Communication and performance in teams
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In many critical environments, teams have to do the job while work conditions change rapidly and time is limited. This puts great emphasis on the ability of teams to perform effectively. Among others, an important factor that influences team performance is communication. Communication can be problematic because there is too little time to communicate or it distracts team members from performing their tasks. However, teams need communication to exchange the necessary information, to preserve up-to-date knowledge of the situation, and to determine strategies to cope with the changes in the situation. These paradoxical demands of a team to communicate or not to communicate are the topic of this thesis.

The ability of teams to work effectively is a prerequisite in a number of critical work environments. From military command and control centers to aircraft cockpits to emergency medicine, from fire fighting to air traffic control to crisis management, teams carry out much of the work. In these environments, teams have to perform under complex and dynamic circumstances that can be characterized by time pressure, heavy workload, deadlines, ambiguous information presentation, and a rapidly changing environment. Furthermore, teams have to deal with high stakes and poor performance may have considerable consequences. Despite the reliance on teams to carry out their work successfully in such critical environments, there is still much to learn about the factors that make teams successful.

To illustrate the importance of effective teamwork, consider the following studies. In the aviation domain, many accidents involving aircraft damage were mainly due to the actions of the flight crew. A central theme in these cases was that human error resulted from failures in interpersonal communications (Helmreich & Foushee, 1993). Heath and Luff (1992) demonstrated that effective crisis management in the London underground line control room depends on how operators monitor each other and exchange information. Flin, Slaven, and Stewart (1996) describe the disastrous fire at the oil platform Piper Alpha. One of the reasons that lives could not be saved was that the chain of command had broken down and that there was no one in charge to lead people to safety. In the medical world, ineffective teamwork has led to a considerable number of incidents in anesthesia (Howard, Gaba, Fish, Yang, & Sarnquist, 1992). Finally, probably more lives could have been saved after the crash of a Hercules military transport aircraft of the Belgian air force had team members exchanged all information concerning the total number of passengers (Van Duin & Rosenthal, 1996).

These studies show that “human error” is not exclusively a matter of individual task performance but also of team performance. Even when a team consists of members with the finest skills or expertise, it is not said that one can speak of a skilled or expert team. Teams, in which members do not communicate, coordinate, cooperate, provide back up to each other or, in other words, do not engage in teamwork, will have a hard time getting good results. The interest of this thesis is in those factors that make a team effective. More specifically, this thesis focuses on the relationship between communication and team performance in time-pressured and dynamic situations. Insight in how teams perform in such situations helps to understand how team members can be supported by means of technical systems, procedures, and work organization and how team members can be trained effectively. We hope that this will give a contribution to teams operating more successfully in critical environments.
1.1 Team performance in time-pressured and dynamic situations

This thesis focuses on teams defined as follows. Teams consist of at least two people that work together toward a common goal, who have been assigned to specific roles or tasks to perform, and where the completion of the goal requires dependency among team members (Dyer, 1984; Salas, Dickinson, Converse, & Tannenbaum, 1992). Other researchers have used similar definitions in which the elements described above are all acknowledged as important ingredients for the definition of a team (Cannon-Bowers, Salas, & Converse, 1993; Duffy, 1993; Orasanu & Salas, 1993). There is discussion among researchers whether teams can be differentiated from groups. The central issue in this discussion is whether high interdependency, unique roles, distributed expertise, and specific needs for coordination are more typical for teams than for groups (Cannon-Bowers et al., 1993; Dickinson & McIntyre, 1997; Dyer, 1984; Guzzo, 1995; Orasanu & Salas, 1993). To further differentiate, several researchers even use specific terminology such as command and control teams (Rasker, Post, & Schraagen, 2000a), tactical decision-making teams (McIntyre & Salas, 1995), action teams (Klein, 2000), or complex decision-making teams (West, Borrill, & Unsworth, 1998), that all appear to refer to teams as defined previously.

We view teams as a special instance of groups. In groups, members typically have less specialization, and less interdependency to reach their goal. In addition, the objective in groups is frequently to reach consensus, whereas this is not the case for teams.

