handling. Besides these, there are various emergency services operating in the airport such as the fire station, security, and medical services.

APPENDIX 2

EXAMPLE PLANNED PROBES FOR CONDUCTING INTERVIEWS

WORK ORIENTED GENERAL QUESTIONS

- Role and responsibility of people.
- Tasks performed.
- Work process/sequence of activities.
- Critical tasks/work activities.
- Means and mechanisms of interaction with other people within the Control Tower and outside.
- Requirements arising during task performance.
- Decisions made during task performance.

DIVERSITY OF WORK COMMUNITIES

- See how diverse are the work communities under observation – goals, work practices, technological arrangements, what information is used, why, and how.
- How much of an understanding do people have of each other's work.

COMMON INFORMATION

- Look at what information is common to different work communities.
- How different actors in each community view it.
- How they adapt it to their work, how it is put to use, made meaningful to their use.
- Are there different views or representations for the same information for different communities.
- If there are same representations how it is perceived in different work communities.
- Artefacts used to place information in common, their characteristics, purpose, function, purpose served.

- What changes are made to the information? How it affects people's work.

COMMON INTERPRETATION

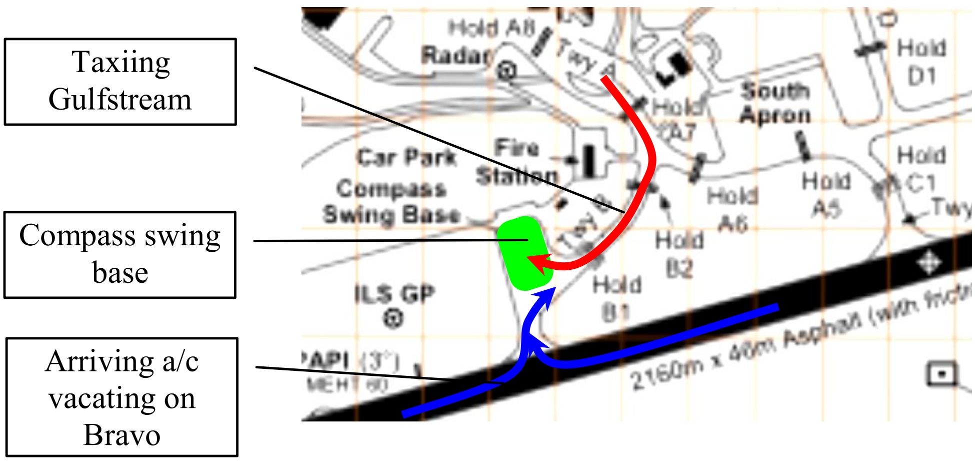
- How familiar are they with each other's work.
- Work practices to establish common interpretation.
- Limitations / obstacles in achieving common interpretation. Issues that arise because of the heterogeneity .
- How is it achieved under different situations.
- Check if there are misinterpretation instances for information shared through common artefacts.

APPENDIX 3

EXAMPLE FIELD NOTE OF OBSERVATION DATA

Complex scenario for Tower Controller

Two a/c inbound for runway 26 (that will land, turn, and backtrack if required vacate on Bravo)
Gulfstream being towed by Signature Tug from stand 16 or Signature hangar to Compass Bay.
The tug was cleared to hold at B1 and "be ready to move as soon as requested"
The first arrival (and EZY) was cleared to land and hold on runway. Mel hoped that they would stop short of the Bravo exit, though, didn't communicate this to a/c.
The EZY did stop short of B; Tug cleared to Compass Swing Base; a/c cleared to vacate and second arrival clear to land.



