Communication and performance in teams
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In this final chapter, we summarize the results of this thesis and draw several conclusions. Subsequently, we discuss the theoretical implications, which includes a brief discussion about the shared mental model construct. This is followed by the limitations as well as the strengths of the research described in this thesis. The chapter finishes with several practical implications of our work.

10.1 Summary and conclusions

In teams that have to perform in time-pressured situations, communication can be problematic because there is too little time to communicate or it distracts members from performing their taskwork. Therefore, researchers assert that performance improves when teams limit their communication (Cannon-Bowers et al., 1998; Kleinman & Serfaty, 1989; Stout et al., 1999). However, communication in teams may be necessary to develop team and situation knowledge in shared mental models. In turn, this supports team members in coordinating implicitly, and performing additional teamwork such as performance monitoring, evaluation, and determining strategies together. Especially in rapidly changing or novel situations, communication may be needed to develop common knowledge that is up-to-date with the changes in the situation. Therefore, researchers assert that performance improves when teams expand their communication (Blickensderfer et al., 1997b; Orasanu, 1993; Rochlin et al., 1987; Seifert & Hutchins, 1992; Stout et al., 1999). To determine what effective communication is, how it can be facilitated, and whether teams must limit or expand their communication, the main objective of this thesis was to investigate the relationship among communication and performance in teams.

The first research question of this thesis was: how can communication and performance be improved by fostering the knowledge team members have in their mental models? Toward that end, we employed two methods: cross training and the provision of team information. In Experiment 1 and 2 (see chapter 5), we provided teams with a cross training method in which members were trained in each other’s tasks (i.e., positional rotation). In Experiment 3 (see chapter 6), we provided team members with information that contained explicit information about each other’s tasks, the informational interdependencies among members, and the moments that information exchange is necessary. The purpose of these methods was to foster members’ team knowledge that includes knowledge of each other’s tasks and informational needs. We expected that this would support teams in coordinating implicitly, and therefore communicating efficiently and effectively by exchanging the necessary information only, in advance of requests, and on the moment in a teammate’s task sequence when this is needed. In turn, we expected that these improved communications would result in better performance.

The second research question of this thesis was: how and when does communication improve performance by fostering the knowledge team members have in their mental models? In contrast to Experiment 1 to 3, we shifted our attention from the potential benefits of limiting the communication to the potential benefits of expanding the communication in Experiment 4 to 7. The experimental task we employed gave us the unique opportunity to manipulate communication between team members.
Because the necessary information could be exchanged by sending standardized electronic messages, we were able to create conditions in which teams communicated either restrictedly or unrestrictedly. In the restricted communication conditions, team members could exchange the necessary information by sending messages electronically. For one part, this forces team members to coordinate implicitly because it is not possible to communicate extensively about “who does what” or “which information must be exchanged when.” Furthermore, it is also is not possible to transfer team or situation knowledge and to determine strategies together. For another part, teams could coordinate more implicitly by sending more often the necessary messages only, in advance of requests, and on the moment in the teammate’s task sequence when this is needed. We expected that the better the team and situation knowledge in team members’ mental models, the better teams could coordinate implicitly by sending the necessary messages in time.

In the unrestricted conditions, teams members could communicate verbally, on top of the electronic message exchange. By giving teams the opportunity to communicate verbally or not, we could switch the communication literally “on” or “off.” Because unrestricted communication enables teams to transfer team and situation knowledge and to perform teamwork that consists of performance monitoring, evaluation, and determining strategies, we expected that unrestricted communication would improve performance. In Experiment 4 and 5 (see chapter 7), we investigated whether performance improves when teams communicate unrestrictedly either during task execution, between task execution, or both. In Experiment 6 (see chapter 8), we investigated the effect of unrestricted communication over time. Although we expected that unrestricted communication would be beneficial for the reasons mentioned, it can be argued that the effect of unrestricted communication diminishes because team members have transferred, after time, all the knowledge important for shared mental models. Therefore we investigated the effect of unrestricted communication in two subsequent sessions in which teams could communicate unrestrictedly in 1) none of the sessions, 2) Session 1 only, or 3) both sessions. In Experiment 7 (see chapter 9), we investigated the effect of unrestricted communication in novel versus routine situations.