We focus further on teams that have to perform in conditions characterized by high time pressure or excessive workload and in dynamic situations that change rapidly and contain novel or unexpected events. The demands for teams to perform effectively in such conditions are high. Team members not only have to perform well on their individual tasks; so-called taskwork, but also on the tasks needed to act as a team; so-called teamwork (Baker, Salas, & Cannon-Bowers, 1998; Dyer, 1984; Fleishman & Zaccaro, 1993; McIntyre & Salas, 1995). One demanding element of teamwork is communication. Communication is needed because the interdependency among team members requires that information exchange takes place. In addition, communication is needed because it helps team members to evaluate and improve task performance, to jointly determine strategies, and keep each other up-to-date with the changes in the situation (Blickensderfer, Cannon-Bowers, & Salas, 1997b; Orasanu, 1990, 1993; Rochlin, LaPorte, & Roberts, 1987; Seifert & Hutchins, 1992; Stout, Cannon-Bowers, & Salas, 1996). Nevertheless, notwithstanding the need for communication, potential problems are that there may be too little time to communicate and that communication may disrupt the individual task performance of team members.

In conditions of high workload and time pressure, communication problems occur when team members have to discuss extensively about “who is responsible for what task” or “who needs what information and when.” Not only is there too little time for such discussions, there is also a potential danger that team members are too late with exchanging the necessary information because of attending such discussions. A study of Kleinman and Serfaty (1989) suggests that ineffective teams frequently engage in this type of communication, which the authors labeled as explicit coordination. Team performance can be maintained if teams adapt to high time pressure by anticipating on each other’s informational needs and providing each other relevant information in advance of requests. This is called implicit coordination, because team members exchange the necessary information and perform their tasks without the need for extensive communications to coordinate explicitly. The blind pass in basketball, where a player passes the ball over his or her shoulder to another player without looking and talking, is an example of implicit coordination.

Although several studies show that performance decreases because communication is inefficient and disrupts the workflow during high-workload periods or after critical, rare events (Hollenbeck, Ilgen,
Tuttle, & Sego, 1995; Hutchins, 1992; Johnston & Briggs, 1968), other studies point to the benefits of communication. In the aviation domain it was found that effective cockpit crews tend to communicate more overall and, in particular, crews who exchanged more information about flight status committed fewer flight errors (Helmreich & Foushee, 1993). Based on observations in a full-mission simulated flight, Orasanu (1990, 1993) concluded that team performance in cockpit crews was positively related to the amount of task-oriented communication including situation updates and the formulation of plans or strategies. Observations by military teams have led McIntyre and Salas (1995) to conclude that in effective teams, members communicate to monitor the performance of each other, provide feedback, and prevent each other from making errors. Finally, Rochlin et al. (1987) concluded that the redundancy in verbal communication, such as crosschecks on decisions made, was partially responsible for the reliability in the complex and high-risk operation of bringing in an aircraft on a flight carrier.

Three things can be learned from these studies. First, communication is potentially problematic when teams work in time-pressured and dynamic situations. Team members cannot exchange the necessary information in time and extensive communications distract team members from their taskwork. Second, although communication may be problematic, there are ways to work around it. Performance can be maintained if team members adapt to the situational demands by limiting the communication through implicit coordination. Third, communication is not necessarily a bad thing at all times. Communication to monitor each other’s performance, provide feedback, and exchange information about the situation, is positively associated with performance. The obvious conclusion is that teams should restrict their communication as much as possible, and communicate only if it is necessary or contributes to performance. However, less obvious is how teams can achieve this. Thus, the questions raised here are "how can teams limit their communication?" and "when is communication needed?"

1.2 Explaining communication in teams: shared mental models?

Recent literature has advanced the construct of shared mental models among team members as an underlying mechanism of team processes and performance in teams (Cannon-Bowers et al., 1993; Rouse, Cannon-Bowers, & Salas, 1992). This construct has emerged from the literature on individual mental models (Rouse & Morris, 1986; Wilson & Rutherford, 1989) that are organized knowledge structures that allow individuals to describe ("what is it?"), explain ("how does it work?"), and predict system functioning ("what is its future state?"). Bringing the mental model construct to a team level, shared mental models are organized knowledge structures that allow team members to describe, explain, and predict the teamwork demands. The knowledge that is shared comprises the internal team (e.g., knowledge about the tasks, roles, responsibilities, and informational needs of the team members, interdependencies in a team, and the characteristics of the team members) and the external situation (e.g., cues, patterns, and ongoing developments). The explanations and expectations generated by this knowledge allow team members to anticipate on each other’s task-related needs by providing each other information, resources, or other support in time (Cannon-Bowers et al., 1993).