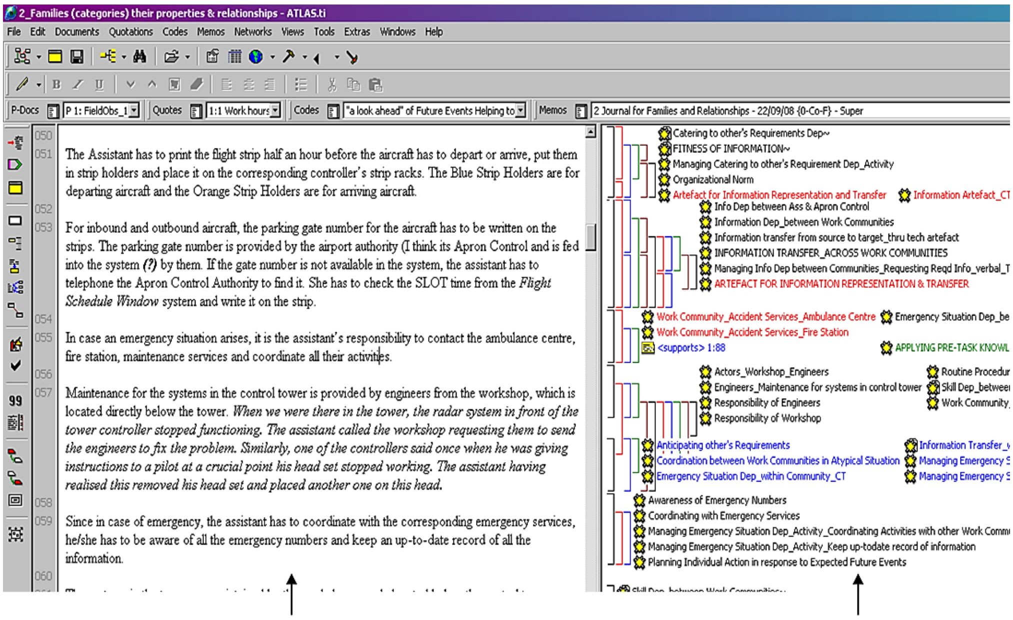
APPENDIX 4

TRANSCRIPT OF SEMI-STRUCTURED INTERVIEW CONDUCTED WITH THE TOWER CONTROLLER IN THE CONTROL TOWER

I	*Can you tell me what the role of the Tower Controller is?*
TC	*The role of the Tower Controller is to look after the runway and aircraft that are flying in the local area. So the Tower Controller will get the aircraft from the Ground Controller and fit them into an inbound pattern by requesting gaps from the Approach over the telephone and that's the case of looking over the Ground Controller and see what traffic they have in order to prepare the gaps in time by phoning the RADAR controller. Then integrating the outbounds with the inbounds, launching them on the runway, taking the inbounds landing on the runway and handing them over to the ground as soon as the inbounds are ready to clear the runway. Anything that is flying over the airfield and the approach cant get through effectively and quickly, they might hand over to us, they might just be transit traffic… helicopters, they might say to us I've got helicopters going to the North, I have a whole string of inbounds can you get them through the Approach? We can look out of the window, we can put aircraft a lot close together, push things a lot tighter than Approach can on RADAR. So we keep things running, watch them cross and then clear things. And also the Tower Controller will work the aircraft that are departing here, just light aircraft that will be going out through one of the traffic lanes.*

APPENDIX 5

SNAPSHOT OF CODING IN ATLASTI SOFTWARE



Observation Data Transcript Codes

APPENDIX 6

ILLUSTRATION OF OPEN CODING UNDERTAKEN DURING DATA ANALYSIS

Selected Quotation

File: [C:\NALLINI\RESEARCH\DATA\DATA ANALYSIS...\2_Families (categories) their properties & relationships.hpr5]