With respect to the first research question; training in each other’s tasks or (i.e., positional rotation) did not improve communication or performance in Experiment 1 and 2. A plethora of explanations exists varying from methodological ones to explanations that question the assumed effectiveness of positional rotation. Most important is that positional rotation is not an effective method to provide team members with the knowledge needed to develop an understanding of what information must be exchanged at what moments. Although positional rotation may acquaint team members with each other’s tasks and system, thorough team knowledge may not be developed. Therefore, an effect of cross training on communication and performance could not be obtained.

In Experiment 3, the results for the provision of team information were more promising. Teams that received team information needed less communication to exchange the same amount of necessary information than teams that did not receive team information. The results also show that the provision of team information fostered members’ team knowledge. The scores on the questionnaire that measured this knowledge were also positively correlated to several communication measures. This indicates that the better the team knowledge, the better the communication. Despite these encouraging results, the provision of team information had no impact on performance. An explanation for this result is that another factor may have weighed more into performance: individual taskwork. Although team members improved their teamwork and communicated more efficiently and effectively, they failed to perform well on their taskwork. Therefore, the effectiveness of the provision of team information might be further improved when team members are fully skilled in their taskwork.
Chapter 10: Conclusions and discussion

Taken Experiment 1 to 3 together, we conclude that we did not find the ideal method to improve communication and performance in teams. Given the sparse support for the assumed effect of training in each other’s tasks, from our experiments as well as from the experiments of other researchers, we conclude that the effectiveness of this type of cross training method is questionable. Better results were obtained with training methods that are directly aimed at the development of team knowledge. In Experiment 3, this resulted in more efficient and effective communication, but not, surprisingly, better performance. Better results may be obtained when training methods are elaborated with hands-on practice. Not only a written instruction, but practice in a dynamic task environment with systematic feedback on members’ teamwork. More work is needed to explore the impact of these types of training methods on communication and performance. For now, we demonstrated that the provision of team information is an effective method to improve communication and possibly performance given adequate taskwork.

With respect to the second research question, the results of Experiment 4 to 7 show that unrestricted communication improves performance, however, not in all conditions. In Experiment 4 and 5, unrestricted communication did improve performance. The communication analysis shows that team members transferred team and situation knowledge and performed teamwork that consisted of performance monitoring, evaluation, and determining strategies. Moreover, the teams that communicated unrestrictedly were more often in time with the provision of a crucial message than the teams that communicated restrictedly. This indicates that they had developed better team knowledge. They knew when in a teammate’s task sequence necessary information had to be provided. The results show further that communicating unrestrictedly was more effective during than between task execution. We explained this by unrestricted communication during task execution allowing team members to monitor each other’s performance, which enabled them to prevent each other from making errors.

That unrestricted communication can also have negative consequences for performance was shown in Experiment 6. In this experiment, team members were trained for a longer time, and investigated in two subsequent sessions. On the positive side, the knowledge questionnaire showed that members’ team and situation knowledge was, as expected, better for the unrestricted than the restricted communicating teams. This indicates that unrestricted communication fosters team and situation knowledge. Furthermore, when team members communicated unrestrictedly in Session 1, performance increased, especially in Session 2 (when team members could not communicate unrestrictedly). Nevertheless, when teams could continue to communicate in Session 2, performance decreased. We think that too much communication in periods with high workload distracted team members from executing their activities. A post-hoc analysis of the verbal communication data showed that team members indeed did not adapt to high workload periods. They communicated as much in high as in low workload periods.

Taken together, Experiment 6 shows that, after communicating unrestrictedly in one session, unrestricted communication had a negative impact on performance in a following session, whereas performance improved for the teams that were forced to communicate restrictedly and coordinate implicitly. Based on this result we conclude that the effect of communicating unrestrictedly decreases after time. When teams have worked and practiced together for some time, team and situation knowledge is transferred that support members to act in sync. Because team members have developed team and situation knowledge, necessary information can be exchanged in time and without explicit communication.

A problem in interpreting the results of Experiment 6 was that the teams were presented with a mix of scenarios, in that they were neither strictly routine nor completely novel. This situational uncertainty may have caused teams to communicate extensively, which may have actually degraded the
performance. Because team members could not perceive the commonalities among the various scenario types (because these were not present in the mix of scenarios), an optimal strategy could not be determined. To investigate whether unrestricted communication is beneficial in novel scenarios to preserve up-to-date situation knowledge, we separated clearly the routine from the novel situations in Experiment 7. We equipped team members also with a team knowledge schema to ensure that team knowledge was equally present. The results show that unrestricted communication improved performance during the novel scenarios, however, not during the routine scenarios. Based on this result, we conclude that when teams have developed sufficient team knowledge, unrestricted communication is needed in novel, however, not in routine situations.