With respect to communication, it is hypothesized that shared mental models allow team members to explain and predict the informational needs of teammates. Because team members rely on their shared mental models, communication takes place efficiently and effectively. Efficiently, because explicit and extensive communications to ask for information or to make arrangements concerning "who does what when" and "who provides which information when" are not needed. Effectively, because team members are able to provide each other with a) the information needed to complete the tasks successfully, b) without explicit communications, and c) on the time in the task sequence of a teammate when this
information is needed (Stout et al., 1996). In other words, shared mental models allow team members to coordinate implicitly. The result is the smooth team functioning of team members who are in sync with each other, and who know exactly when to talk and what to say.

Although shared mental models may result in efficient and effective communications, it is also hypothesized that communication is important for the development and maintenance of shared mental models (Orasanu, 1990, 1993; Stout et al., 1996). Communication during task execution refines team members’ shared mental models with contextual cues. This may result in more accurate explanations and predictions of the teamwork demands (Stout et al., 1996). For maintenance purposes, communication is needed to keep the shared mental models up-to-date with the changes that occur during task execution. Especially in dynamic or novel situations, communication is needed to preserve an up-to-date shared mental model of the situation and to adjust strategies or develop new ones to deal with the situation (Orasanu, 1990, 1993). Shared mental models in changing and novel situations serve as an organizing framework that enables team members to make suggestions, provide alternative explanations, employ their expertise, generate and test hypotheses, and offer information useful to determine strategies in that particular situation. In contrast to implicit coordination, which implies that mature teams are silent teams, this emphasizes the need for explicit communication to arrive at a joint interpretation of the situation and the generation of strategies to deal with that situation.

The potential power of shared mental models to explain and predict team processes in general and, more specifically, communication in teams, has appealed many researchers. This resulted in a tremendous growth of research, as evidenced by the overview described in the next chapter (see section 2.3). In the early nineties, shared mental models were mainly conceptually explored and used to explain team processes a posteriori. At the time the research for this thesis started, in the mid nineties, there were still few empirical studies that had investigated team processes in relation to shared mental models. The main reason for this paucity in the empirical work is that there were no adequate measures of shared mental models (see also Mohammed & Dumville, 2001). Recent work has attempted to measure and investigate shared mental models more directly (Cannon-Bowers, Salas, Blickensderfer, & Bowers, 1998; Marks, Zaccaro, & Mathieu, 2000; Mathieu, Goodwin, Heffner, Salas, & Cannon-Bowers, 2000; Stout, Cannon-Bowers, Salas, & Milanovich, 1999).

To date, the empirical research has concentrated mainly upon the question how team processes and performance can be improved by fostering team members’ shared mental models. Several antecedents of shared mental models including various types of cross and team training (Blickensderfer, Cannon-Bowers, & Salas, 1997c, 1998b; Cannon-Bowers et al., 1998; Entin & Serfaty, 1999; McCann, Baranski, Thompson, & Pigeau, 2000; Minionis, Zaccaro, & Perez, 1995; Schaal & Bots, 1997), leader briefings (Marks et al., 2000), team planning (Stout et al., 1999), and experience within the team (Mathieu et al., 2000; Rentzsch, Heffner, & Duffy, 1994) were investigated. In these studies, shared mental models were measured in various ways (if at all). Some studies investigated the knowledge content of individual team members (Cannon-Bowers et al., 1998), whereas in other studies the similarity among team members’ mental model was measured (Marks et al., 2000; Mathieu et al., 2000). Team processes were also investigated differently. Some studies assessed team processes by rating teamwork behaviors observed by subject matter experts (Cannon-Bowers et al., 1998; Entin & Serfaty, 1999; Marks et al., 2000; Mathieu et al., 2000; Volpe, Cannon-Bowers, Salas, & Spector, 1995), whereas in other studies the provision of information in advance of requests was used as a measure of implicit coordination (Blickensderfer et al., 1997c; Cannon-Bowers et al., 1998; Entin & Serfaty, 1999; Schaal & Bots, 1997; Stout et al., 1999; Volpe et al., 1995). All studies included measurements of team performance.
Despite this research interest, many issues have to be addressed to ensure that the shared mental model construct is a valid psychological construct. The main concern is that the research so far does not give a clear picture of the effect of shared mental models on team processes and, in turn, performance. Although some studies established a positive relationship between shared mental models and performance (Blickensderfer et al., 1997c; Marks et al., 2000; Mathieu et al., 2000), this relationship was not established in other studies (Cannon-Bowers et al., 1998; Minionis et al., 1995; Stout et al., 1999). Especially the effect of shared mental models on communication shows inconsistent results. Similarly, the results with respect to the relationship between team processes and performance are conflicting. Only one study demonstrated that team processes mediated the relationship between shared mental models and performance (Mathieu et al., 2000). The problem that underlies these conflicting empirical results is that researchers have not been consistent in the way shared mental models are defined, manipulated, and measured. In other words, there is no shared understanding among researchers what shared mental models are and how they operate.