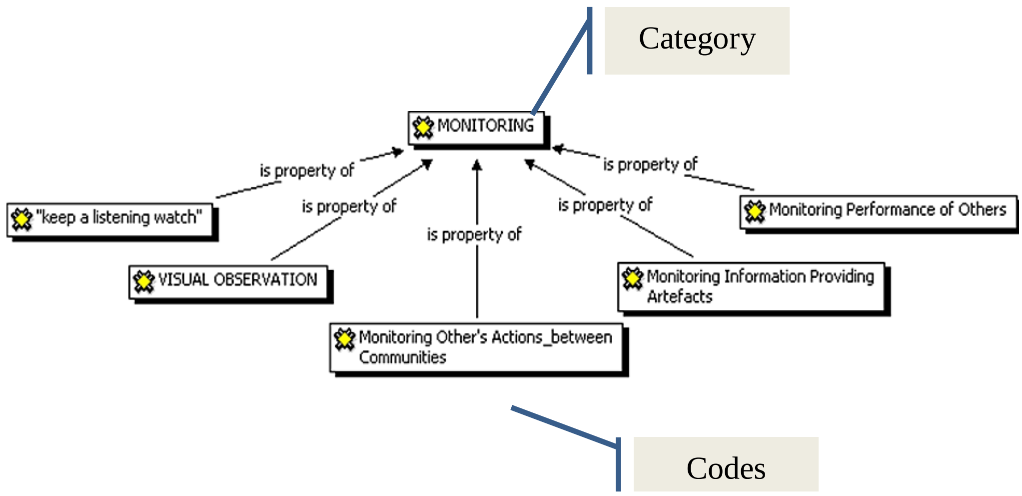
P 4: FieldInterview_1.rtf - 4:4 [This is the Aerodrome Radar. I..] (16:16) (Super)

Interview with Ground Controller (GC) in Control Tower

Interview Transcript	Codes
Starts with an overview of the systems used in the ground controller position. This is the Aerodrome Radar. It is controlled from the tower position. So I don't have any direct control over this. What I use it for is to have an awareness of what the inbound traffic is going to be like.	• Artefact for Information Representation and Transfer • Awareness Created by Visual Observation • Information Artefact Helping to Assess Situation
I can also do that by glancing across to the tower desk to see what strips are there. What it would be basically is see what traffic was building up…let the Air Position know what time he is pushing so that he can anticipate it and call the Radar for gaps, to arrange gaps.	• Anticipating Future Events • Anticipating Other's Requirements • Catering to Other's Requirements