Turning back to the second research question of this thesis, what can we conclude about the benefits of communication for performance? Based on Experiment 4 to 7, we conclude that communication is especially important in the beginning of a team’s lifetime. Communication is beneficial to transfer team knowledge. It refines member’s general team knowledge into specific procedural rules of what to communicate and when. Transferring situation knowledge is important to develop a compatible understanding of the situation. Based on this knowledge team members can effectively determine strategies together. In mature teams, where members have fully developed team and situation knowledge, teams should limit their communication as much as possible. In that case, performance can be maintained when team members exchange the necessary information on the moment in a teammate’s task sequence when this information is needed.

This being said, however, we have seen that communication also has a positive impact on performance because it facilitates additional teamwork such as performance monitoring or determining strategies. For teams that perform in routine situations and are fully trained, communication is less important than for teams that are not fully trained or encounter novel situations. Hence, the answer to the question whether teams should communicate or not, cannot be easily answered with a simple yes or no. In general, we conclude that teams should limit their communication with respect to the fixed elements in team functioning. More precise, teams should a) not transfer team and situation knowledge in routine situations, b) not coordinate explicitly and communicate about “who does what” and “who needs what information and when,” and c) not continuously request each other for information. Limiting this type of communication would leave team members free to perform their own tasks as well as they can. At the same time, this would leave as much spare communication capacity available for that type of communication that is important for performance. That is, for performance monitoring, evaluation, and determining strategies together and, only in changing or novel situations, to transfer situation knowledge.

The following list summarizes our conclusions:

1. Training in each other’s tasks is not an effective method to improve communication and performance in teams (Experiment 1 and 2).
2. The provision of team information that consists of explicit information about each other’s tasks, the informational interdependencies among members, and the moments that information exchange is necessary, is an effective method to improve communication in teams (Experiment 3).
3. Communication improves performance because it supports team members in developing team and situation knowledge and it facilitates teamwork that consists of performance monitoring, evaluation, and developing strategies (Experiment 4 and 5).
4. When teams have practiced for a longer time and have developed team and situation knowledge, communication has no positive impact on performance (Experiment 6).
5. Too much communication has a negative impact on performance because it distracts team members in performing their taskwork (Experiment 6).

6. When team members have team knowledge, unrestricted communication does not contribute to performance in routine situations. However, in novel situations, communication is needed to preserve up-to-date situation knowledge and to determine strategies together (Experiment 7).

7. Communication is especially important for teams that are in the beginning of their lifetime because it fosters the development of team and situation knowledge (Experiment 4 to 7).

8. Teams should limit their communication as much as possible. If there is spare room to communicate, communication should not be used to coordinate explicitly, but for performance monitoring, evaluation, and determining strategies together and, only in changing or novel situations, to transfer situation knowledge (Experiment 1 to 7).

10.2 Theoretical implications

10.2.1 Results of this thesis

In chapter 2 (see section 2.3.3), we presented a model in which we illustrated the relationships among the antecedents, shared mental models, team processes, and performance. To position our own work in the context of the other research in this field, we determined for each relationship to what extent we found empirical support in the experiments of this thesis. Figure 10.1 shows the model of chapter 2 again, elaborated with the dimensions we manipulated and measured in the experiments described in this thesis (denoted by italics). The relationships that are illustrated by the uninterrupted lines are supported by our results.

![Diagram](image)

**Figure 10.1:** Shared mental model dimensions that were under investigation in this thesis (denoted by italics)

The results of Experiment 1 and 2 did not support the hypothesized positive relationships between cross training and communication (Relationship 2), or performance (Relationship 3). Because there was no measure of team member’s knowledge or shared mental models in Experiment 1 and 2, no support can be given for the hypothesized positive relationship of cross training on team member’s knowledge or shared mental models (Relationship 1). In Experiment 3, we did find support for Relationship 1 and 2. The provision of team information resulted in better team knowledge and more efficient and effective communication. However, Relationship 3 was not supported by the results of Experiment 5.
Performance was not influenced by the provision of team information. In sum, for one antecedent, namely the provision of team information, we found support for the hypothesized relationship between this particular antecedent, team knowledge, and team processes.

