Communication and performance in teams
Rasker, P.C.

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4 COGNITIVE TEAM TASK ANALYSIS

This chapter describes a cognitive team task analysis of the fire-fighting task. We performed this analysis to determine the teamwork and the knowledge needed to perform the fire-fighting task. In addition, we examined the way communication may foster the knowledge in shared mental models. We performed a qualitative analysis of the verbal communication that took place in the teams that participated in Experiment 5 (see chapter 7). Altogether, the cognitive team task analysis gives a description of the relationships between team processes, knowledge in shared mental models, and performance in the fire-fighting task.

4.1 Introduction

In chapter 3, the fire-fighting task was introduced as an experimental team task. We performed a task analysis to determine to what extent the fire-fighting task contains command and control tasks, team members have specific roles and responsibilities, are interdependent, and to what extent tasks have to be performed in parallel. Nevertheless, this is only one part of the picture. What is missing is an analysis of the teamwork and knowledge team members need in order to perform the fire-fighting task effectively. In terms of Potter, Roth, Woods, and Elm (2000), the task analysis of chapter 3 provides an analysis of the domain in which the focus is on developing an understanding of the way the world works and what it requires of the team members. Here, we provide an analysis of the teamwork and the knowledge needed for the fire-fighting task.

The cognitive team task analysis is important for the research questions formulated in the introduction of this thesis. To investigate these questions, the fire-fighting task must contain the relevant psychological aspects concerning the theory under investigation (Driskell & Salas, 1992a). For the shared mental model theory, these aspects are knowledge and teamwork. More precisely, it is hypothesized that team and situation knowledge in shared mental models influence the way team members communicate, coordinate implicitly, and determine strategies together and, the other way around, communication influences team members' team and situation knowledge in shared mental models. Thus, the psychological aspects that must be present in the fire-fighting task are communication, implicit coordination, and team and situation knowledge. When these aspects are present in the fire-fighting task, we have greater confidence that we can test the shared mental model theory empirically. In line with Driskell and Salas (1992a), we assert that, in turn, the theory, not the task, can be generalized to real world teams in which these aspects are also present. The main purpose of the analysis is, therefore, to reveal to what extent teamwork and knowledge are present in the fire-fighting task.

The analysis serves several other purposes as well. First, the analysis must make clear whether the knowledge needed for the teamwork in the fire-fighting task has to be shared among team members. Therefore, the description of the knowledge needed to accomplish the teamwork must be examined in relation to the knowledge that researchers have hypothesized to be important in shared mental models. This way, the issue of sharedness (i.e., whether knowledge is overlapping or distributed among team
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members) will be, at least for the fire-fighting task, resolved. Second, the analysis must make clear how communication can be used to foster the knowledge of team members in a mental model. Therefore, it must be determined how team members communicate and what knowledge is transferred. Third, the analysis must make clear what the relationship is between the knowledge, teamwork, and the performance measurements. This can be used to determine to what extent the performance is an indication of effective teamwork and having shared mental models. Finally, the analysis must make clear what teamwork and knowledge can be measured in the fire-fighting task.

Because it is not an easy task to provide a complete analysis of the teamwork, knowledge needed, and communication, we analyzed this step-by-step. The strategy we adopted was to begin with the relatively simplest condition, and subsequently add more complexity. Therefore, the first step was to describe normatively the teamwork and the knowledge needed for the condition in which teams have no opportunity to communicate verbally. In this condition, the information exchange needed to accomplish the tasks takes place by using the standardized electronic messages. Team members can only send each other messages and cannot speak freely to, for example, determine strategies cooperatively or to transfer knowledge about the teamwork demands. Because team members are restricted in their opportunities to communicate, this condition is referred to as the restricted condition. The task analysis of chapter 3 is taken as a starting point to determine what teamwork is needed in the fire-fighting task when teams communicate restrictively. Subsequently, we described for each task, including the teamwork tasks, the knowledge needed. Based on this description, we linked the teamwork in the fire-fighting task to the generally formulated teamwork concepts. Likewise, we linked the knowledge needed for the teamwork in the fire-fighting task to the knowledge that is expected to be important in shared mental models. Finally, we related this to the performance measures. Section 4.2 describes the first step of the analysis.

The second step was to analyze the condition in which teams have the opportunity to communicate verbally. In this condition, team members must also exchange the information that is needed to accomplish the tasks using the standardized electronic messages. However, on top of that, team members are allowed to communicate verbally and are free to exchange any information they like. Verbal communication can be viewed as an additional opportunity team members have to optimize their task performance. Team members may use this opportunity to transfer knowledge, perform the command and control tasks jointly, or to perform teamwork. Because team members are unrestricted in their opportunities to communicate, this condition is referred to as the unrestricted condition. For this condition, we also described normatively the teamwork that can be performed when team members can communicate unrestrictedly and the knowledge needed for that purpose. Based on the literature we developed a model in which the relationships between the knowledge in shared mental models, task performance and teamwork is illustrated. We used the model to describe the knowledge that is expected to be transferred between team members and to define categories in which the communication can be classified.

The last step in the analysis was to examine the verbal communication in order to get a better picture of the knowledge that is transferred between team members and how team members use their communication opportunity to optimize task performance. The communication that took place during Experiment 5 (see chapter 7) was transcribed into verbal protocols. Based on the verbal protocols we examined how team members communicated and whether this could be linked to the communication categories we normatively defined. Subsequently, a detailed description is provided of the knowledge that is transferred in each of the categories. This is linked to the knowledge that we normatively determined to be needed to perform teamwork in the fire-fighting task. Altogether, this must provide a
good understanding of how communication may foster the knowledge team members have in their mental models. Section 4.3 describes the second and the third step of the analysis.

The advantage of analyzing the restricted and unrestricted condition separately is that it gives a clear description of what happens when team members have the opportunity to communicate unrestrictedly compared to the team members that do not have this opportunity. Note, however, that the normative analyses of the restricted communication condition can also be applied to the teams that communicated unrestrictedly. In both conditions, the command and control tasks are similar and teams must exchange the information needed to accomplish the tasks by using the standardized electronic messages. Unrestricted communication is not needed to perform the fire-fighting task successfully. However, it may help team members to perform additional tasks and optimize their task performance. In chapter 5 and 6, which comprise the first perspective in this thesis, teams are investigated that could only communicate restrictedly. From this perspective, we are interested in the communication as a result of shared mental models. Therefore, we analyzed whether the standardized electronic messages reflect implicit coordination as a result of shared mental models. In chapter 7 to 9, which comprise the second perspective in this thesis, the opportunity to communicate unrestrictedly was varied in several ways. From this perspective, we are interested in communication as antecedent of shared mental models. Therefore, in various conditions, teams had the opportunity to communicate unrestrictedly either during scenarios, between scenarios, or both. To test the effect of communication on shared mental models and performance these teams were contrasted with teams that could only communicate restrictedly.

4.2 Restricted communication

In this section, we are interested in two questions. First, what teamwork tasks must team members perform to accomplish the tasks in the fire-fighting task successfully, and, second, what knowledge do team members need to perform the (teamwork) tasks? The starting point of the cognitive team task analysis is the TOSD of the prototypical scenario of the second version of the fire-fighting task (see chapter 3). For each coherent series of tasks (e.g., from detecting a fire to sending information about that fire) a specific TOSD is developed. This can be viewed as a snapshot of a task sequence that shows when and which tasks, including the teamwork tasks, have to be performed to be in time in the fire-fighting task and to accomplish the tasks successfully. For each task in the TOSD, we determined the cognitive tasks or critical decisions team members have to perform and the knowledge that is needed (Potter et al., 2000). This is described in separate tables that are linked to the TOSDs. Each task in the TOSD is labeled with a number that corresponds to the row in the table. Subsequently, the row describes the cognitive tasks or critical decisions, and the knowledge. The complete set of TOSDs and the corresponding tables in this section represent all task sequences that are present in Version 2 and 3 of the fire-fighting task. TOSD 1 and 2 and the corresponding tables can be applied to Version 1. However, the difference is that in Version 1 a period lasts 30 seconds, whereas in Version 2 and 3 a period lasts 15 seconds.

4.2.1 Restricted communication, teamwork, and knowledge

Team operational sequence diagram 1

The first task sequence begins when a building is on fire. The observer detects and identifies fires and sends the information to the dispatcher. Figure 4.1 presents a TOSD of these tasks. In Table 4.1, a description is provided of the cognitive tasks versus critical decisions and the knowledge needed to perform the tasks presented in Figure 4.1. To perform fire detection and identification, the observer
needs declarative knowledge about the city, building types, and potential casualties associated with each building type.

<table>
<thead>
<tr>
<th>Period</th>
<th>Observer</th>
<th>Dispatcher</th>
<th>System</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Table 4.1.A</td>
<td>Fire Detection</td>
<td></td>
<td>Fire House E (1 unit)</td>
</tr>
<tr>
<td></td>
<td>Table 4.1.B</td>
<td>Fire Identification</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Table 4.1.C</td>
<td>Send Information</td>
<td>Table 4.1.D</td>
<td>Read Information</td>
</tr>
</tbody>
</table>

**Figure 4.1:** TOSD 1; from fire detection to read information

In all subsequent TOSDs, teamwork tasks are marked in boldface. Teamwork in TOSD 1 is the communication task *send information*. The observer must send the information about the fires to the dispatcher. The standardized electronic message facility can be used for that purpose. Therefore, the observer needs procedural knowledge of how to use this facility. To decide that the information about fires is important for the dispatcher, the observer must know that the dispatcher uses this information to decide on the allocation of units. To read the message about the fires, the dispatcher must know that messages contain information about new fires. To coordinate implicitly, the information about fires must be sent in time and without requests by the dispatcher. Therefore, the observer must know *when* this information is important to give to the dispatcher (i.e., within one period). The knowledge needed to perform the tasks of TOSD 1 can be obtained from the instructions that are developed to train team members in the fire-fighting task. The instructions describe how team members can use the standardized electronic message facility to exchange the necessary information. The roles and responsibility of the team members are also explained. There is no explicit description of how to coordinate implicitly. However, the instruction does emphasize the importance to exchange information in time.

TOSD 1 shows that teamwork, namely communication and implicit coordination, is included. Table 4.1 shows further that to perform this, the observer needs knowledge about the dispatcher’s task and team interaction knowledge of when information must be provided.
Table 4.1: Cognitive tasks versus critical decisions and the knowledge needed for fire detection and identification, and send and read information

<table>
<thead>
<tr>
<th>Task</th>
<th>Cognitive tasks/ critical decisions</th>
<th>Knowledge</th>
</tr>
</thead>
</table>
| 4.1.A Fire detection (observer) | • Monitor the map of the city  
• Detect fires by perceiving a flashing red colored contour around buildings | • The city contains buildings which can catch fire  
• A flashing red colored contour around a building means fire |
| 4.1.B Fire identification (observer) | • Decide on clicking on the building when a fire is detected  
• Read information about the building  
• Determine building type  
• Determine potential casualties  
• Determine the number of units needed to extinguish the present fire | • Clicking on a building gives information about the building type  
• Different buildings in the city represent different building types (house, apartment building, school, factory, and hospital)  
• Different building types have different numbers of potential casualties  
• Different building types need different numbers of units to extinguish the fire |
| 4.1.C Send information (observer) | • Decide that the information of the building on fire is needed by the dispatcher  
• Decide that this information must be sent at this time  
• Decide to put information in the outbox window  
• Decide to send information to the dispatcher | • The dispatcher needs information of buildings on fire to decide on the allocation of units  
• The sooner the dispatcher receives this information, the sooner the fire can be extinguished  
• Information of fires should be sent within one period  
• Information can be sent using the outbox window  
• Information is sent to the dispatcher by clicking the send button |
| 4.1.D Read information (dispatcher) | • Decide on reading the message in the inbox  
• Read information about the building | • Messages in the inbox contain information of the observer about new fires |

Team operational sequence diagram 2

After reading the information about the fire, the dispatcher decides whether units will be allocated to that fire. Therefore, the allocation amount, time, and building must be determined. These tasks are represented in TOSD 2 depicted in Figure 4.2. In Table 4.2, the cognitive tasks versus critical decisions and the knowledge needed are described. First, the dispatcher determines the number of units needed to extinguish the present fire and compares this number with the units available in the station. The dispatcher must know that there is a limited number of units and that there are different building types that need different numbers of units to extinguish the potential fires. To determine whether units can be withdrawn, the dispatcher needs knowledge about when and how withdrawal must take place. The dispatcher can obtain this knowledge from the instructions that describe the allocation procedure in detail. The instruction of the observer does not contain such detailed information about the allocation procedure. However, the instruction of the observers does contain information about that different building types need different numbers of units and that the number of units available is limited.