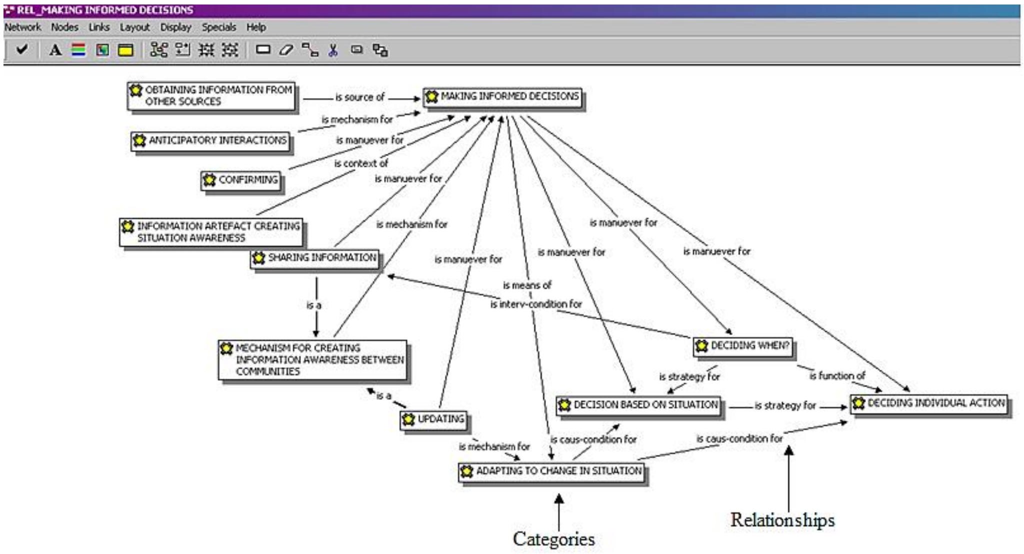
APPENDIX 7

ILLUSTRATION OF CODES FORMING A CATEGORY MODELLED IN ATLAS.TI SOFTWARE



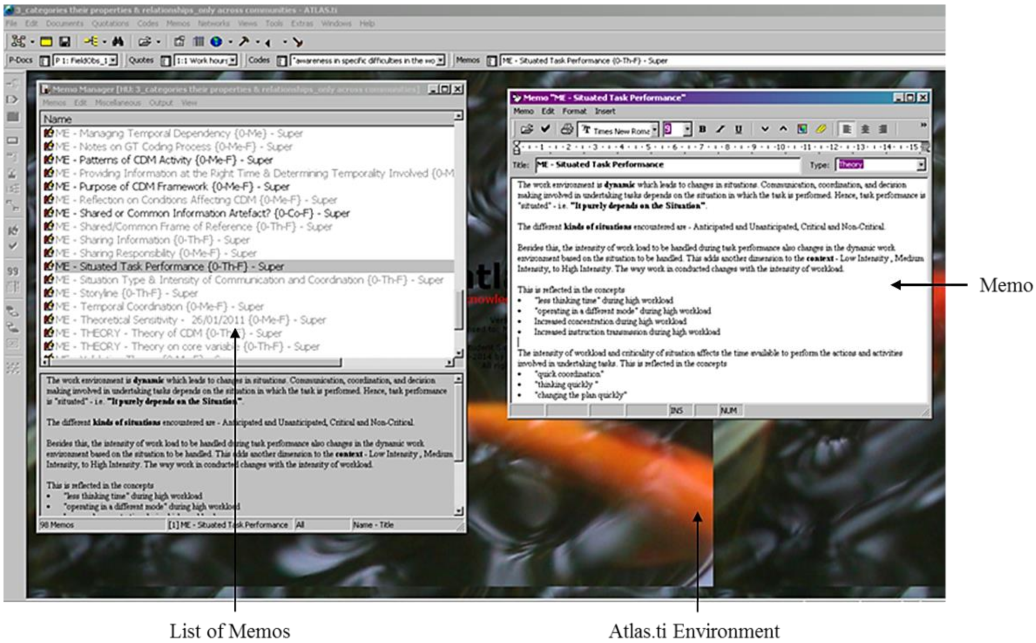
APPENDIX 8

SNAPSHOT OF MODELLING RELATIONSHIPS BETWEEN CATEGORIES IN ATLASTI SOFTWARE



APPENDIX 9

SNAPSHOT OF MEMO WRITING IN ATLAS.TI



APPENDIX 10

MEMO_SITUATED TASK PERFORMANCE

HU: 3_categories their properties & relationships_only across communities
File: [C:\NALLINI\RESEARCH\DATA\...\3_categories their properties & relationships_only across communities.hpr5]

MEMO: ME - Situated Task Performance

Type: Theory

Text highlighted in bold: Codes

Text within speech marks: in-vivo codes

The work environment is **dynamic** which leads to changes in situations. Communication, coordination, and decision making involved in undertaking tasks depends on the situation in which the task is performed. Hence, task performance is "situated" - i.e. "It purely depends on the Situation".

The different **kinds of situations** encountered are – Anticipated, Unanticipated, Critical and Non-Critical.

Besides, the intensity of work load to be handled during task performance also changes in the dynamic work environment with respect to the situation to be handled. This adds another dimension to the **context -** Low Intensity, Medium Intensity, and High Intensity. The way work activities are conducted changes with the intensity of workload.

This is reflected in the concepts

- "less thinking time" during high workload
- "operating in a different mode" during high workload
- Increased concentration during high workload
- Increased instruction transmission during high workload

The intensity of workload and criticality of situation affects the time available to perform the actions and activities involved in undertaking tasks. This is reflected in the concepts

- "quick coordination"
- "thinking quickly "
- "changing the plan quickly"

APPENDIX 11

FLYER CREATED AND USED TO INFORM STUDIED PERSONNEL DURING DATA COLLECTION

interaction
design • centre

ATC Research at Middlesex

The Project

Researchers from the School of Computing Science at Middlesex University are conducting a study in collaboration with NATS to understand the ways that tower staff are able to coordinate their activities with one another. The current focus of this study will be the Tower at Luton Airport.