Relationship 4 to 6 are important with respect to the construct validity of shared mental models. Recall that the shared mental model theory states that the relationship among shared mental models and performance (Relationship 5) is mediated by team processes. In Experiment 5, we found support for Relationship 4. The better the team knowledge the more efficient and effective the communication. We also found support for the relationship between communication and performance. Exchanging the necessary information in time was positively associated with performance. Both results are in line with the shared mental model theory. However, we were not able to demonstrate statistically that the positive relationship between team knowledge and performance was mediated by communication.

The results of Experiment 4 to 7 show that the relationship among unrestricted communication and performance (Relationship 6) depends on the conditions in which teams perform. There is a positive relationship when teams are immature or perform in novel situations. In routine situations, unrestricted communication has no positive impact on performance. The results of Experiment 6 indicate that unrestricted communication may even lead to worse performance. Finally, as demonstrated qualitatively with the help of the verbal protocols in chapter 4 (see section 4.3.2), the results of Experiment 6 show that unrestricted communication resulted in better team and situation knowledge. Thus, our results provide support for Relationship 4, which states that unrestricted communication fosters team member’s knowledge in mental models.

10.2.2 Shared mental model support

Placing our results in the bigger picture of the shared mental model research, several points can be made. With respect to Relationship 1 and 2, we conclude that the empirical support for this relationship is conflicting and limited. We already outlined the conflicting results with respect to cross training as antecedent of shared mental models. Furthermore, the experience of the members in the team as antecedent of shared mental models shows also conflicting results (Blickensderfer, 2000; Mathieu et al., 2000; Rentsch et al., 1994). Other antecedents such as team interaction training (Marks et al., 2000; Minionis et al., 1995), team planning (Stout et al., 1999), leader briefings (Marks et al., 2000) were positively associated with shared mental models. However, the shared mental model measurements vary highly across these studies. Taken together, it seems that researchers (ourselves included) do not yet exactly know how shared mental models can be manipulated.

When looking across the body of research that investigated Relationship 4 to 6, we conclude that the empirical support is again limited and conflicting. The effect of shared mental models on teamwork was established in two studies (Marks et al., 2000; Mathieu et al., 2000), however, not in another study (Cannon-Bowers et al., 1998). Conflicting is also the hypothesized positive effect of shared mental models on communication and implicit coordination. Although our study and that of Blickensderfer et al. (1997c) found support for this hypothesis, in the study of Cannon-Bowers et al. (1998) and Stout et al. (1999) this hypothesis was not supported. Moreover, so far, only one study has demonstrated that the relationship between shared mental models (concerning team knowledge) and performance is mediated by team processes (Mathieu et al., 2000).

Taken together, the shared mental model construct is a powerful construct to explain processes and performance in teams that work in time-pressured and dynamic situations. In this thesis, it explains when and how communication can be limited, and when and how communication must be expanded to
obtain a good performance. By utilizing the shared mental model construct and therefore trying to open the “black box,” researchers develop a better understanding of why antecedents such as particular training methods affect team processes, and, in turn, performance. Nevertheless, the current body of research does not allow one to reach closure on how shared mental models can be manipulated or measured, and how they operate. Researchers have employed such different interpretations and measurements of the construct, that we are not at all sure if any two authors mean the same thing when they use it. This is problematic. If we do not reach consensus on how to define the construct, and how to manipulate and measure shared mental models, the construct becomes meaningless and loses its explaining and predictive power. Despite its explaining and predictive power, we conclude that the empirical research so far yields no indisputable evidence for the existence and working of shared mental models.

Recent research does not seem to reconcile these problems. In the broader field of shared cognition, Cannon-Bowers and Salas (2001) also conclude that shared mental model-like constructs become meaningless if researchers will not become more consistent and exact in defining and measuring these constructs. Recently published work on shared mental model-like constructs, have addressed the interesting topic whether team members’ mental models are more (or less) similar as result of various antecedents. These antecedents comprise experience and military rank (Smith-Jentsch, Campbell, Milanovich, & Reynolds, 2001), team composition, acquisition mode, and size (Rentsch & Klimoski, 2001), and team experience in a software development project (Levesque, Wilson, & Wholey, 2001). Although these studies partially address the sharedness issue (see below), this line of research does not provide new insights in how shared mental models influence team processes, and, in turn performance. Team processes were even not measured. Given that shared mental models were initially originated to explain and predict team processes and, in turn, performance, we believe that future research should concentrate more on these relationships.