To determine the best time to allocate units, the dispatcher needs procedural knowledge that describes that the sooner units are present, the sooner the fire will be extinguished. For large buildings (i.e., factories and hospitals), this procedural rule is slightly different. Units have to be present at the onset of the fire. Otherwise, the building cannot be saved. Note that the sector and the type of fires in large buildings can be predicted by determining a pattern in small buildings at the beginning of a scenario. Thus, when a pattern is determined in time, the dispatcher can allocate units at the beginning of a fire. In combination with the knowledge about the number of units available and the opportunities to withdraw units, the dispatcher can determine whether it is possible to allocate units in time to the present fire.
the instructions of the observer as well as the dispatcher, it is highlighted that fires must be extinguished as soon as possible. With respect to the large building in danger, the instructions explain explicitly that units have to be present at the onset of the fire.

Finally, the dispatcher determines whether the present fire has more priority over the fires that started earlier. Declarative knowledge is needed about the number of potential casualties associated with each building type. For both team members the instructions include a table that gives an overview of the building type, number of potential casualties, and number of units needed in case of a fire. Strategic knowledge describes whether the fire in the present situation has priority over fires that started earlier. The knowledge elements needed to determine the allocation time and building are task related.

When the allocation decision is made, the dispatcher may fulfil his or her teamwork and send this information to the observer. Just as with the observer, the dispatcher needs procedural knowledge about how to send the standardized electronic messages. To decide that the information of the allocation decision is important for the observer, the dispatcher must know that the observer uses this information to decide on which fire has higher priority to watch. The instruction informs the dispatcher about the responsibility of the observer to watch fires. To coordinate implicitly, the information about the

Figure 4.2: TOSD 2; from send information to fire watching
allocation decision must be sent in time and without requests by the observer. Therefore, the dispatcher must know when this information is important for the observer. Although the instruction of the dispatcher does not include an explicit explanation of how to coordinate implicitly, the importance to be in time is emphasized.

**Table 4.2: Cognitive tasks versus critical decisions and the knowledge needed for determine allocation amount, time, and building, and send and read allocation decision**

<table>
<thead>
<tr>
<th>Task</th>
<th>Cognitive tasks/ critical decisions</th>
<th>Knowledge</th>
</tr>
</thead>
</table>
| 4.2.A Determine allocation amount (dispatcher) | - Determine the number of units needed to extinguish the present fire  
- Determine the number of units available in the station  
- Determine whether there are sufficient units available to allocate to the present fire  
- Determine the number of units that are in transport to a building  
- Determine the number of units present at a building  
- Determine the building types where units are allocated  
- Determine the number of periods that units are present when a building is on fire | - Different building types need different numbers of units to extinguish the fire  
- The number of units is limited (six units available)  
- Units in transport cannot be allocated or withdrawn  
- Units that are present cannot be allocated  
- Units must first be withdrawn to the station before they can be allocated  
- Different buildings in the city represent different building types (house, apartment building, school, factory, and hospital)  
- The more periods units are present, the more the fire is extinguished |
| 4.2.B Determine allocation time (dispatcher)   | - Determine whether the time to allocate is in time to extinguish the fire | - The more periods units are too late, the smaller the chance that a building can be extinguished  
- If a sufficient number of units is not available at the beginning of a predicted fire in a large building, then the fire cannot be extinguished  
- Present fire can be extinguished in time |
| 4.2.C Determine allocation building (dispatcher) | - Decide on the withdrawal of units  
- Decide on the allocation of units to the present building | - Different building types have different numbers of potential casualties  
- Present fire has more priority than previous fire |
| 4.2.D Send allocation decision (dispatcher)    | - Decide that the information of the allocation decision is needed by the observer  
- Decide that this information must be sent at this time  
- Decide to put information in the outbox window  
- Decide to send information to the observer | - The observer needs information of the allocation decision to decide which fire has higher priority to be watched  
- The sooner the observer receives this information, the sooner the fire can be watched  
- Information of the allocation decision should be sent within one period  
- Information can be sent using the outbox window  
- Information is sent to the observer by clicking the send button |
| 4.2.E Read allocation decision (observer)       | - Decide on reading the message in the inbox  
- Read information about the building | - Messages in the inbox contain information of the dispatcher about the allocation decision |

The dispatcher needs mostly task-related knowledge to perform the tasks described TOSD 2. To perform the teamwork (i.e., communication and implicit coordination). Table 4.2 shows that the dispatcher needs declarative knowledge about the task of the observer and procedural knowledge of when information must be provided.
When there are buildings on fire, the observer must monitor the status (i.e., fire, saved, or burned down) of the buildings and watch the number of units needed. TOSD 3 depicted in Figure 4.3 represents these tasks. In Table 4.3, the cognitive tasks versus critical decisions and the knowledge needed are described. Dependent on the number of units present, the number of units can be different each period. That is, fewer units are needed when a building is about to be saved and more units are needed when a building is about to be burned down. Knowledge is needed to know when the number of units is most likely to change (i.e., not during a period, but after the clock resets and the new period begins) and a building is saved or burned down. The observer can obtain this knowledge from the instruction that describes how a fire typically evolves.

<table>
<thead>
<tr>
<th>Period</th>
<th>Table 4.3.A</th>
<th>Table 4.3.B</th>
<th>Table 4.3.C</th>
<th>System 1</th>
<th>Event 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>Fire Watching</td>
<td>Send Information School K</td>
<td>Read Information School K</td>
<td>Fire School K (2 units)</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Fire Watching</td>
<td></td>
<td>Determine Allocation Amount</td>
<td>Transport 1 unit (Withdrawal)</td>
<td>Fire School K (1 unit)</td>
</tr>
</tbody>
</table>

**Figure 4.3:** TOSD 3: from fire watching to fire watching

Again, the observer must perform teamwork by giving the information about the building (including the number of units needed) to the dispatcher. Knowledge about how to send standardized electronic messages is needed and can be obtained from the instructions. To decide that the information about the number of units is important for the dispatcher, the observer must know that the dispatcher uses this information to decide on the allocation amount and building. Note that it is inefficient for the observer to send continuously information about the buildings on fire. Implicit coordination implies that the observer only sends information about a building on fire when the number of units needed is changed. Therefore, the observer must know that only the information about changes in the number of units needed to extinguish a fire is important for the dispatcher. The instruction of the observer provides a description of the role and informational needs of the dispatcher. Although the instruction describes that
the dispatcher needs information about new fires and the changes in the number of units, there is no explicit instruction of how to coordinate implicitly and provide the necessary information in advance of requests.

TOSD 3 shows that this task sequence contains teamwork. To communicate effectively and engage in implicit coordination, the observer needs declarative knowledge about the dispatcher’s task and procedural knowledge of when information must be provided.

**Table 4.3:** Cognitive tasks versus critical decisions and the knowledge needed for fire watching, and send and read information

<table>
<thead>
<tr>
<th>Task</th>
<th>Cognitive tasks/ critical decisions</th>
<th>Knowledge</th>
</tr>
</thead>
</table>
| 4.3.A Fire watching (observer) | - Determine when a building on fire needs more or less units  
- Detect extinguished fires by perceiving a flashing green colored contour around a building  
- Detect burned fires by perceiving a black colored contour around a building  
- Decide on clicking on a building  
- Read information about the building | - Within a period the number of units needed remains the same  
- Dependent on the number of units allocated, buildings on fire need more or less units  
- Green colored contour means a building is extinguished and the potential casualties are saved  
- Black colored contour means a building is burned down and the potential casualties are expired  
- At the beginning of each period the number of units may change |
| 4.3.B Send information (observer) | - Decide that the information about the number of units needed to extinguish the fire is needed by the dispatcher  
- Decide that this information must be sent on this time  
- Decide to put information in the outbox window  
- Decide to send information to the dispatcher | - The dispatcher needs information about the number of units needed to extinguish the fire to determine the allocation amount and building  
- The dispatcher needs information about the changes in the number of units needed to extinguish the fire  
- The sooner the dispatcher receives this information, the sooner the dispatcher can allocate or withdraw units  
- Information of fires should be sent within one period  
- Information can be sent using the outbox window  
- Information is sent to the dispatcher by clicking the send button |
| 4.3.C Read information (dispatcher) | - Decide on reading the message in the inbox  
- Read information about the building | - Messages in the inbox contain information of the observer about the number of units needed to extinguish fires |

**Team operational sequence diagram 4**

In the previous paragraphs, we described how team members react on a detected fire and allocate units. Efficient and timely communication is important to be on time to extinguish the fires and save the buildings. The tasks and knowledge elements that are involved are typical for the first six periods of a scenario. From the seventh period, team members must predict the type and sector of a large building based on a pattern in fires of small buildings. This is important because in order to extinguish a fire in a large building (i.e., a factory or a hospital) units must be present at the beginning of that fire. It is essential that the observer finds the expected fire in a large building before it starts to burn and provide this information to the dispatcher. If the dispatcher does not receive this information in time (i.e., before Period 9), then the dispatcher cannot allocate units in time and save the large building. Recall that
predicting the building type and the sector helps the observer to search the large building more closely, whereas the dispatcher uses this to withdraw units in time and reallocate them to the large fire in danger.

Predicting the building type begins with the observation that a series of fires in one sector forms a pattern. After the detection and identification of the fire that forms the last part of a pattern, both team members start to predict the building type. TOSD 4 depicted in Figure 4.4 represents these tasks. In Table 4.4, the cognitive tasks versus critical decisions and the knowledge needed are described. Declarative knowledge is needed to know that there are patterns in a series of small fires in each scenario. Procedural knowledge is needed to know how the various patterns predict a fire in one of the two large building types (i.e., a factory or hospital). The instructions of both the observer and the dispatcher contain the procedural rules that describe how a large building in danger can be predicted from a series of fires in small buildings.

<table>
<thead>
<tr>
<th>Period 7</th>
<th>Observer</th>
<th>Dispatcher</th>
<th>System</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table 4.1.A</td>
<td>Fire Detection</td>
<td>Fire House S (1 unit)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Table 4.1.B</td>
<td>Fire Identification</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Table 4.4.A</td>
<td>Send Information House</td>
<td>Pattern</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Table 4.4.C</td>
<td>Predict Building Type</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Table 4.4.E</td>
<td>Read Information Type</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Table 4.4.B</td>
<td>Read Information House</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Table 4.4.C</td>
<td>Predict Building Type</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Table 4.4.D</td>
<td>Send Information Type</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 4.4**: TOSD 4; from fire detection to read information type

Teamwork in this TOSD 4 begins with the observer that must send the information of the building on fire to the dispatcher. We already outlined that the observer must provide timely information about the detected and identified fires to the dispatcher (see TOSD 2). In this case, the knowledge needed to provide this information is slightly different. Instead of knowing that the dispatcher uses information of the fires to (re)allocate units, the observer must know that the dispatcher also uses this knowledge to predict the building type. This may seem look unimportant because the information of fires will be sent anyhow. However, because this is the last fire of a pattern and there are insufficient units to extinguish this fire anyway, the observer might think that the dispatcher does not need this information. To ensure that this information will be sent, it is important that the observer knows that the information of the last fire of a pattern is important for the dispatcher to predict the building type, and hence the number of units that need to be withdrawn from other buildings. To provide this information in time and without requests by the dispatcher (i.e., implicit coordination), the observer needs procedural knowledge about
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when in the dispatcher’s task sequence this information must be provided (Period 7). The instruction provides the observer with general information that describes that the dispatcher is responsible for the timely withdrawal of units.