One motivation for the study will be to inform the design of future ATC technology, with the aim of ensuring that new tools support rather than upset the ways that controllers are able to maintain an awareness of colleagues' work and coordinate their own tasks with those of others.

For the study we are making a series of visits to the Luton Tower to observe controllers' and assistants' activities and to find out more about how coordination between people takes place. So you are likely to see us around in the tower over the next few weeks.

We welcome your help in this study, but should make it clear that participation is voluntary and you should feel free to decline to be observed or interviewed. The notes that we make and any other data we collect will remain confidential and anonymous. Participants' identities will not be revealed to anyone outside the Middlesex research team.

The Team

The interdisciplinary research team possesses a range of expertise from Computer Science, Psychology, Human Factors and the Social Sciences, and has conducted research in ATC and aviation human factors for over a decade. The members involved in this work are:

Nallini Selvaraj (n.selvaraj@mdx.ac.uk)
Bob Fields (b.fields@mdx.ac.uk)
Paola Amaldi (p.amaldi-trillo@mdx.ac.uk)

Contact

For more information contact Nallini Selvaraj (n.selvaraj@mdx.ac.uk) or visit the web site of our research group, the Interaction Design Centre:

http://www.cs.mdx.ac.uk/research/idc/

APPENDIX 12

LIST OF CODES AND CATEGORIES FROM DATA ANALYSIS USED TO DEVELOP THE THEORY OF COLLABORATIVE DECISION MAKING

Theoretical Codes and Categories

- Contextual Conditions
  - Dynamics of Situation
    - Typical Situation
    - Atypical Situation
  - Heterogeneity of Work Units
    - Spatio-Temporal Heterogeneity
    - Procedural Heterogeneity
    - Situational Heterogeneity
    - Resource Heterogeneity
- Causal Condition
  - Dependencies
    - Types of Dependencies
- Managing Interdependencies
  - Aligning Work Activities
    - Synchronizing Actions
      - Managing Temporality
      - Making Informed Decisions
      - Correlating Actions
    - Synchronizing Decision Making
      - Correlating Decisions
      - Cohering Decision Making
    - Synchronizing Perception
      - Avoiding Misunderstanding
      - Avoiding Surprises
      - Integrating Viewpoints

- Keeping People in the Loop
  - Modes of Interaction
    - Anticipatory Interactions
    - Reactionary Interactions
  - Fitness of Information
    - Form of Information Transfer
    - Means of Information Transfer
    - Timing of Information Transfer

- Modes of CDM Activity
  - Sequential Decision Making
    - Notifying
    - Requesting
    - Acting in Response
  - Mutually Consented Decision Making
    - Getting Approval
    - Confirming
    - “working things between each other”
  - Manipulative Decision Making
    - Bypassing Standard Procedure
    - Working Around Authority
  - Emergent Decision Making
    - “it purely depends of the situation”
    - Making Tactical Changes
    - Acting in Response