A final issue we would like to discuss is whether shared means that knowledge is similar or distributed among team members. Based on the cognitive team task analysis described in chapter 4, we already concluded that this remains a difficult matter. It can be argued that commonly held knowledge of each other’s tasks is important to understand why information must be exchanged and when. Similarly, it can be argued that commonly held team interaction knowledge is important to know when to provide and expect necessary information. Nevertheless, it can also be argued that it is sufficient when individual team members know simply what information must be exchanged and when. The results of Experiment 5 point to this latter argument. Communication improvements were obtained whereas the scores on the knowledge questionnaire show that this knowledge was distributed. For situation knowledge, the theory states that team members must have similar situation knowledge so that team members are allowed to determine strategies in a compatible manner. The cognitive team task analysis as well as the results of Experiment 6 support this view.

Keeping in mind the theoretical principle of parsimony, the question arises whether we need a multidimensional construct such as shared mental models to explain team processes. The shared mental model construct implies that team members not only have knowledge, but also that it is shared among team members and organized in a mental model. It can be argued that team processes can be explained more directly by knowledge that team members individually have about the team and the situation. With respect to the sharedness of knowledge, our results suggest that for a positive effect on communication, there is no need for members to have common team knowledge, whereas it is important that team members have common situation knowledge to determine strategies together. With respect to the organization of knowledge, our results do not lend themselves to draw conclusions. We had no
measures that examined the possible organization of knowledge in mental models. Most studies in this field, however, assert that it is the organization of knowledge that counts (see, for example, Mathieu et al., 2000, p. 280) followed by content and the accuracy of team members' knowledge.

**10.2.3 Directions for future research**

Given what is said, where do we go from here with the shared mental model research? First, researchers might take a step back and examine the value of a mental model construct. The important question to answer is whether we need this construct to explain human behavior, or whether we can explain this simpler in terms of having specific knowledge. Second, researchers must develop a shared understanding of what is meant by shared mental models. There is much to be gained when researchers a) employ similar definitions of the knowledge content, b) measure the construct similarly, and c) have similar descriptions of how it operates. In that, researchers have to be very specific. Researchers not only have to be very clear in what knowledge is important, but also in what knowledge must be similar or distributed. Furthermore, researchers have to be more specific about the effect of shared mental models on team processes. Simply stating that shared mental models have a positive effect on teamwork is not very informative. What types of teamwork and how it is affected by shared mental models must be described more precisely. On the same token, researchers must be exact in what is measured. This goes for the shared mental model construct itself as well as the team processes.

For future experiments designed to investigate shared mental models, we recommend that these be preceded by a thorough cognitive team task analysis. Such an analysis helps to describe the interdependencies in a team, the teamwork, and the knowledge needed to perform effectively. Moreover, it describes conceptually whether knowledge is shared or distributed among members. This gives not only insight in how knowledge affects teamwork, but also what knowledge and teamwork should be measured. Subsequently, specific knowledge elements can be linked to the general knowledge elements that are expected to be important for shared mental models. To investigate which knowledge elements are the most important for team performance, various knowledge elements can be investigated one-by-one in relation to teamwork. Antecedents such as specific training methods or support aids can be used to foster different knowledge elements. To investigate the effect of common versus distributed knowledge one can attempt to provide team members with different knowledge than their teammates versus similar knowledge elements across members. Knowledge measurements should measure all aspects of shared mental models. That is, the content, extent of similarity, accuracy, and organization of knowledge. Questionnaires can be used for the knowledge content, whereas team interaction concept maps (Marks et al., 2000) can be used for the knowledge organization. Finally, teamwork should be described and measured explicitly. Thorough analysis and ratings of the communication provide a rich source for investigating teamwork.