Table 4.4: Cognitive tasks versus critical decisions and knowledge needed for predict building type, and send and read information

<table>
<thead>
<tr>
<th>Task</th>
<th>Cognitive tasks/ critical decisions</th>
<th>Knowledge</th>
</tr>
</thead>
</table>
| 4.4.A  Send information (observer) | • Decide that the information of the building on fire is needed by the dispatcher  
• Decide that this information must be send on this time  
• Decide to put information in the outbox window  
• Decide to send information to the dispatcher | • The dispatcher needs information of buildings on fire to determine a pattern in a series of fires  
• The sooner the dispatcher receives this information, the sooner a pattern can be determined  
• Information of fires should be sent within one period  
• Information can be sent using the outbox window  
• Information is sent to the dispatcher by clicking the send button |
| 4.4.B  Read information (dispatcher) | • Decide on reading the message in the inbox  
• Read information about the building | • Messages in the inbox contain information of the observer about new fires |
| 4.4.C  Predict building type (observer and dispatcher) | • Decide that there is a pattern in the fires of small buildings  
• Determine the building types of the small fires in the same sector  
• Determine the type of building that is expected to be set on fire | • A series of three fires in small buildings in one sector forms a pattern  
• Different sequences of building types in a series of three fires in small buildings determine the fire in a large building:  
• The pattern: “apartment building-house-house” predicts a fire in a factory  
• The pattern: “apartment building-apartment building-house” predicts a fire in a factory  
• The pattern: “apartment building-house-apartment building” predicts a fire in a hospital  
• The pattern: “apartment building-apartment building-apartment building” predicts a fire in a hospital |
| 4.4.D  Send information type (dispatcher) | • Decide that the information of the predicted type is important for the observer  
• Decide that this information must be sent at this time  
• Decide to push the building type button | • The observer may need information of the building type to direct his or her search  
The sooner the observer receives this information, the sooner the observer can start the fire search  
When the building type button is pushed, the building in the panel on the observer’s display is highlighted |
| 4.4.E  Read information type (observer) | • Decide on reading the building panel | • Highlighted buildings on the panel, is a message of the dispatcher about his or her prediction of the building type |

Another teamwork task concerns the backup of the observer by the dispatcher with information about the predicted building type. With the help of a button panel, the dispatcher can inform the observer about the building type that is expected to be on fire. When the dispatcher pushes the button that corresponds to the predicted building, this building is highlighted on the display of the observer. The information about the predicted building type is not necessarily needed. The observer is able to predict the building type by him or herself. Nevertheless, the dispatcher can backup the observer by performing this task and providing the information about the expected building type. In other words, this task sequence shows that the dispatcher can perform a teamwork task by backing the observer up. In order to backup, the dispatcher must know that the observer uses the information about the predicted building...
type to direct his or her search. Both the observer and dispatcher are instructed upon the functionality of the button panel and the way to use it. The instruction of the dispatcher describes that the observer uses the information of the type of the large building in danger in order to direct his or her search.

To predict the building type, the observer and the dispatcher need knowledge about the patterns in a series of small fires. Both team members can obtain this knowledge from the instructions that describe the procedural rules of how a large building can be predicted. Teamwork is present in two ways. First, the observer must provide the information of the fire that forms the last part of a pattern. The observer must know that the dispatcher uses this information to predict the building type. Second, the dispatcher can help the observer by providing his or her prediction concerning the building type. To perform this backup behavior, the dispatcher must know that the observer uses the predicted building type to direct his or her search for the expected large fire. For both teamwork tasks, declarative knowledge about each other roles, responsibilities, and tasks is important. Procedural knowledge about when information must be provided is also important.

**Team operational sequence diagram 5**

After predicting the building type, both team members must predict the building sector and time. TOSD 5 depicted in Figure 4.5 represents these tasks. In Table 4.5, the cognitive tasks versus critical decisions and the knowledge needed are described.

![Team operational sequence diagram 5](image)

*Figure 4.5: TOSD 5; from send information type to predict expected time of fire*

The city map on the screen display of the observer contains four sectors. Based on the pattern in the series of fires in the small buildings, each team member can predict in which sector a large building will be set on fire. Declarative knowledge is needed to know that there are patterns in a series of small fires in each scenario. Procedural knowledge is needed to know how the various patterns predict a fire in one of the sectors. The expected time of fire can also be predicted from the pattern. Declarative knowledge is needed to know that when a pattern is completed, the expected fire starts to burn after three periods
Chapter 4: Cognitive team task analysis

(i.e., Period 10). The instructions of both team members explain in detail how the sector, type of building, and time of fire of the large building in danger can be predicted from a series of fires in small buildings.

Table 4.5: Cognitive tasks versus critical decisions and knowledge needed for predict sector and expected time of fire, and send and read information

<table>
<thead>
<tr>
<th>Task</th>
<th>Cognitive tasks/ critical decisions</th>
<th>Knowledge</th>
</tr>
</thead>
</table>
| 4.5.A | Predict sector (observer and dispatcher) | - Determine the number of small buildings on fire in the same sector  
- Determine the sector of the building that is expected to be set on fire | - A series of three fires in small buildings in one sector forms a pattern:  
- A pattern in sector I predicts an expected fire in sector IV  
- A pattern in sector II predicts an expected fire in sector III  
- A pattern in sector III predicts an expected fire in sector II  
- A pattern in sector IV predicts an expected fire in sector I |
| 4.5.B | Send information sector (dispatcher) | - Decide that the information of the predicted sector is important for the observer  
- Decide that this information must be sent at this time  
- Decide to push the building type button | - The observer may need the information of the sector to direct his or her search  
- The sooner the observer receives this information, the sooner the observer can start the fire search  
- When the building sector button is pushed, the sector on the panel on the observer's display is highlighted |
| 4.5.C | Read information sector (observer) | - Decide on reading the building panel | - A highlighted sector on the panel, is a message of the dispatcher about his or her prediction of the sector |
| 4.5.D | Predict expected time of fire (observer and dispatcher) | - Determine in which period the pattern of a series of fires in small buildings is established  
- Add three periods to the period number when a pattern is established | - The expected fire will burn after three periods from the period when the pattern is completed (Period 10) |

Teamwork concerns the information about the predicted sector. As with the building type, the dispatcher can backup the observer with information about the expected sector with the help of a button panel. When the dispatcher pushes the button that corresponds with the predicted sector, this sector is highlighted on the screen display of the observer. Providing the information of the sector serves the same purpose as with the provision of information concerning the building type. Although the observer does not necessarily need this knowledge, the dispatcher can help the observer by providing this information. Again, the dispatcher can perform a teamwork task by backing the observer up. To perform this task, the dispatcher must know that the observer uses the sector information to direct his or her search for the expected large fire. The instruction of the dispatcher describes that the observer uses the information of the sector of the large building in danger to direct his or her search.

To predict the sector, both the observer and the dispatcher need knowledge about the patterns in a series of small fires. TOSD 5 shows that teamwork is present when the dispatcher helps the observer by providing his or her prediction regarding the sector. To engage in this backup behavior, the dispatcher needs to know that the observer uses the sector to direct his or her search for a large building. For this teamwork task, knowledge about each other’s roles, responsibilities, and tasks is important.

Team operational sequence diagram 6

When the observer and the dispatcher have determined the expected type of building and the sector, then the dispatcher must withdraw the units that are currently allocated to other fires. The observer must,
based on the prediction of the building type and sector, start a search for the building that is expected to be on fire. Figure 4.6 shows TOSD 6 of these tasks. In Table 4.6, the cognitive tasks versus critical decisions and the knowledge needed are described.

<table>
<thead>
<tr>
<th>Observer</th>
<th>Dispatcher</th>
<th>System</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table 4.5.D</td>
<td>Predict Expected Time of Fire</td>
<td>Table 4.5.D</td>
<td>Predict Expected Time of Fire</td>
</tr>
<tr>
<td>Table 4.3.A</td>
<td>Fire Watching</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Table 4.6.A</td>
<td>Send Information School K</td>
<td>Table 4.6.B</td>
<td>Read Information School K</td>
</tr>
<tr>
<td>Table 4.3.A</td>
<td>Fire Watching</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Table 4.6.A</td>
<td>Send Information House S</td>
<td>Table 4.6.B</td>
<td>Read Information House S</td>
</tr>
<tr>
<td>Table 4.6.C</td>
<td>(Start) Fire Search</td>
<td>Table 4.2.A</td>
<td>Determine Allocation Amount</td>
</tr>
<tr>
<td>Table 4.6.D</td>
<td>Send Information Building in Danger</td>
<td>Table 4.6.E</td>
<td>Read Information Building in Danger</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Transport 4 Units (Withdrawal)</td>
</tr>
</tbody>
</table>

Figure 4.6: TOSD 6; from predict expected time of fire to read information large building in danger

To find the building that is expected to be on fire or, in other words, in danger, the observer must search by clicking the large buildings in the expected sector that correspond to the expected type. The observer must know that the large building in danger can be found by clicking on the buildings and that clicking on a building yields information that describes whether it is in danger. The instructions describe how the observer can find the large building in danger once a pattern is recognized.
Table 4.6: Cognitive tasks versus critical decisions and knowledge needed for fire search, and send and read information

<table>
<thead>
<tr>
<th>Task</th>
<th>Cognitive tasks/ critical decisions</th>
<th>Knowledge</th>
</tr>
</thead>
</table>
| 4.6.A Send information (observer) | • Decide that this information must be send on this time  
• Decide to put information in the outbox window  
• Decide to send information to the dispatcher | • The sooner the dispatcher receives this information, the sooner units can be withdrawn  
• Information of fires should be sent within one period  
• Information can be sent using the outbox window  
• Information is send to the dispatcher by clicking the send button |
| 4.6.B Read information (dispatcher) | • Decide on reading the message in the inbox  
• Read information about the building | • Messages in the inbox contain information of the observer about fires |
| 4.6.C (Start) Fire search | • Decide on clicking on the predicted large buildings in the predicted sector on the map of the city  
• Read information about the building  
• Determine whether the building is in danger | • A building that is about to be on fire can be found by clicking on the buildings  
• Clicking on a building gives information whether or not a building is about to be on fire ("in danger")  
• A building that is about to be on fire is labeled with "danger" |
| 4.6.D Send information (observer) | • Decide that the information of the large building in danger is needed by the dispatcher  
• Decide that this information must be sent at this time  
• Decide to put information in the outbox window  
• Decide to send information to the dispatcher | • The dispatcher needs information of buildings in danger to decide on the allocation of units  
• The sooner the dispatcher receives this information, the sooner the fire can be extinguished  
• Information of the large building in danger must be provided early in Period 8, because the dispatcher needs time to allocate units  
• Information can be sent using the outbox window  
• Information is sent to the dispatcher by clicking the send button |
| 4.6.E Read information (dispatcher) | • Decide on reading the message in the inbox | • Messages in the inbox contain information of the observer about buildings in danger |

The observer must perform several teamwork tasks in TOSD 6. First, before the observer can start the search for the large building in danger, the observer must inform the dispatcher about the current fires. The dispatcher uses this information to decide on the withdrawal of units. Therefore, the observer must watch the fires and, subsequently, send the information about the fires. Besides procedural knowledge about how to send standardized electronic messages, the observer must know that this information is important for the task of the dispatcher. To provide this information in advance of requests, the observer must also know that it is important to send this information within one period.

The second teamwork task concerns the provision of information about the large building in danger. This is the most crucial teamwork task in the fire-fighting task. The dispatcher can only allocate units in time to a large fire in danger when the dispatcher receives this message from the observer. When the dispatcher does not receive this message, the dispatcher cannot put this information in the message overview window and is, therefore, not able to allocate units. Units are always one period in transit before they are present at a fire. Therefore, to be in time for the large fire (in danger) in Period 10, the dispatcher must allocate units in Period 8. This way, the units are in transit in Period 9 and present in Period 10. This means that the observer must give the information of the large building in danger at least in Period 8. Thus, to provide this information timely and in advance of requests (i.e., implicit coordination), the observer needs to know that this information is needed before Period 8 finishes. More
specifically, the observer must know that the dispatcher uses this information to allocate units and that this activity takes some time. Therefore, the observer must not wait to the end of Period 8. The observer must know that the sooner in Period 8 the information about the large building in danger is provided, the more likely it is that the dispatcher can allocate the units. Note that to make sure that this information is provided in time, the observer must complete his or her task in time. In other words, the observer must tune his or her activities to those of the dispatcher. Declarative knowledge about each other’s roles, responsibilities, and tasks as well as procedural knowledge of when information must be exchanged is, therefore, important for the observer to have. The instructions of the observer are very detailed on this point. It contains explicit information about the importance of this message. Moreover, the instruction includes an example that describes how the observer can be in time with the provision of the crucial information concerning the large building in danger.

TOSD 6 shows that the observer must perform teamwork. The most important teamwork task is the provision of information about the large building in danger in time. Table 4.6 shows that to perform this task, the observer needs declarative knowledge about the dispatcher’s task and procedural knowledge of when information must be provided.