In this roaring field of shared mental model research, the research described in this thesis was conducted. The above-described issues with respect to the shared mental model construct will not all be addressed. For one part, because we were mainly interested in the optimization of communication and performance in teams. Hence, we gained the most insight in this area. For another part, because we too had no adequate measures of shared mental models. Nevertheless, the knowledge content of shared mental models is analyzed in detail and measured at several points. In addition, we describe how this knowledge influences communication processes and vice versa. This way we address several issues with respect to the shared mental model construct that may serve future research. We will return to these issues in the concluding chapter 10.

1.3 Research questions

The shared mental model construct explains how communication can be limited. Team members that rely on their mental models provide each other the necessary information in time, that is, in advance of requests. It also explains why and when communication is needed: to develop shared mental models and to keep them up-to-date. These notions inspired us to perform the research described in this thesis. The main objective was to investigate empirically the relationship between communication and performance in teams. This was investigated from two different perspectives. First, we were interested in how communication can be limited by communicating as efficiently and effectively as possible. The basic idea is that antecedents (such as training) foster the knowledge in team members’ mental models. In turn, this has a positive effect on the effectiveness and efficiency of the communication. The research question for this first perspective was:

How can communication and performance be improved by fostering the knowledge team members have in their mental models?

From the second perspective, we were interested in how team members can use their communication to improve their performance. In contrast to the first perspective, we were now interested in how performance can be improved by expanding the communication. The basic idea is that communication fosters the development and maintenance of the knowledge in team members’ mental models. Hence, from this perspective, communication is viewed as a team process that is not only influenced by shared mental models, but also is an antecedent of shared mental models.
The research question for this second perspective was:

*How and when does communication improve performance by fostering the knowledge team members have in their mental models?*

The answers to the two research questions should provide more insight in how and when communication influences team performance. Given the limited room for communication due to high time pressure or excessive workload, it is essential that the room left to communicate is used as effectively as possible. In this thesis we examined how this communication room can be used optimally.

### 1.4 Organization of this thesis

As described above we focus on teams that perform in time-pressured and dynamic situations. The reader that is unfamiliar with this field of small-group research will find an overview of what it entails in chapter 2. In this chapter, we also describe in detail the theory and research concerning shared mental models. Chapter 3 addresses the method used throughout this thesis. It delineates how we developed an experimental team task for two team members based on methodological considerations, requirements extracted from the literature, and an analysis of command and control tasks. In chapter 4, a cognitive team task analysis is applied to the experimental team task. In this chapter, we determine the teamwork, the knowledge team members need to perform this teamwork, whether this knowledge is important for shared mental models, and the knowledge that is transferred when team members communicate in this particular team task.

After the theoretical, methodological, and conceptual examination of team processes and performance in chapter 2 to 4, the thesis turns to the empirical work. Chapter 5 and 6 comprise the first perspective in which we investigate how communication and performance can be improved by fostering the knowledge team members have in their mental models. In chapter 5, two experiments are described that investigate the effect of cross training on communication and team performance. Chapter 6 continues with the investigation of how communication and performance can be improved. This time, a different method is employed and a questionnaire is used to measure the team knowledge of the members.

Chapter 7 to 9 comprise the second perspective in which we investigate how and when communication improves performance by fostering the knowledge team members have in their mental models. The two experiments described in chapter 7 investigate the effect of communication on team performance. In the first experiment, the question is addressed whether team performance improves when teams can communicate freely compared to a restricted type of communication in which team members can exchange only the necessary information. In the second experiment, the opportunity to communicate freely is varied systematically during and between task execution. In the experiment described in chapter 8, we again focus on the effect of communication on team performance. This time, we are interested in whether communication is beneficial when team members have worked together for a longer period. The final experiment of this thesis is described in chapter 9 in which the effect of communication on team performance is investigated in routine as opposed to novel situations.

Chapter 10 concludes with a summary of the main results, a discussion of the theoretical implications, the limitations and strengths of the research, and the practical implications.