Taken together, more work is needed to ensure that the shared mental model construct becomes a meaningful construct. We recommend that more empirical studies be conducted in which the sharedness, organization, content, and type of knowledge is systematically varied and examined in relation to communication and other teamwork behaviors. The recently developed measurements of shared mental models (Cooke et al., 2000b; Mohammed et al., 2000) and team processes must be refined and further incorporated. In doing that, researchers might think of those experiments that are designed not to find support, but to refute the shared mental model theory (Popper, 1963). If researchers fail to refute, we can be more confident that shared mental models are a valid construct. Up to now, the construct validity and usefulness of shared mental models remains questionable.
10.3 Limitations and strengths

The research reported in this thesis has several limitations. A first limitation is concerned with the theoretical framework of shared mental models. Although we rely heavily on the shared mental model theory in explaining most of our results, we inferred the existence of shared mental models mostly from team processes (communication) and output measures (performance). To put it even more bluntly: it can be stated that we did not capture shared mental models adequately. In that, the research described in this thesis reflects the developments of the research in the field of shared mental models. The research is in its formative stage and adequate measures of shared mental models are just beginning to come into use (see Mohammed et al., 2000). In the nineties, most research in the field of shared mental models was concerned with the conceptual development of the construct, defining teamwork competencies, and exploring how these competencies are affected by shared mental models. One of the first challenges for the empirical research in this area was to develop an adequate experimental task for teams. Developing networked simulations in order to create a complex and dynamic team task environment, which was needed to capture all dimensions of the shared mental model theory, was no sinecure (Weaver et al., 1995). Looking back, there is no doubt in saying that we made progress on several of these points. However, measuring shared mental models was not one of them.

Because we had no adequate measures of shared mental models, we cannot draw conclusions with respect to the way knowledge might have been organized. Nevertheless, we believe that our results do provide insight in team members’ knowledge content. First, with the help of the cognitive team task analysis we examined conceptually what knowledge is needed to perform teamwork. Second, the existence of team and situation knowledge can be inferred from the communication and performance measures. Third, in two experiments we had questionnaires to measure team members’ knowledge as part of their shared mental models. These three points partially reconcile the inadequacy of our shared mental model measures.

A second limitation is concerned with the mediating role of particular communication categories in the relationship among the communication conditions and performance in Experiment 4 to 7. We were not able to demonstrate that the theoretically relevant communication categories such as performance monitoring or determining strategies mediated more than the irrelevant communication category remaining communication. For Experiment 4 to 7, we correlated the number of statements in each category and the performance measure (i.e., percentage of casualties saved) for each condition, each experiment, and all experiments. We encountered two problems in interpreting these correlations. First, with respect to the correlations taken from several conditions (i.e., the ones for each experiment and all experiments together) the differences in the conditions interfered with a sound interpretation of these correlations. Second, with respect to the correlations taken from each condition the number of correlated items were small (i.e., varying from 11 to 20 pairs of items per condition). Naturally, these problems came into mind because the overall picture of correlations was rather puzzling. Many of the correlations were not significant and in some conditions certain communication categories were positively correlated with performance, whereas in other conditions these were negatively correlated. Taken together, we conclude that there is no linear relationship between (unrestricted) communication and performance. Rather, what seems to be more important than the volume of communication is the communication content. It can even be argued that the best teams are able to transfer knowledge and perform additional teamwork with a minimum of communication effort.

We can also think of several strengths with respect to the research described in this thesis. First, we experimentally investigated team processes in complex and dynamic conditions, rather than to perform observational studies in the field. Admittedly, we used a contrived team task, but this enabled us to
control a lot of error variance, and to be able to investigate the effects of theoretically relevant variables. In our experimental approach, we also measured team processes directly by rating all communication into categories, whereas the majority of team research relies on self-reports, peer reviews, or questionnaires taken a posteriori. Together with the verbal protocols, this gives a better and more objective picture of the communication in teams. In general, the experimental approach and the direct communication measures supported us to gain a good insight in the causal relationships among the antecedents, shared mental models, team processes, and performance.

The second strength of the research reported here is that we explicitly described the knowledge, team processes, performance, and their relationships. While on the contrary most studies provide rather general descriptions of shared mental models and teamwork, we attempted to be very specific about that. Especially how shared mental models influence teamwork remains often unclear. Instead, we defined the knowledge important for shared mental models in chapter 2 (see section 2.3.1) which was linked to the knowledge needed to perform the teamwork in the experimental task in chapter 4. This was also linked to team processes that comprise the communication features of implicit coordination (see section 4.2.2, Table 4.7) as well as additional teamwork illustrated in a model in chapter 4 (see section 4.3.1, Figure 4.8). This way, we attempted to translate abstract concepts as shared mental models and teamwork into concrete descriptions and apply these to an actual team task.