*Team operational sequence diagram 7*

After sending the information of the large building in danger by the observer, the last phase in fire fighting starts. The dispatcher must have sufficient units available and allocate these directly to the large building in danger. It is crucial that this is performed during Period 8. If this is accomplished, the units are in transport during Period 9 and present in Period 10, which is exactly in time. After that, the scenario proceeds relatively calmly. Team members can use the last periods to watch the fires and withdraw units. Sometimes, one or two units can be allocated to a small building that is still on fire. These tasks are shown in TOSD 7 depicted in Figure 4.7. As can been seen in Figure 4.7 these tasks, including the cognitive tasks and critical decisions and knowledge are described previously. Therefore, the cognitive tasks or critical decisions, and the knowledge can also be found in the previous tables.
Figure 4.7: TOSD 7: from fire search to fire watching
So far, we determined the teamwork and the knowledge by examining each TOSD separately. Consequently, we overlooked the teamwork and knowledge needed to handle the complete scenario. For example, teamwork depends on the strategy team members choose to fight fires. If team members choose to save only the large building in danger, the information exchange about the small fires at the beginning of the scenario is not needed any more. In this case, less teamwork is present which may have consequences for the knowledge of the team members. From a normative perspective, team members ought to save as many potential casualties as possible. The best strategy to achieve this goal is to save the first three small buildings at the beginning of the scenario and the large building in danger. To adapt this strategy, both team members need declarative knowledge of what the goal is. Strategic knowledge that includes action plans and priorities is also needed. This is related to teamwork and determines which information must be exchanged. For example, if both team members adapt the strategy to save the first three buildings, the dispatcher does not need to send information about the allocation decision to the observer. Based on the strategic knowledge that describes which buildings will be saved in a scenario, the observer knows which buildings have priority and, therefore, which fires need to be watched. In other words, strategic knowledge is important to develop accurate expectations of the information that is needed to exchange.

4.2.2 Summary and conclusions restricted communication

The purpose of the cognitive team task analyses in this section was to determine normatively a) what teamwork tasks team members have to perform and b) which knowledge team members need to perform the (teamwork) tasks in the fire-fighting task. In the following paragraphs, these subjects will be discussed separately. Subsequently, we outline the relationships between teamwork, knowledge, and performance in the restricted condition of the fire-fighting task.

Teamwork

Team members need to possess three teamwork skills to carry out the fire-fighting task effectively: information exchange, implicit coordination, and backup. These will be discussed in turn.

Information exchange. Team members are interdependent of each other’s information to accomplish the tasks in the fire-fighting task. At several moments in the scenario, it is crucial that information is exchanged. That is, the observer must provide information about the new fires, the changes in the number of units needed, and the large building in danger. Without this information, the dispatcher cannot allocate units and save potential casualties when a building is on fire. The dispatcher must provide information about the allocation decision. The observer uses this information to watch the buildings. Hence, communication in order to exchange the necessary information is an important teamwork task that has to be performed in the fire-fighting task.

Implicit coordination. One of the most important teamwork skills that researchers expect to be influenced by shared mental models is implicit coordination. Implicit coordination is expressed by the communication of team members. That is, team members provide each other the necessary information only (i.e., the information needed to accomplish the tasks). Furthermore, this information is provided in advance of requests and on the time in a teammate’s task sequence when this information is needed. It is expected that team members improve their performance when they coordinate implicitly. Especially in conditions of high time pressure, because in these conditions explicit coordination takes too much time. In the fire-fighting task, team members must perform their tasks under considerable time pressure.
Periods last just 15 seconds, in which tasks have to be performed and information must be exchanged. Moreover, to save the large building in danger, the observer must send the information of that building at least in Period 8. The TOSDs show that the timely exchange of information is important. Hence, we expect that implicit coordination is important teamwork that team members must perform in the firefighting task.

Table 4.7: Communication features when team members coordinate implicitly in general versus during fire fighting

<table>
<thead>
<tr>
<th>General communication features</th>
<th>Communication features during fire fighting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less communication</td>
<td>• Team members do not communicate to coordinate or to strategize</td>
</tr>
<tr>
<td></td>
<td>• Observer does not send messages about buildings that are not burning or in danger</td>
</tr>
<tr>
<td></td>
<td>• Observer does not send messages about a new fire after two or more periods when the fire started</td>
</tr>
<tr>
<td></td>
<td>• Observer does not send the same message more than once</td>
</tr>
<tr>
<td></td>
<td>• Dispatcher does not send the same message more than once</td>
</tr>
<tr>
<td>The exchange of relevant information only</td>
<td>• Observer sends only messages about new fires, changes in units needed, and large building in danger</td>
</tr>
<tr>
<td>The exchange of information in advance of requests</td>
<td>• Both team members send relevant messages in advance of requests</td>
</tr>
<tr>
<td>Less requests</td>
<td>• Both team members send fewer messages with question marks</td>
</tr>
<tr>
<td>In case of requests, answers will be given</td>
<td>• In cases of messages with question marks, both team members give each other the answer</td>
</tr>
<tr>
<td>The exchange of relevant information in time</td>
<td>• Observer sends the relevant information of fires and changes in units needed within one period</td>
</tr>
<tr>
<td></td>
<td>• Observer sends the relevant information of the large building in danger at least in Period 8</td>
</tr>
<tr>
<td></td>
<td>• Dispatcher sends the relevant information about the allocation decision within one period</td>
</tr>
<tr>
<td>In case of requests, answers will be given as soon as possible</td>
<td>• In cases of messages with question marks, both team members give each other the answer as soon as possible</td>
</tr>
</tbody>
</table>

We created Table 4.7 to determine how implicit coordination takes place in the fire-fighting task. This table is based on the communication features when team members coordinate implicitly, which we presented in section 2.3.1 (see Table 2.1). Based on the TOSDs we could specify for each communication feature how implicit coordination should take place in the fire-fighting task. In general, implicit coordination implies that team members exchange only the information needed to accomplish the tasks. In the restricted condition of fire-fighting task, team members can send each other only standardized electronic messages. Therefore, communication to coordinate, strategize, or to optimize task performance otherwise is not possible. However, it is not said that team members cannot exchange irrelevant information. Team members can send each other irrelevant messages when, for example, the observer continuously send messages about the status of fires instead of changes in the units only. Implicit coordination implies that team members refrain from this type of communication because this information is not needed by the dispatcher. Implicit coordination also implies that team members should provide each other with information in advance of requests. Thus, no messages are sent in which team members request each other for information. However, if there are any requests, team members will give each other the answer. Finally, implicit coordination implies that team members provide each other relevant information in time. In the fire-fighting task, this means that team members must exchange information within one period. Especially important is also the message of the observer about the large building in danger. It is crucial that this message is sent before Period 8 finishes. If the observer is not able to send this message in time, the dispatcher cannot allocate units to the large building. In case of requests, team members must give each other the answer as soon as possible.
Backup. The last teamwork task that can be found in the TOSDs is the information of the predicted building type and sector that the dispatcher can give to the observer. This information exchange is not strictly necessary. Observers can predict the building type and sector on their own. However, dispatchers may decide to help their teammate and send this information. This way, the dispatcher can back the observer up. Thus, although not necessarily needed, backup behavior can be considered as teamwork in the fire-fighting task.

In conclusion, the normative analysis of the unrestricted condition shows that teamwork is needed to perform the fire-fighting task successfully. Team members are interdependent of each other and information exchange is needed. Furthermore, because there is considerable time pressure and information must be exchanged before particular moments in the scenario, we expect that implicit coordination is important teamwork needed to perform effectively. Finally, backup behavior may be demonstrated by the dispatcher.

Knowledge

The TOSDs and tables show that team members need a considerable amount of task-related knowledge to accomplish the tasks. Declarative knowledge is needed and includes knowledge about the city, the buildings, and numbers of potential casualties. Procedural knowledge is needed and includes knowledge about sending messages, the allocation of units, and how a large building can be predicted from a pattern. The TOSDs and tables show that each team member has specific knowledge that is not needed by the other team member. For example, the observer needs to know that contours around buildings in the city mean that the building is on fire (red contour), extinguished (green contour), or burned down (black contour). This information is irrelevant for the dispatcher. Hence, several task-related knowledge elements are distributed among team members. In several cases, team members perform similar tasks (such as sending information or predicting sector and building type). Because the knowledge needed to perform these tasks is also similar, team members have several task-related knowledge elements in common. Nevertheless, within the context of shared mental models, this is not what is meant with shared knowledge. Although team members have certain task-related knowledge elements in common, the shared mental model theory asserts that team members must share those elements that improve teamwork.

Based on the TOSDs we concluded that three teamwork tasks are present in the fire-fighting task: information exchange, implicit coordination, and backup behavior. In addition, we determined what knowledge is needed to perform these tasks. In order to determine that the knowledge needed to perform the teamwork tasks in the fire-fighting task is similar to the knowledge from which researchers expect that it is important for shared mental models, we have compared this. In chapter 2 (section 2.3.1), we described four knowledge elements of shared mental models that are expected to be important for teamwork. These elements are equipment knowledge, task knowledge, team interaction knowledge, and knowledge of the characteristics of the team members (Cannon-Bowers et al., 1993). For each of these four elements, we described to what extent this is present in the fire-fighting task and important to perform teamwork:

1. **Equipment knowledge.** In order to perform teamwork in the fire-fighting task, team members must know how to use the standardized electronic message facility. Because the necessary information must be sent using this facility, team members need equipment knowledge about how to put information in the inbox and send it to the teammate.

2. **Task knowledge.** Task knowledge that is important to perform the teamwork in the fire-fighting task comprises knowledge of each other’s tasks. The observer must know that the dispatcher is
responsible for the decisions regarding the allocation and withdrawal of units. The dispatcher must know that the observer is responsible for the assessment of the situation and the search to the large building in danger. Both team members must know the most optimal strategy to save the first two buildings and the large building in danger.

3. **Team interaction knowledge.** In the fire-fighting task, team interaction knowledge is concerned with team members’ informational needs about the status of buildings and the way units are allocated. The observer must know that the dispatcher needs information about the number of units needed when a building starts to burn, changes in the number of units when a fire is about to be extinguished, and series of small buildings (i.e., in order to be able to determine the pattern). The dispatcher must know that the observer needs information about the allocation decision (i.e., the building were units are allocated) and the building type and sector. Most important in the fire-fighting task is that information is exchanged in time. This procedural knowledge concerning the timing of activities and information exchange involves knowledge that information must be exchanged within one period and the sooner information is provided the sooner the teammate can perform his or her tasks. One piece of crucial information that concerns the large building in danger must be timely exchanged by the observer. Therefore, the observer must know that this information must be provided early in Period 8.

4. **Team members’ characteristics.** The knowledge we determined for the fire-fighting task does not include knowledge of the characteristics of the team members. In order to perform the teamwork tasks in the fire-fighting task it is not necessary to know the skills, attitudes, or preferences of the teammate. This type of knowledge can be used by team members to tailor their behavior to their teammate. For example, team members can compensate for each other’s deficiencies or provide information in a manner that is preferred by the teammate. In the fire-fighting task, the tasks and information exchange are fixed such that there is little room to perform such teamwork.

Besides these four knowledge elements, Blickensderfer et al. (2000) asserts that it is also important to have common knowledge of the goal. With respect to the fire-fighting task, team members must know that the goal is to save as many potential casualties as possible. Situation knowledge that concerns knowledge about the elements in the environment outside the team is not needed to perform teamwork in the fire-fighting task. Situation knowledge is especially important to determine strategies cooperatively (Orasanu, 1990, 1993; Stout et al., 1996). Since team members in the restricted condition cannot communicate freely, there is no teamwork involved in determining strategies.

In conclusion, based on the examination of the knowledge with the help of the TOSDs, we believe that to perform teamwork in the fire-fighting task, team members need knowledge that corresponds to the knowledge expected to be important for shared mental models.

Given the knowledge elements defined for the fire-fighting task, what can we conclude about the sharedness of this knowledge? The cognitive team task analysis shows that it is important to have knowledge of each other’s tasks such that team members know what information must be exchanged and when. The question is to what extent this corresponds to the knowledge of that of the teammate. If it is sufficient to know what information must be exchanged when, it is not necessary that team members have this knowledge in common. After all, team members know when to provide the necessary information to their teammates. However, the shared mental model theory also asserts that it is important to know what information team members can expect of their teammates and when. When this is known, team members do not have to ask for information, but can just wait until the information is provided. This argues for commonly held knowledge about the content and timing of the information
exchange. For the sender to know what information must be provided at what time, for the receiver to know what information can be expected at what time. Based on this knowledge team members can attune their information exchange on each other without the need for explicit coordination.