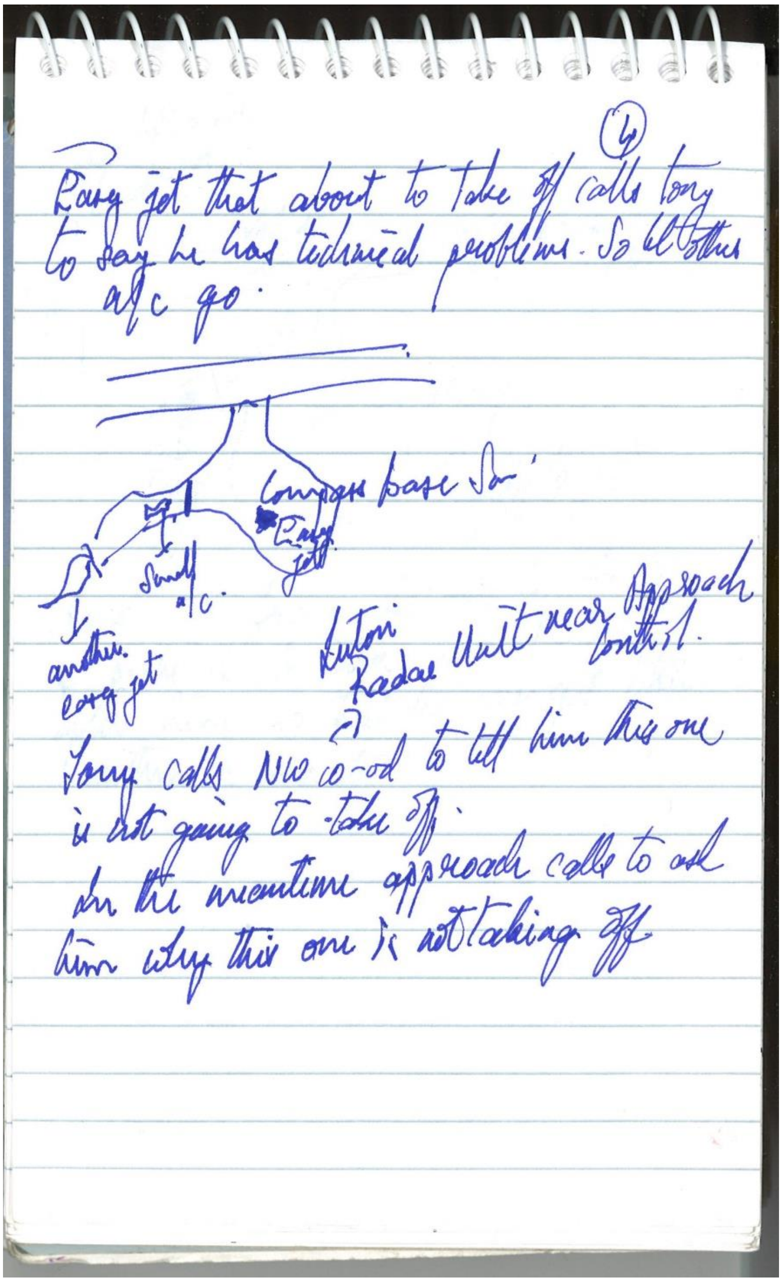
APPENDIX 13

LIST OF SCENARIOS DEPICTING DIFFERENT SITUATION TYPES

Situation Types	Non-critical Situation	Critical Situation
Typical Situation (Anticipated)	• Planned Aircraft Arrival • Planned Aircraft Take-off • Lighting Inspection • Engine Test Run • Conditional Clearance	• Tight Spacing between Aircraft • High Traffic/Workload • Low Visibility Procedures
Atypical Situation (Unanticipated)	• Aircraft Pilot Calling Controller on Wrong Frequency • Delay in Aircraft Take-off • Departing Aircraft Returning to Stand • Slot Change for Departing Aircraft • Parking Stand Unavailable for Arriving Aircraft • Flight Plan “Dropped” Out of the System • Flight Progress Strip Unavailable	• Helicopter Take-off • Controller forgetting to arrange gaps between arriving aircraft • Aircraft “straying” into wrong control zone • Missed Approach • Technical Problem in Aircraft • Technical Problem in Systems in the Control Centres