The final strength we would like to point out is the integration of the research areas that are concerned with human factors and performance on the one hand and organizational behavior on the other hand. The human factors research is traditionally concerned with topics comprising individual processes such as man machine interface, decision making, workload, or human computer interaction. The majority of the studies use cognitive theory and modeling techniques to explain and predict performance with respect to individual taskwork. Conversely, the research from the field of organizational behavior is typically concerned with processes and performance of work groups in organizations. Major themes in this research are leadership, cohesion, group polarization, organizational culture, and so forth. Whereas in the one research field the unit of analysis is the individual, in the other field this is the team or the group. In the research described in this thesis, we attempted to integrate this by applying cognitive theory and models to processes measured on a team level. We believe that explaining team processes from a cognitive perspective is promising for future research.

### 10.4 Practical implications

The results of this thesis also have practical implications. We organized these around three themes: team design, team training, and team support.

#### 10.4.1 Team design

*Employing cognitive team task analysis*

The first practical spin-off of our research is the development of a method for cognitive team task analysis that can be used for team design. Recent overviews in the areas of cognitive task analysis (Schraagen, Chipman, & Shalin, 2000) and team design (Schraagen, 2001) have pointed out the lack of methods for cognitive team tasks analysis and psychologically motivated principles for team design. The approach to cognitive team task analysis we employed in chapter 4 worked well and can be applied to more complex tasks. Given the potential costs of communication, our results would suggest designing for minimal communication interdependency among team members. Our approach to team task analysis...
helps to provide insight in this interdependency. The functional decomposition as described in chapter 3 not only involves the tasks, but also the information dependency between tasks. By assigning tasks to team member roles and present them sequentially in a TOSD, it can be easily determined on what moments and how often interaction is needed. Hence, the consequences of assigning tasks to team members in terms of interdependency become clear. With the help of TOSDs various task assignments can be compared, and the one with the lowest communication interdependency can be selected. The cognitive part of the analysis gives insight in the knowledge team members need for their taskwork and teamwork. This description guides the determination of what should be trained to perform effectively.

**Future military naval command and control centers**

Our results may also have implications for a major theme in future military naval command and control centers, which is the downsizing of the personnel (i.e., often mentioned figures for downsizing are from about 20 to five persons). In current command and control centers, tasks are often assigned such that there are members that perform tasks and others that supervise and monitor the task performance. Our results indicate that a team is more robust for errors when members can communicate freely to monitor each other's performance; members can provide feedback and correct each other's errors. Possible consequences of downsizing may be that there are no members left responsible for performance monitoring, or that the workload is too high to communicate at all. If downsizing of the personnel means that there are fewer opportunities for performance monitoring, then this may result in a performance decrease, particularly in novel situations. When assigning tasks to team members during team design, it must be taken into account that team members have the means and the time to monitor each other's performance.

One way to achieve that downsized teams have the same performance as their larger counter parts is to create a flexible team organization. With such an organization, teams are able to adapt to high workload periods by reassigning tasks from team members with high workload to team members with low workload. By backing up for each other’s tasks, team members are able to keep the workload at acceptable levels for each team member. The consequence is, however, that member’s team knowledge concerning “who does what and when” is not applicable any more. Our results suggest that, because the team organization changes and tasks are reassigned, communication is needed to preserve up-to-date team knowledge. In case of designing a flexible team organization, it must be taken into account that teams members need the time and opportunity to communicate freely.

**10.4.2 Team training**

*Training taskwork and teamwork*

In many areas such as the military, crisis management, fire fighting, and so forth, training is often geared to team member’s individual taskwork. This may result in a team of experts, however, not in an expert team. The results of this thesis echo the research of many other studies; the success of teams depends on both taskwork and teamwork. For that reason, we recommend that if people must work in a team, training also includes teamwork. Team members must be learned how to communicate, coordinate, monitor each other’s performance, and back each other up. A candidate for such a training is the Team Dimensional Training method developed by Smith-Jentsch et al., (1998b). This method is centered on the four ATOM teamwork behaviors (Smith-Jentsch et al., 1998a) that involves information exchange, communication, supportive behavior, and team leadership. A procedure is included that helps instructors not only to train teams, but also to diagnose their teamwork performance. By giving meaningful and exact feedback, using scoring schemas, individuals learn how to act as a team member.
Cross training

In the discussion of the main results of this thesis at the beginning of this chapter, we mentioned briefly some implications for team training. Given the sparse and conflicting empirical support for training in each other's tasks as a cross training method to foster team knowledge and improve communication, we do not recommend to train team members by means of positional rotation. An additional reason to refrain from this type of training is that in the real world, training in each other's tasks is long lasting and costly, especially for highly specialized functions. Our results indicate that a more fruitful training method is to explain team members directly a) what information must be exchanged, b) at what moments, c) and for what reason. To ensure that team members translate this from a conceptual notion into applicable procedural rules, additional practice might be needed. Based on our results, we believe that good results can be obtained when team members practice in a dynamic task environment with systematic and meaningful feedback about the way they exchange information.