Although it can be argued that commonly held knowledge about the content and timing of the information exchange is important, the question remains whether it is important that team members have knowledge about each other’s tasks. An important argument for having this knowledge is that it gives team members a better understanding of the information exchange that must take place. Team members not only know that information must be exchanged at certain points in time, but also for what reason. Knowledge of each other’s tasks means that team members hold certain task-related elements in common. For example, the observer knows that the dispatcher needs information about new fires to decide on the allocation of units, whereas the dispatcher knows that he or she can decide on the allocation of units. This means that both team members have common knowledge about the dispatcher’s responsibility for the decision to allocate units. Thus, it is important that team members hold the knowledge of each other’s tasks, roles, and responsibilities in common.

In conclusion, many task-related knowledge elements are distributed among team members. Nevertheless, it can be argued that team members should have knowledge in common about the content and timing of the information exchange. Commonly held knowledge of each other’s tasks seems also important, at least to the extent that it helps to develop an understanding of why information must be exchanged and when.

**Knowledge, teamwork, and performance**

Performance is defined in terms of achieving the task goal, which is to save as many potential casualties as possible. The best performance can be obtained when team members save the first two small buildings (e.g., an apartment building and a school) at the beginning of a scenario and the large building in danger (e.g., a factory). To accomplish this, team members must perform their taskwork accurately. Fires have to be detected in time, units must be allocated to fires with the highest priority, location and type of the large building in danger must be predicted well, and units have to be withdrawn and allocated in time to the large building in danger. The TOSDs show that these tasks can only be accomplished when information is accurately exchanged. That is, the information about the new fires, changes in the number of units needed, the large building in danger, and the allocation decision must be sent in time. In other words, performance depends on the teamwork of the team members. A link can also be established between the knowledge of the team members and performance. In the fire-fighting task, performance depends on the timely exchange of crucial pieces of information. Team knowledge is essential to understand when to send what information.

### 4.3 Unrestricted communication

In the previous section, we described the condition in which team members exchange the information needed to accomplish the tasks. It is clear that to perform effectively, information exchange is necessary and, therefore, one of the most important purposes of communication. However, communication may also serve several other purposes. On top of the communication needed to complete the tasks, which we define from now on as information exchange, team members may also communicate to fulfill other teamwork tasks and optimize task performance. In this section, we are interested in how this may take place. Therefore, we formulated three questions. First, what additional teamwork is introduced when team members have the opportunity to communicate unrestrictedly? Second, which knowledge is
needed to perform this teamwork successfully? Third, what knowledge is transferred when team members communicate unrestrictedly and how does this foster the shared mental models of the team members and vice versa? To answer these questions, we first developed, based on the literature, a model in which we defined the teamwork that may take place when teams communicate unrestrictedly. Subsequently, we determined what knowledge is needed to perform this teamwork. Third, we described what knowledge might be transferred when team members communicate unrestrictedly. Finally, we analyzed qualitatively the verbal protocols of the teams that participated in Experiment 5 (see chapter 7). Altogether, this should give a good insight in the relationships between communication, knowledge, and performance in the unrestricted condition of the fire-fighting task.

4.3.1 Unrestricted communication, teamwork, and knowledge

To determine the teamwork, the knowledge needed, and the knowledge transferred when teams communicate unrestrictedly, we developed the model depicted in Figure 4.8. This model can be viewed as a specification of the model in chapter 2 (see section 2.3.3, Figure 2.2) in which the various dimensions and relationships of shared mental models are illustrated. In the model depicted in Figure 4.8 we set aside the possible antecedents of shared mental models and specified the team processes. We included implicit coordination, performance monitoring, evaluation, and determining strategies. As can be seen in Figure 4.8, we hypothesize that shared mental models influence implicit coordination as well as other teamwork (represented by the gray arrows from the shared mental model box into the boxes implicit coordination and teamwork). We also hypothesize that teamwork influences the development of shared mental models (represented by the black arrows from the box performance monitoring and determining strategies to the shared mental model box). In the following paragraphs, the different elements of the model are described in detail.

Implicit coordination

Central in the model is task execution (in our case fire fighting). A task can be decomposed into several subtasks. The completion of one task results in information that is needed for the next task. Because team members are interdependent of each other’s information to complete their own tasks, information exchange between team members is needed. Furthermore, when teams have to perform tasks in dynamic and time-pressured situations, it is expected that this type of information exchange must take place without the need for explicit coordination. Thus, the box on top of the model represents the implicit coordination process that consists of the exchange of information in time, and without deliberations to coordinate or requests for information. This process is normatively described in the previous section with the help of the TOSDs. Team members can coordinate implicitly by exchanging the standardized electronic messages. Dependent on the necessity and timing of the messages and whether the messages are sent in advance of requests, team members coordinate more or less implicitly.
Now we introduce the opportunity to communicate unrestrictedly. Team members can use this opportunity to exchange the necessary information verbally. Note, however, that in the fire-fighting task the necessary information must also be exchanged by using the standardized electronic messages. The opportunity to communicate unrestrictedly may also be used for other purposes. The box at the bottom of the model represents this process and shows which teamwork can be performed when team members have the opportunity to communicate unrestrictedly.

The first teamwork task that team members perform when communicating unrestrictedly is performance monitoring. Performance monitoring is the process in which team members watch each other’s task execution, give information about the own task performance, and give feedback on each other’s tasks execution. This takes place especially during the process of task execution. Observational studies have shown that effective teamwork requires team members to keep track of each other’s task performance and, in turn, give each other feedback about it (McIntyre & Salas, 1995). Such feedback on each other’s tasks can immediately be used to adjust the ongoing task execution. For example, team members may prevent each other from making errors.

Performance monitoring is a form of team self-correction that takes place based on events and performance during task execution. Team-self correction can also occur on the basis of the performance outcome or, when team members are still busy executing tasks, the expected performance outcome (Blickensderfer et al., 1997b). These team self-correction discussions contain two elements. First, team members look back, evaluate their performance, and analyze about the possible causes of the achieved
performance. In our model, this is referred to as evaluation. Second, team members look ahead and communicate about strategies to optimize performance in the future, which we call determining strategies. Blickensderfer et al. (1997b) emphasize the importance of team self-correction in relation to teamwork. That is, team members evaluate and determine strategies to improve their teamwork. For example, team members clarify each other’s tasks, roles, and responsibilities such that they increase their understanding of how to coordinate their actions efficiently and work with each other effectively. This fosters team knowledge in the mental models of team members.

The processes of evaluation and determining strategies can also be applied to the situation. Especially when problems occur or when the situation is novel and contains unexpected features, team members may evaluate their performance in terms of what was different in the situation than usual and to what extent the strategies are still appropriate. Team members interpret the situation cooperatively, provide each other with alternative explanations, employ their expertise, generate and test hypotheses, and offer information that is useful to solve the problems for the next time (Orasanu, 1990, 1993; Stout et al., 1996). Based on studies in a full-mission simulated flight, Orasanu (1990, 1993) concluded that effective teams engaged in more task-oriented communication than less effective teams including the formulation of plans and strategies. Stout et al. (1996) refer to the process of strategizing that includes the communication in which team members clarify, confirm and disseminate information, plans, expectations, roles, procedures, strategies, and future states. Orasanu as well as Stout reason that this type of communication is important for the development and maintenance of up-to-date knowledge and, therefore, improves teamwork and performance.

Knowledge

In the restricted communication condition, team members cannot perform the aforementioned teamwork. Because communication is only possible by exchanging the standardized electronic messages, there is no teamwork present to monitor the performance, evaluate, or determine strategies. When team members have the opportunity to communicate unrestrictedly, however, team members can perform this. It is hypothesized that in order to perform this accurately, team members need shared mental models with knowledge of the team and the situation. In the model depicted in Figure 4.8, the left-sided box and the arrow back into the box teamwork illustrates this hypothesized relationship. When team members have shared mental models of each other’s task, team members are better able to monitor each other’s performance, determine whether it went wrong, and provide feedback on it. Furthermore, shared mental models are important to ensure that team members interpret and evaluate the performance similarly and develop corresponding strategies (Orasanu, 1990, 1993). Especially in novel situations, it is important to preserve an up-to-date shared mental model because it enables team members to interpret the environment in a compatible manner and to take actions that are both accurate and expected by their teammates (Stout et al., 1996).

In order to determine the knowledge needed for performance monitoring, evaluation, and determining strategies in the fire-fighting task we created Table 4.8 and 4.9. In these tables, we determined for each task, the cognitive tasks or critical decisions and the knowledge needed to perform those tasks. This is described for the routine scenarios in Table 4.8 and for the novel scenarios in Table 4.9.
The knowledge needed for performance monitoring is task related. If team members have no opportunity to communicate unrestrictedly, team members can only monitor their own task performance and need, therefore, only task-related knowledge about their own tasks. However, in the condition in which unrestricted communication is possible, team members can also monitor each other's performance. In that case, knowledge is needed of each other's tasks. This includes procedural knowledge of when and how tasks have to be performed. Moreover, strategic knowledge about the teammate's ongoing task execution is needed. Team members must also have common knowledge of the goal and have similar norms of the way fire fighting should take place. This includes procedural knowledge of how and when tasks are performed.
knowledge of when and how tasks must be executed and strategic knowledge of the priorities. With the help of this knowledge team members can monitor each other’s task performance and optimize when needed.

To evaluate the task performance, team members first need to know what the (expected) performance outcome is. When the performance outcome must be predicted, team members must know how the currently allocated units will result in a certain performance outcome. To compare the performance outcome with the desired outcome, team members must know that the goal is to save as many casualties as possible. The next step is to analyze the past scenario. In order to analyze which activities led to good or poor performance, team members must know what good performance is. This includes declarative knowledge about what tasks have to be performed and procedural knowledge of when and how tasks have to be performed in the fire-fighting task. In the unrestricted condition, team members are able to evaluate together. In that case, knowledge is needed about each other’s tasks, roles, and responsibilities such that team members are able to analyze each other’s performance and to determine where it went wrong or well.

To determine strategies, team members need knowledge about where it went wrong or well in the past scenario. Based on this knowledge team members can adjust strategies or develop new ones when necessary. For example, when team members know that it went wrong because the dispatcher was too late with the allocation of units to the large building in danger, team members can think about a strategy to be in time for the next time. Several alternative strategies can be developed that lead to different outcomes. Strategies can be related to teamwork and determine how to exchange information or allocate units. In both cases, it is important that team members have this knowledge in common. Based on this knowledge team members can develop accurate expectations of the information that is needed to exchange. For example, if team members decide to save the large building in danger only, then the dispatcher needs and expects only information about that building. Thus, commonly held knowledge of the strategies ensures that the tasks of the team members are attuned to each other.

In novel scenarios the large fire is set in another sector and in another building than team members would expect based on the pattern in a small series of fires they learned in their training. When teams are confronted with novel scenarios, team members must derive the new patterns. In other words, task optimizing must take place to handle novel situations. Team members must engage in performance monitoring, evaluation, and determining strategies in order to get the new patterns or develop other strategies to handle the situation. In Table 4.9, the cognitive tasks versus critical decisions and the knowledge needed for these tasks in novel situations are described.

Team members need situation knowledge to monitor the performance, evaluate, and determine strategies in novel scenarios. Performance monitoring to determine that the situation is different from usual is not necessarily teamwork. The observer as well as the dispatcher can obtain the information of the patterns from their screen displays. Both team members also have knowledge about the different patterns and how the large building in danger can be predicted from that. Nevertheless, team members can inform each other about the ongoing task performance. For example, the observer can inform the dispatcher that he or she is busy with the fire search and that the large building in danger cannot be found in the expected sector. This might trigger team members to think about the possibility that there are other patterns than the ones learned. For evaluation and determining strategies, situation knowledge is needed that helps team members to determine why it went wrong and what alternative strategies can be employed to reconcile this for the next time. When team members communicate unrestrictedly, strategies can be determined in cooperation. Therefore, team members need shared knowledge of the situation. When both team members have similar knowledge of how the situation developed, team
members are able to give suggestions or generate alternative hypotheses that are appropriate for that situation. For example, if both team members know that the large building in danger could not be found because the pattern in a series of small buildings is changed, team members can give each other suggestions about other possible patterns. Thus, commonly held situation knowledge supports team members in determining strategies.