APPENDIX 14

SNAPSHOT OF OBESERVATION DATA FROM FIELD-NOTE



4

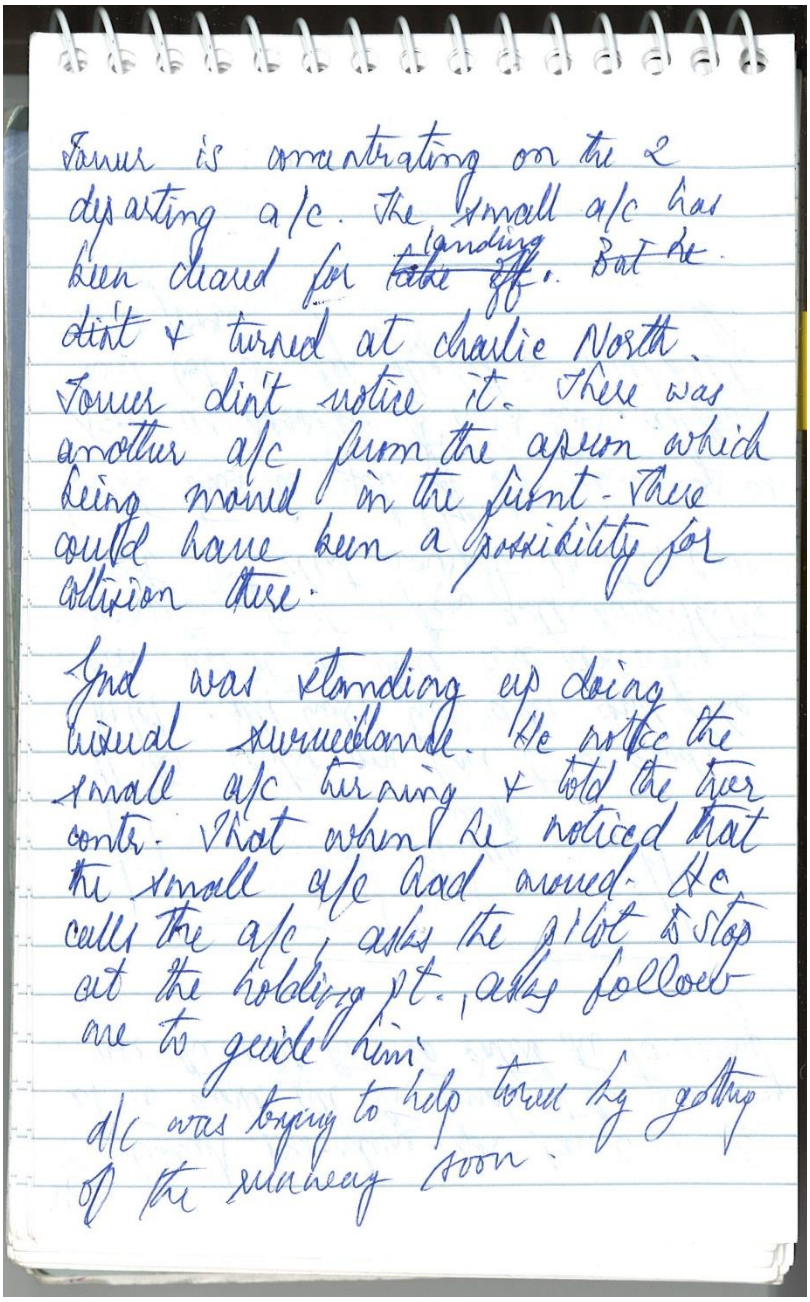
Easy jet that about to take off calls tony
to say he has technical problems. So let other
a/c go.

Company base Sa'
Easy jet
Small a/c
another easy jet
Luton Radar Unit near Approach Control.

Tony calls NW co-ord to tell him this one
is not going to take off.
In the meantime approach calls to ask
him why this one is not taking off