10.4.3 Team support

Support systems

Communication can be limited when support systems are designed such that the necessary information is available to the team members who need it. Morrison, Kelly, Moore, and Hutchins (1998) evaluated a support system for naval command and control. They found that support systems that provide basic data and tactical information about tracks (such as location, status, kinematics, identity, and relative position) reduced the teams' need to request and provide this data verbally. Given the results of Experiment 6 (see chapter 7) that too much communication in periods with high workload may have distracted team members from executing their tasks, this might be highly beneficial. Moreover, when team members communicate less concerning the necessary data, more time is left for communication that can be used to preserve up-to-date situation knowledge. The study of Morrison et al. (1998) indicates that although team members communicated less concerning basic track data, they communicated proportionally more about critical contacts. This type of situation information may be important to share among team members to ensure that team members have a compatible approach in determining strategies.

An important means for team members to preserve up-to-date situation knowledge is to provide each other regularly with situation reports. In practice, however, these reports are often unstructured, incomplete, too long or too short, unclear or not given at all. It often depends on the individual capabilities of team members whether a situation report is successful or not. Because our results show that having up-to-date situation knowledge is important, a support system may be equipped with means to exchange important situation information among team members. For example, a team support system may be equipped with a window containing relevant and up-to-date situation information in a logical and structured order (see also Lenox, Hahn, Lewis, & Roth, 1999). The utilization of large screen displays in which relevant and up-to-date situation information is presented is another possibility for support.

Work-agreements

Besides support systems, teams can also be supported by using adequate procedures or making work-agreements. To prevent team members from communicating extensively about "who is responsible for what task" or "who needs what information and when," team members can make work-agreements before task execution (Rasker & Willeboordse, 2001). Teams can be guided in making work-agreements by providing a list of items that members can agree upon. Rasker and Willeboordse (2001) provide an
example of such a list for naval command centers teams. This list includes items such as: what information must be passed and when, who is responsible for contacts on airways, who takes the small and who takes the large radar range, and so forth. We expect that work-agreements made before task execution result in less communication during task execution.

10.5 Concluding remarks

The research described in this thesis reveals and illustrates the benefits and costs of communication in teams that perform in time-pressured and dynamic situations. The results lead us to conclude that communication must be limited as much as possible. If teams have spare room left to communicate, teams should use this room for developing team and situation knowledge and performing additional teamwork consisting of performance monitoring, evaluation, and determining strategies. Developing team knowledge is especially important for immature teams. Once teams are experienced and have developed team knowledge, they should communicate only when encountering novel or rapidly changing situations. In that case, communication is important to preserve up-to-date shared knowledge of the changes in the situation.

We explained communication from a cognitive perspective in terms of shared mental models comprising team and situation knowledge. On that account, we have not investigated one-sidedly either team or cognitive processes but rather attempted to bring this together. We did not succeed totally. Based on the currently developed insight, we now acknowledge that our measurements of (shared) mental models could have been more adequate. Nevertheless, we managed to develop an experimental team task that contained the important psychological elements needed to investigate communication in teams as well as the theory of interest. In addition, we had direct measures of communication and performance. Finally, the cognitive team task analysis illustrates comprehensively how concepts operate in an actual team environment. Altogether, this gives a profound insight in cognitive and team processes, performance, and their relationships.

We advocate strongly that future research continue to relate team processes to cognitive theories and models. We expect that this approach will reveal theoretically new insights that account for team processes yet unexplained. Moreover, a good understanding in the cognitive functioning of team members supports researchers to develop adequate team training methods, design better team tasks, and adapt automation to team settings. This thesis offers results, methods, and insights that contribute to the present research and also provide a ground for future research investigating teams from a cognitive point of view. Altogether, these efforts support the continuous search of researchers to the factors that make a team successful.