**Table 4.9:** Cognitive tasks versus critical decisions and knowledge needed for performance monitoring, evaluation, and determining strategies in novel situations

<table>
<thead>
<tr>
<th>Task</th>
<th>Cognitive task/ critical decision</th>
<th>Knowledge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Performance monitoring (observer and dispatcher)</td>
<td>• Determine that the situation is different from the situation of the training</td>
<td>• Patterns of the training scenarios</td>
</tr>
<tr>
<td></td>
<td>• After task performance (between scenarios): read performance (number of casualties saved) and determine whether this can be optimized</td>
<td>• The pattern of the current scenario does not predict the expected sector, building type, or both</td>
</tr>
<tr>
<td></td>
<td>• During task performance: predict the expected performance outcome</td>
<td>• Optimal performance is when three small buildings (at the beginning or the scenario) and the large building in danger are extinguished</td>
</tr>
<tr>
<td></td>
<td>• Compare performance outcome with desired goal</td>
<td>• The way units are currently allocated (e.g., number of units present, building type, time of allocation) will result in a certain performance outcome</td>
</tr>
<tr>
<td></td>
<td>• Cognitive “walkthrough” of the past scenario and determine that performance was decreased because the situation changed compared to the situation team members were trained in</td>
<td>• The goal is to save as many potential casualties as possible</td>
</tr>
<tr>
<td></td>
<td>• Decide that performance can be maintained with adjusted or new strategies</td>
<td>• Training scenarios: different sequences of building types in a series of three fires in small buildings determine the large building in danger</td>
</tr>
<tr>
<td></td>
<td>• Form hypothesis or alternative strategies that might be appropriate for the novel situation faced with</td>
<td>• In novel scenarios the pattern does not predict the threatened building (whereas in the training scenarios the pattern does predict the threatened building)</td>
</tr>
<tr>
<td></td>
<td>• Test hypothesis of alternative strategies by predicting the threatened building based on a alternative pattern</td>
<td>• There are different patterns that determine the large building in danger</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• There are alternative patterns that might determine the threatened fire in a large building</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• The fires in small buildings of the past scenario</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• The sector in which the small buildings were set on fire in the past scenario</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• The building type of the large building in danger of the past scenario</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• The sector of the large building in danger of the past scenario</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• The pattern of the current scenario does not predict the expected sector, building type, or both</td>
</tr>
</tbody>
</table>

In conclusion, when team members have the opportunity to communicate unrestrictedly, additional teamwork tasks, besides the exchange of the necessary information, may be performed. For that purpose, team members need to have team and situation knowledge in common. For performance monitoring, evaluation, and determining strategies it also is important that team members have strategic knowledge. Based on that knowledge team members can adjust their performance and determine strategies "on the fly." When team members have this type of knowledge in common, it is ensured that strategies will be determined for the same situation.

**Knowledge transfer**

In the previous paragraphs, we determined the teamwork tasks and the knowledge needed when teams have the opportunity to communicate unrestrictedly. Here, we determine how the knowledge of the team
members is fostered in a shared mental model by communication. Based on the model presented in Figure 4.8, we classified the communication into six categories. Table 4.10 shows these categories and their definitions. For each category, we determine what knowledge we expect that will be transferred between team members.

Table 4.10: Unrestricted communication; overview of the categories and their definitions

<table>
<thead>
<tr>
<th>Category</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Information exchange</td>
<td>Necessary information exchange about the status of buildings (i.e., fire, extinguished, burned down), number of units needed, units available, units in transport, the allocation decision, and the large building in danger</td>
</tr>
<tr>
<td>Performance monitoring</td>
<td>Communications about the tasks team members perform during the scenario. That is, explicitly telling each other what one is doing at that moment, giving each other advice what to do, giving each other feedback about each other's performance, and discuss the best course of action on that moment</td>
</tr>
<tr>
<td>Evaluation</td>
<td>Evaluative statements or judgements concerning the tasks of the scenario just played. Analyses of why things went well or wrong at particular times</td>
</tr>
<tr>
<td>Determining strategies</td>
<td>Information that expresses intentions to adjust the way the team should engage in the task, deliberations about alternative strategies, rationalizations of the strategy adopted so far</td>
</tr>
<tr>
<td>Team knowledge</td>
<td>Information about each other's tasks, roles, responsibilities, information dependency, and when and how information must be exchanged</td>
</tr>
<tr>
<td>Situation knowledge</td>
<td>Information about the situation, the pattern or changes in the pattern of a series of small buildings, and the prediction of the large building in danger</td>
</tr>
</tbody>
</table>

*Information exchange* concerns the information that is necessary to accomplish the tasks. This is information about the new fires, the changes in the number of units needed, the large building in danger, and the allocation decision. In the fire-fighting task, this information must be exchanged also with the standardized electronic messages. Communication in this category does not foster the knowledge of the team members in a mental model because no knowledge is transferred among the members.

*Performance monitoring* is communication about the tasks team members perform during task performance. Team members tell each other about the tasks they are performing and how their task execution develops. Furthermore, team members give each other advice, suggestions, or feedback about the best course of action. This type of communication may be especially important to develop specific procedural knowledge of how things work and when activities have to be performed. For example, based on the ongoing task performance, team members may clarify why and when certain information is important to exchange. When applying this example to fire fighting during Period 8, the dispatcher can tell the observer that the message about the building in danger has to be sent immediately, otherwise it is too late to allocate units. This type of performance feedback concerning the ongoing task may refine the knowledge of the team members about when interaction is needed. In other words, general background knowledge (e.g., I have to provide information in time to my teammate) is translated into specific knowledge that can be applied to that task (e.g., I have to provide information about the large building in danger before Period 8 finishes). We expect that, based on this knowledge, team members have better explanations and expectations of the teamwork, which increases performance.

During *evaluation*, team members judge the performance outcome and analyze what and in which way various factors were responsible for that outcome. Team members can evaluate their teamwork and determine, for example, that the necessary information was not provided or provided too late. By analyzing this, team members develop knowledge about when information exchange must take place. Team members may also clarify why it went well or wrong in each other’s tasks, roles, and responsibilities such that team members increase their knowledge about how to coordinate their actions efficiently and work with each other effectively. With respect to the (changing) situation, team members may discover during evaluation that the performance decreased because, due to the changed situation,
their strategies are not suitable any more. By analyzing situational elements, for example the pattern in a series of small fires in the fire-fighting task, team members develop common knowledge of that situation. Thus, evaluating in cooperation gives common knowledge of the teamwork, team strategies, and the role of members herein.

When team members determine strategies, alternative strategies to optimize task performance are discussed. The importance of determining strategies jointly is that team members develop shared team knowledge about the strategies, action plans, and priorities. For example, in the fire-fighting task, team members may develop a strategy to pay attention only to the first three small buildings and the large building in danger. When this strategy is commonly held among the two team members, the observer knows that the only important information to provide is about those buildings, whereas the dispatcher knows that that is the only information he or she can expect. Thus, communication about strategies fosters team members' strategic knowledge in a mental model.

Team members may also exchange information that contributes directly to the development of team and situation knowledge. With respect to team knowledge, team members inform each other about their tasks, timing, and sequences of their tasks. Furthermore, team members tell each other what information is necessary and at what moments. Finally, team members communicate about their own tasks. This type of communication fosters team members' knowledge of each other's tasks, task sequence, and informational needs. With respect to situation knowledge, team members communicate about the elements in the situation, features, and situational changes. This fosters team members' situational knowledge and ensures that team members develop common and up-to-date knowledge of the situation.

4.3.2 Verbal protocol analysis

In the previous section, we described normatively what type of communication is expected when team members communicate unrestrictedly and how this affects team members' knowledge in a mental model. We classified communication into seven categories and described what knowledge may be transferred. In this section, the communication of team members will be analyzed qualitatively. The main purpose is to gain a better insight in the knowledge that is transferred among team members. Furthermore, the analysis must give a better picture of whether the normatively described teamwork and communication actually take place.

The teams that participated in Experiment 5 (see chapter 7) were used for the analysis. These teams had to perform 16 scenarios of Version 2 of the fire-fighting task. The first eight scenarios consisted of routine scenarios and the second eight scenarios consisted of novel scenarios. There were two conditions. In the first condition, teams could communicate verbally during scenarios. In the second condition, teams could communicate verbally during the time between two subsequent scenarios. From these teams, the communication was taped and literally transcribed into verbal protocols. In total, 11 teams that communicated during scenarios (approximately one hour per team) and 11 teams that communicated between scenarios (approximately ten minutes per team) were transcribed. These protocols were then used to determine the type of communication that took place. The verbal protocols presented in this chapter are translated from Dutch.

We examined the verbal protocols in two ways. First, we selected the best performing team of the during and the between condition. For the teams that communicated during scenarios we selected the protocols of four scenarios: the first and the last routine scenario (Scenario 1 and 8), and the first and the last novel scenario (Scenario 9 and 16). For the teams that communicated between scenarios, we selected the protocols of the time after those scenarios (exception was Scenario 16, for which we
selected the protocol between Scenario 15 and 16, also we added the protocol between Scenario 9 and 10. These protocols were subsequently translated, written down, and interpreted in terms of teamwork and knowledge transfer. Second, we examined the verbal protocols of all teams. For each communication category defined in the previous section, we selected several statements that are prototypical examples of that category. Again these statements were translated, written down, and interpreted in terms of teamwork and knowledge transfer. Altogether, this must provide a good insight in the teamwork and type of knowledge that is transferred.

Communication during scenarios

Team 6, routine Scenario 1. After starting the scenario, team members start to communicate (Period 1 to 3):

Observer: Hello?
Dispatcher: Hi!
Observer: I will give you all the information, but I think that it is the easiest to neglect all small buildings
Dispatcher: No, no, not at the beginning of a scenario. I have time to allocate some units, but please do give me all the information. This is particularly convenient to recognize the patterns
Observer: Yeah, right. If apartment buildings are going to be on fire, then there will be a pattern
Dispatcher: Yes
Observer: Thus, if the second apartment building, or it is usually a house, is going to be on fire, then you must not allocate units anymore
Dispatcher: Yes
Observer: Otherwise the units are in transport and we are too late
Dispatcher: No, no, it is possible. I am able to handle the first building and if there comes another apartment building, I will stop
Observer: Exactly, the other two fires cannot be saved because you also have something like a school
Dispatcher: Yes

Team members greet each other and directly begin to discuss the best strategies to fight fires. First, the observer and the dispatcher coordinate explicitly to agree upon which information is important to exchange. Second, team members jointly determine a strategy for the allocation of units. There is discussion whether units must be allocated to the small buildings at the beginning of a scenario. This indicates that both team members know that the most important building to save is the large building at the end of a scenario. Based on these commonly held expectations of how the scenario will develop (situation knowledge) team members discuss the best strategy. Knowledge is transferred concerning the pattern (“if apartment buildings are going to be on fire, then there will be a pattern”), the timing of tasks (“otherwise the units are in transport and we are too late”), and possible future fires (“you also have something like a school”). All these knowledge elements are important to determine the best strategy for allocating units. Team members continue to communicate (Period 4 to 6):

Observer: Such as the school that is on fire now!
Dispatcher: Yes, units are on their way and units are present at the apartment building
Dispatcher: I don’t know what you see
Observer: I see when fires start, now the second apartment building is started
Dispatcher: Yes
Observer: Thus, in a moment it will be a ...
Dispatcher: Yes
Observer: Now we get a house or an apartment building, and then we know what the large building is
Dispatcher: No units will be allocated
Observer: Usually, we have four periods, so we can be there on time

At this point in the scenario, a school is on fire. The observer gives information about the school and the apartment building, which also can be sent by the standardized electronic messages. Note that, to be able to allocate units, this information must also be sent electronically. Apparently, the observer feels the
need to exchange this information verbally as well. The dispatcher responds to this information by informing the observer how many units are in transport and present at a building. This type of communication allows the observer to monitor the performance of the dispatcher. Because the pattern in a series of small buildings is almost complete, the observer begins to predict what the building type will be. Knowledge is transferred about the timing of tasks ("usually, we have four periods") which emphasizes the importance of being in time for the large building. From the seventh period, the team members must predict the building type and the sector of the large building in danger (Period 7):

Observer: Well, I think it will be a factory
Dispatcher: Yes? Are you sure, is there a house on fire?
Observer: Yes, I found the factory, here it comes
Dispatcher: Yeah, right. Back and back
Observer: By the way, you might save the school also
Dispatcher: Yes, that might be possible. Units are on their way to the factory. That is, several units depart now, and one will be departing later

The observer informs the dispatcher about the predicted fire. In turn, the dispatcher checks whether the observer is confident about it. The observer gives advice (i.e., performance monitoring) about the school. Finally, the dispatcher gives information about how the units to the factory are allocated. This allows the observer to monitor the allocation and determine whether this goes right. Note that the observer is also interested in the task of the dispatcher and takes the initiative to think of the best way to allocate units. From Period 8 to the end of the scenario team members must handle the present fires, watch the number of units, and withdraw units when necessary (Period 8 to 12):

Dispatcher: How many units are there needed for the school, still two?
Observer: Yes, still two units
Observer: Yes, now one unit!
Dispatcher: Okay
Observer: And now zero
Dispatcher: In that case, I am able to...
Observer: Factory needs four units
Dispatcher: I can do something with the house. Oh, to I will never make it in time
Observer: Yeah, it costs tree periods before the units will arrive
Observer: Yes, the factory is..., and there goes an apartment building. School is saved

Information exchange takes place about the number of units needed for the school and the factory. The dispatcher is thinking aloud about the decision what to do with the house. The observer transfers knowledge about the number of periods that is needed before units arrive. This emphasis on the timing of events and activities may foster team members’ procedural knowledge.