APPENDIX 15

SNAPSHOT OF OBESERVATION DATA FROM FIELD-NOTE



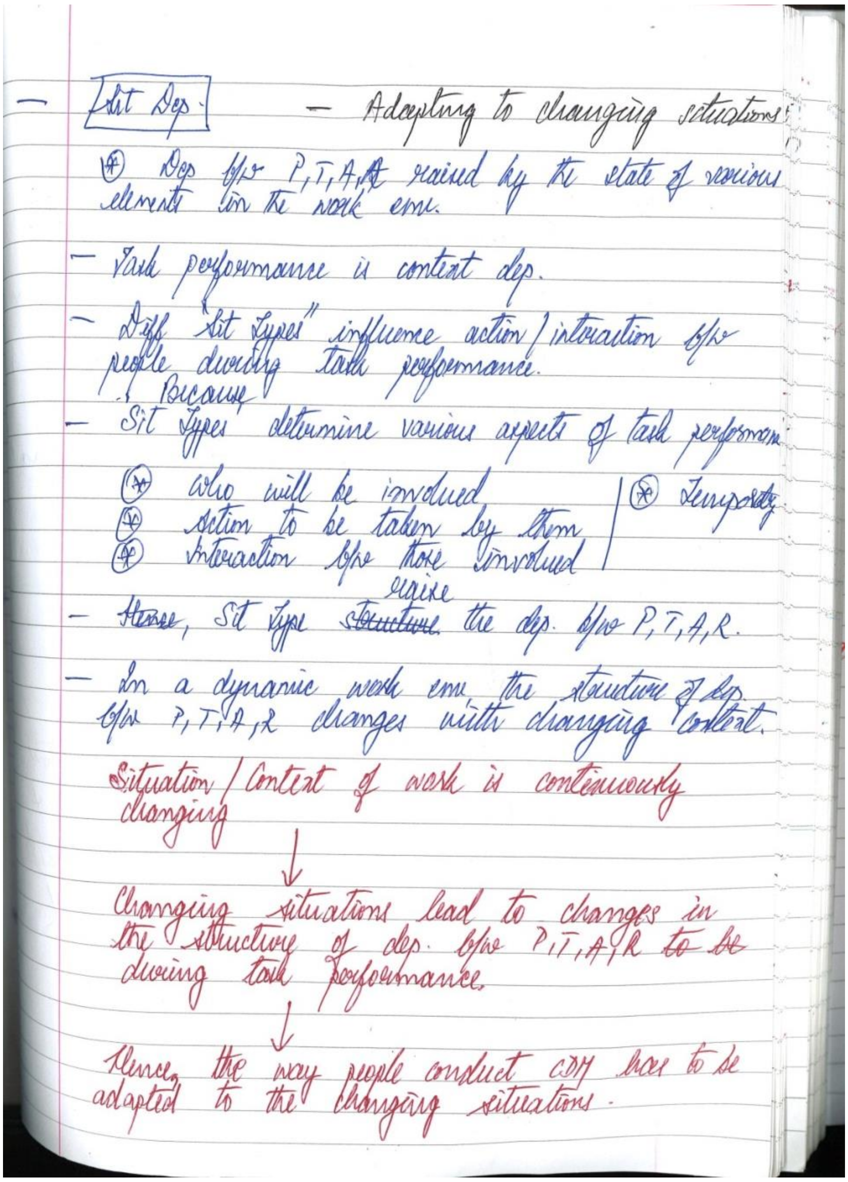
Tower is concentrating on the 2 departing a/c. The small a/c has been cleared for ~~take off~~ landing. But he didn't & turned at charlie North. Tower didn't notice it. There was another a/c from the apron which being moved in the front - there could have been a possibility for collision there.

Gnd was standing up doing visual surveillance. He notice the small a/c turning & told the tower contr. That when he noticed that the small a/c had moved. He calls the a/c, asks the pilot to stop at the holding pt., asks follow me to guide him.

a/c was trying to help tower by getting of the runway soon.

APPENDIX 16

SNAPSHOT OF MEMO WRITTEN ON PAPER



$\boxed{\text{Sit Dep.}}$ – Adapting to changing situations:

* Dep b/w P, T, A, R raised by the state of various elements in the work env.

– Task performance is context dep.

– Diff "Sit Types" influence action / interaction b/w people during task performance.

∴ Because

– Sit Types determine various aspects of task performance

* who will be involved
* Action to be taken by them
* Interaction b/w those involved
* Temporality

– Hence, Sit Type ~~structure~~ raise the dep. b/w P, T, A, R.

– In a dynamic work env the structure of dep. b/w P, T, A, R changes with changing context.

Situation / Context of work is continuously changing

↓

Changing situations lead to changes in the structure of dep. b/w P, T, A, R ~~to be~~ during task performance.

↓

Hence, the way people conduct CDM have to be adapted to the changing situations.