**Team 6, routine Scenario 8.** After a short break (about 30 seconds) between two scenarios (the headsets were switched off during the break) team members start to communicate (Period 1 to 4):

Dispatcher: Hello?
Observer: Hello, what was the score? I didn’t pay attention to it
Dispatcher: 178 out of 624 or something like that
Observer: Hmmm...
Dispatcher: Yeah, right. It was the school that was still on fire
Observer: Yes, that’s right
Dispatcher: Still nothing?
Observer: Here it comes, an apartment building
Dispatcher: An apartment building. It was really annoying that, because it was just in time before the clock resets. I wanted to correct and then I was just too late and two units went back and forth for nothing
Observer: Oh, that is annoying indeed
Dispatcher: So I had to withdraw units from the school, otherwise I was too late for the factory
Team members evaluate the performance outcome and analyze where it went wrong in the scenario. According to them, the school caused the relatively high number of potential casualties. The dispatcher informs the observer in detail why it went wrong and emphasizes the importance to be on time. Again, this may be important for team members’ procedural knowledge. The scenario continues (Period 5 to 10):

Observer: Another apartment building
Dispatcher: Okay, I do nothing about it. It is in another sector isn’t it?
Observer: Yes, it is in another sector. Don’t do anything about it
Dispatcher: Okay, I won’t. I don’t make it anyway
Observer: Another one in sector I. It is jumping around
Dispatcher: I wonder, is it still the right pattern?
Observer: Yes, I think so, because here I have a house. There is something coming up, I believe
Dispatcher: Still no factory in sector IV?
Observer: It is a factory
Dispatcher: I though so
Observer: In Period 10, you will manage that easily
Dispatcher: Yes, units will be on their way in a moment, what about the apartment building of the beginning?
Observer: Still two needed
Dispatcher: Still two
Observer: Indeed, still two
Dispatcher: As soon as that becomes one, it is possible to save a house
Observer: It is one now
Dispatcher: The factory, units are present now
Observer: That’s great. Even one period too early

Team members communicate mainly about the ongoing situation and the best way to allocate units. At several times, the importance to be on time is highlighted (“in Period 10, you can manage that easily” and “even one period too early”). These cues may sharpen team members’ procedural knowledge about when tasks (and thus information exchange) must be completed. In the last periods, the team members are examining the possibility to save a small building (Period 11 to 12):

Observer: Apartment building is burned down and another one is repaired
Dispatcher: Yes, I can see that
Observer: Send the units to another apartment building
Dispatcher: Yes
Observer: There is still one
Dispatcher: Yes, actually I had two available, but one was just...
Observer: Oh, the apartment building is also burned down
Dispatcher: Which one? Okay, then I can pull back units
Observer: There are only a couple of houses
Dispatcher: Well then I sent units over there. Are there extra houses left?
Observer: No, there are no new fires, it will be too late anyway. It doesn’t matter anymore
Dispatcher: Okay, I am busy saving a house and a factory, so...
Observer: Well, it doesn’t matter anymore
Dispatcher: How many units are there needed by the factory?

Because there is too little time (two periods) to allocate units, the effort of the team members to save a small building is not successful. Team members realize that and the dispatcher checks the balance (“I am busy saving a house and a factory”). These attempts to save as many buildings as possible give team members a good understanding of the best strategy possible.

When compared to Scenario 1, less knowledge is transferred about how to exchange information. There are also fewer discussions about how to save buildings in general. Instead, the communication is more aimed at the present performance and the best way to handle particular moments. In Scenario 8, team members are mainly busy with monitoring the performance and giving each other suggestions about
how to act. In the following protocols, team members are confronted with novel scenarios in which the pattern in a series of small buildings does not predict the large building in danger as usual.

**Team 6, novel Scenario 9.** After the scenario starts, team members first begin to evaluate the past scenario (Period 2 and 3):

Observer: Well, it is directly a house again, I see  
Dispatcher: Yes, the past scenario shows that if we are in time at the factory in Period 10, you get about 80 casualties  
Observer: Yes, exactly  
Dispatcher: Or something like that uh...  
Observer: So we can do better?  
Dispatcher: Maybe

The importance to be on time in Period 10 is highlighted. Nevertheless, team members do not go beyond that and determine, for example, the best way to achieve that. The scenario continues (Period 4 to 5):

Observer: A school  
Dispatcher: A school  
Observer: It is in sector II  
Dispatcher: Well, what shall I say, it is not important  
Observer: Apartment building in sector III  
Dispatcher: I don't do anything about that  
Observer: And the house?  
Dispatcher: No, there is a unit present, but I can pull it back in time and save the house  
Dispatcher: If it is necessary, otherwise I leave it that way

The observer gives the dispatcher the necessary information. In turn, the dispatcher keeps the observer informed about the allocation of units. From Period 6, the search to the large building in danger can start (Period 6 to 8):

Observer: Second apartment building, same sector, thus it will be a...  
Dispatcher: Another apartment building, okay  
Observer: And, again another apartment building  
Dispatcher: yes  
Observer: Let's see, it will be a factory again  
Dispatcher: Okay, which sector?  
Observer: Ooh, it is not in the right sector  
Dispatcher: Oh?  
Observer: Ah, I found it, it is in sector IV now  
Dispatcher: Yes, sometimes it is different

As usual, team members start to predict the expected building type and location. The observer soon finds out that the predicted location is not correct and informs the dispatcher about that. Thus, strategic knowledge of the situation is transferred. From now on, both team members know that patterns do not necessarily predict the expected sector. The observer is very lucky. By chance, the large building is found in danger in another sector. The observer informs the dispatcher about the sector. Both team members not only know that the pattern is changed, but also which sector it was this time. This common situation knowledge can be used to determine the new pattern jointly. Now team members are able to respond to the large building in danger (Period 7 to 8):

Dispatcher: Can I pull back the unit from the house?  
Observer: Well, you have to  
Observer: Thus, that is very annoying, normally as the pattern develops in III then it is a factory in II, but this time not  
Dispatcher: Indeed
Team members start reallocating units and the observer again emphasizes the fact that the pattern was not correct. Probably because it is very busy in these periods, team members do not go a step further and determine what the new pattern is. The reallocation of units has the highest priority now (Period 8 to 12):

Dispatcher: Can I pull back one unit from the school?
Observer: yes, you can do that immediately
Dispatcher: I have three units ready
Observer: Yes, you can withdraw, yes
Dispatcher: Yes
Observer: But you have to do it right away
Dispatcher: Yes
Observer: The factory is of higher value
Dispatcher: Hmmm...
Dispatcher: Yes, but it is one round later than usual
Observer: School needs only one unit now
Dispatcher: Okay. Is the house burned down? It probably is
Observer: Yes and the school is saved
Dispatcher: Okay
Observer: Apartment building down
Dispatcher: Which apartment buildings are still out there? T and H?
Observer: Only H.
Dispatcher: Okay, I send some units to that
Observer: H is gone too
Dispatcher: Ah

In the last periods, the communication is mainly about the units needed by the present burning buildings. First, to determine where the dispatcher could pull back the units most effectively, second, to determine which small buildings could be saved at last.

**Team 6, novel Scenario 16.** Scenario 16 is the last scenario team members have to perform. Team members have received eight novel scenarios. When teams were able to grasp the new pattern, the novelty should be gone by now. Team members again start to evaluate the past scenario (Period 1 to 3):

Dispatcher: Again 80
Observer: A school is on fire
Dispatcher: Yes, that one we gonna save
Observer: But, indeed again 80, yes
Dispatcher: Just give me all fires, also the apartment buildings
Observer: Nothing is happening now
Dispatcher: I was thinking, maybe we can leave the units one period longer so that we can get less than 80 casualties
Observer: Hmmm...
Dispatcher: Well, it is just a idea, maybe it won’t work

Although performing the last scenario, team members are still discussing alternative strategies to optimize task performance. This time, the dispatcher considers the possibility to wait one period with the withdrawal of units. The pattern in the series of small buildings is now starting (Period 4 to 7):

Observer: School still needs three units
Observer: Still three, and an apartment building starts
Dispatcher: Still three for the school?
Observer: Yes
Observer: Now a second apartment building, the pattern is beginning
Dispatcher: Yes
Observer: So, hold on
Dispatcher: And the school, still three?
Observer: No, two units now
Dispatcher: In that case, I pull one back
Observer: Watch, another apartment building, now we can search for the hospital
Dispatcher: And the school?
Observer: Wait a minute, I am busy looking for the hospital, that’s more important now
Dispatcher: Yes, yes, yes
Observer: There it is, sector III

The observer attempts to discover the pattern. It is likely that the observer knows by now what the new pattern is. Otherwise, it would be fruitless to put effort in predicting the building type and sector. The observer manages to be on time with finding the large building in danger. In the meanwhile the dispatcher wants to know exactly the number of units needed for the school in order to withdraw as soon as possible. The dispatcher’s request for information is disturbing. The observer gives her a reprimand that the search for the hospital is more important now. The dispatcher has to wait.

In conclusion, team members use their opportunity to communicate unrestrictedly during task execution to optimize task performance. Team members monitor their performance, evaluate, determine strategies, and transfer knowledge about the team and the situation. The communication is several times very precise with respect to the timing of events and actions. We think that communicating unrestrictedly during the scenarios helps team members to develop specific knowledge of the team and the situation.

Communication between scenarios

Team 16, between routine Scenario 1 and 2. Team members just accomplished the first scenario. The headsets are switched on and the team members start to communicate immediately:

Observer: Hello?
Dispatcher: Hi
Observer: If it is possible, I would like to receive information about when the units are present
Observer: And, if there are too many fires to extinguish, we just have to prioritize, I think
Dispatcher: Yes, I don’t allocate units to houses anyway
Observer: No, not even at the beginning?
Dispatcher: No, there are only two buildings, and the units are gone, and it takes four periods to allocate them and then pull back
Observer: Okay, that’s right
Dispatcher: It’s only two humans
Observer: Yes
Dispatcher: However, they’re still humans, of course
Observer: Yes. But what about an apartment building, do you allocate units to that?
Dispatcher: Yes, an apartment building surely, because that’s ten
Observer: Exactly
Dispatcher: However, giving messages to you is sometimes difficult, because it happens all so fast, so…
Observer: Okay, I understand
Dispatcher: But, I will see to it

The observer directly starts to inform the dispatcher about the information she would like to receive. Later the dispatcher responds to her request and makes clear that it is difficult to give this information. In this type of communication, team members clarify each other’s informational needs and tasks that may give a better understanding of why interactions are needed. The observer and the dispatcher jointly determine the best strategy to fight fires. Knowledge is transferred about the number of periods needed to allocate and withdraw units. Team members continue to communicate:

Observer: Okay, when a fire is extinguished, then it becomes green on my screen
Dispatcher: Hmmm…
Observer: Then I send you the message immediately. It is possible, however, that you get a lot of messages at once
Observer: I also check continuously whether a building still needs units, and if it is extinguished, then the number of units is zero I assume?
Dispatcher: Hmmm…
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Here, the observer informs the dispatcher about her task. This task-related information gives the dispatcher insight in the information that can be expected. Moreover, the dispatcher can verify the observer’s knowledge about how fires develop and units that are dependent on that. Based on this, the dispatcher asserts that the number of units count down. This information makes the observer realize that it is important to check the fires regularly to determine the number of units needed. Team knowledge is further transferred when the dispatcher makes clear which information she needs. Based on this knowledge, team members can coordinate implicitly for the next time.

Team 17, between routine Scenario 8 and novel Scenario 9. By now, team members have performed eight routine scenarios:

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Observer: Okay, I think we have the best score possible
Dispatcher: Yes, I do too
Observer: Well, maybe we could save the second apartment building too. Two units are needed there
Dispatcher: There were two units allocated to that building
Observer: Oh, is it? Maybe it is still burning?
Dispatcher: Yes maybe
Observer: But, you had four units for the factory, so that leaves us with two for the apartment building
Dispatcher: No, there were four units in the station
Observer: If the station? Oh, and you had sent only two units away?
Dispatcher: No, I had sent them right away and they were exactly on time, I think
Observer: Okay, that’s good. So at first, you had only one unit allocated to the apartment building?
Dispatcher: Indeed, that’s why it went wrong, I think I was just one period too late. Just like the other times.
Observer: Yes, yes, yes

Team members evaluate the performance of the past scenario in detail. The observer forces the dispatcher to rethink the way units were allocated in order to determine why the apartment building was not saved. Team members continue to evaluate:

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Dispatcher: I did that to be on time for the factory or the hospital
Observer: Yes
Dispatcher: So, maybe, but I am not sure, I don’t know how many periods we have
Observer: Well, three periods should be enough
Dispatcher: Hmmm, but that depends on how soon you inform me
Observer: Yes
Dispatcher: I mean, when it is just in the last three seconds...
Observer: Of a period
Dispatcher: Yes, of a period, then...
Observer: You are not able to respond on time
Dispatcher: Indeed
Observer: Okay, now we gonna save a lot of people

The outcome of the evaluation is that the second apartment building can be saved when both units are present one period earlier. The observer transfers knowledge about the number of periods needed to allocate units to the large building. Finally, team members discuss the consequences of their new
strategy in terms of the communication needed. This gives the observer very detailed knowledge about the fact that information must be provided as soon as possible within a period ("when it is just in the last three seconds").

**Team 17, between novel Scenario 9 and 10.** Scenario 9 is the first novel scenario team members perform:

Observer: That was the same score as before  
Dispatcher: Yes  
Observer: Our score is relatively constant  
Dispatcher: Yes, that's true  
Observer: Well I think we talked everything through  
Dispatcher: Yes, I do too  
Observer: I think we have a half an hour to go  
Dispatcher: So, that means more casualties  
Observer: That's for sure. Because a scenario lasts, what is it? About five minutes? Than we have six scenarios to go  
Dispatcher: Yes, so that will be about 680 casualties  
Observer: Well say 480 to, maybe we will get a disaster scenario, 700 casualties in total, I hope  
Dispatcher: I do too  
Observer: Then I'm happy  
Dispatcher: Me too  
Observer: Yes  
Dispatcher: But also a little sad, because as a feeling person you cannot push it all away  
Observer: Indeed not entirely, even though they are all virtual human beings  
Dispatcher: Virtual human beings are also human beings  
Observer: In a virtual world  
Dispatcher: It's what you want to believe, isn't it?

Surprisingly, team members do not communicate about the fact that the pattern in a series of small buildings was incorrect. Probably the observer found the factory by chance and did not pay further attention to it. The communication is further confined to a brief evaluative statement about the score. Subsequently, team members communicate, less seriously, about the scenarios to go. With respect to the first scenario, no knowledge is transferred or strategies are determined. It seems that team members communicate to fill the spare time.

**Team 17, between novel Scenario 10 and 11.** Because team members did not pay attention to the novel scenario whatsoever, we analyzed also the protocol from the time between Scenario 10 and 11. Now team members have been confronted for the second time with a novel scenario:

Observer: With a little more luck we could save the apartment building also  
Dispatcher: Yes, or at least half, but it is still guessing, isn't?  
Observer: Indeed, for me too, because the pattern predicted another sector  
Dispatcher: Hmmm...  
Observer: So I had to search where the large building was  
Dispatcher: Yes  
Observer: I had to watch all the buildings to find out where the building in danger was  
Dispatcher: How do you search?  
Observer: Well, usually you have, for example, a pattern in sector I and then you can predict that it comes in sector IV  
Dispatcher: Yes  
Observer: But now I was clicking on the buildings in sector IV and this time there was no building with a message in danger  
Dispatcher: Hmmm...

This time the team members have discovered that the pattern is incorrect. While evaluating, the observer tells the dispatcher that the fire search is difficult because the pattern does not predict the sector as expected. Meanwhile, the dispatcher is also informed about how the observer performs the fire search.
Hence, information of each other's task is exchanged. Knowledge about the learned pattern is also transferred. Team members continue to communicate about the pattern:

Observer: So I had to click all the buildings in the map to find the large building in danger
Dispatcher: Yes
Observer: Therefore, I was somewhat late with the message
Dispatcher: But, in general, the pattern is correct?
Observer: No, the past two times not. I think the scenarios become more difficult now
Dispatcher: Hmm... but the pattern still predicts the expected building type
Observer: For now, yes. So an apartment building and two houses predicts a factory, such as in the last scenario
Dispatcher: An apartment building and two houses?
Observer: First an apartment building, then a house, and then another house
Dispatcher: Yes
Observer: And then a factory is on fire

The observer explains why the message of the building in danger was sent too late. Common knowledge is developed about the situation. Both team members are now aware that the pattern in a series of small fires has changed. Subsequently, the dispatcher wants to know exactly what elements of the pattern have changed. The dispatcher is especially interested in whether the pattern still predicts the large building in danger as usual. This is important for the dispatcher's task execution, because this information is needed to decide on the withdrawal of units in Period 7. However, because the focus is on how the pattern predicts the building type, team members have no time to determine how the new pattern predicts the sector.

**Team 17, between novel Scenario 15 and 16.** The time between Scenario 15 and 16 is the last time that team members communicate unrestrictedly with each other:

Observer: That's disappointing
Dispatcher: Only one period too late and then...
Observer: Did you pull one unit back from that apartment building?
Dispatcher: Yes
Observer: That wasn't necessary
Dispatcher: If it was a hospital, then it was
Observer: Yes, but I had told you that it was going to be a factory?
Dispatcher: Yes, but I wanted to react on the developments
Observer: Yes, yes
Dispatcher: But when I heard that it was a factory, I put it right back
Observer: Yeah, great
Dispatcher: That wasn't of any use, I think
Observer: No. because it was saved anyway
Dispatcher: Okay
Observer: So we saved another ten

First, team members judge their performance and, subsequently, analyze where it went wrong. The way units were allocated is discussed in detail. Knowledge is transferred about the numbers of casualties associated with an apartment building ("we saved another ten"). Team members continue to communicate:

Dispatcher: Well I expect a bouquet
Observer: At least
Dispatcher: So, this was not the last time
Observer: No, apparently not
Dispatcher: Maybe, this evaluating conversation is also important
Observer: Yes, they need that on tape also
Dispatcher: I don't think we have said anything interesting
Observer: I don't think so either
Dispatcher: Well, say something crucial
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Observer: It is going outstanding
Dispatcher: So his thesis will be more thicker
Observer: Yes, exactly
Dispatcher: I can say something Malaysian, so that they have to consult all sorts of dictionaries
Observer: Okay, go on
Dispatcher: (...)
Observer: (...)
Dispatcher: There comes another round
Observer: Yes!

Because team members arrive at the last scenario, there is probably nothing more to say or to evaluate. The time left between scenarios is filled with social communication. Team members make jokes and talk about one thing and another.

In conclusion, team members use their opportunity to communicate between scenarios to evaluate and determine strategies. With respect to the communication during scenarios, team members communicate less about the specific periods when events take place and activities have to be performed.

Examples of verbal protocols

We now turn to some selected examples from protocols to illustrate the communication categories.

Information exchange. Team members often inform each other verbally about the status of fires (Team 5, Scenario 1, Period 10):

Observer: School is free, an apartment building is burned down, and another apartment building is almost extinguished
Dispatcher: Okay

The dispatcher may inform the observer about the allocation decision (Team 11, Scenario 3, Period 8):

Dispatcher: I sent five units to the hospital

The dispatcher may also inform the observer about the number of units present at the station (Team 1, Scenario 9, Period 10):

Dispatcher: Unfortunately, I have only two units available

Performance monitoring. Performance monitoring is communication about the tasks team members perform during the scenario. It occurs when team members inform each other about what they are doing at particular moments (Team 3, Scenario 15, Period 3):

Observer: Okay, here is apartment building M
Dispatcher: Right, I send two units

This type of communication allows team members to watch each other’s task performance. For example, when the dispatcher made a wrong decision by sending two units to the apartment building, the observer is now able to verify this. In case of mistakes, the observer can give feedback and tell the dispatcher the right number of units needed to extinguish the fire. In the following example, the observer corrects the dispatcher (Team 9, Scenario 3, Period 5 and 6):

Observer: Did you send one unit to that house?
Dispatcher: Yes, I did
Observer: Well, maybe it is better if you pull back ... because there comes another apartment building in IV
Dispatcher: Okay, I pull one unit back
Observer: Otherwise it becomes a mess
By informing each other about the present activities, team members may also determine the best course of action during task performance (Team 5, Scenario 4, Period 8):

Observer: Let's see
Dispatcher: We are still able to save two houses
Observer: Yes, one house is going to need more units
Dispatcher: Oh
Observer: We cannot save that one, but house Q maybe, and the apartment buildings, F maybe?

One of the team knowledge elements important in shared mental models is knowledge about the sequence and timing in activities. In the fire-fighting task, it is crucial that information about the building in danger is exchanged before Period 8 finishes so that the dispatcher has enough time to (re)allocate units. During performance monitoring, team members can transfer knowledge about the sequence and timing of actions, which may refine the knowledge of the team members. In the following example, the dispatcher informs the observer about the number of periods that is needed to allocate units in time (Team 5, Scenario 13, Period 8):

Dispatcher: Units are on their way to the large building in eight, in Period 9 they're present
Observer: That's one period too late
Dispatcher: Huh?
Observer: That's one period too late, because in Period 10 the building starts to burn
Dispatcher: No, in Period 9 they're present, just in time
Observer: Yes? Okay.
Dispatcher: Yes

The observer may also inform the dispatcher about her search for the large fire in danger (Team 3, Scenario 14, Period 7 to 8):

Observer: I am going to look for the hospital. Well, the pattern is not right. I am always looking in the wrong sector
Dispatcher: Yes, we are being misled

When the observer informs the dispatcher that the large building in danger cannot be found, this is a sign that the team may be confronted with a novel situation. This is important when team members are going to evaluate their task performance. Based on this situational knowledge, team members can track down that the performance decrease was due to the incorrect pattern in a series of small fires. Another example is (Team 2, Scenario 8, Period 9):

Dispatcher: Okay, we are in trouble. We are now in Period 9 and there is still no large building
Observer: Well, then there will be a big thing in a minute
Dispatcher: Do you think?
Observer: You can count on it

Here the dispatcher realizes that there is still no large building. By informing the observer, he receives feedback that things must be sped up to be on time. The dispatcher also mentions Period 9, which may refine the knowledge of the observer about the period that information about the large building must be exchanged (i.e., at least in Period 8).

**Evaluation.** In the during condition, evaluation occurs typically at the beginning of a scenario when the workload in the fire-fighting task is relatively low (Team 5, Scenario 14, Period 1):

Dispatcher: This one went great. What do you think?
Observer: Yes, indeed
Dispatcher: Yes
Observer: Not bad at all
Dispatcher: I think we must keep going on like this
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Observer: Thus, first saving one or two small buildings and then...
Dispatcher: Yes, but the house, wasn't that burned down yet?
Observer: No, I don't think so

This example shows that team members first give a judgement of the past scenario. Subsequently, team members analyze in more detail specific moments of the scenario. Team members also establish the best strategy ("thus, first saving one or two small buildings"). This gives members a common understanding of the strategy. Another example of evaluation is (Team 1, Scenario 2, Period 2 to 3):

Dispatcher: That were a lot of casualties
Observer: Yes, that was because we didn't pay attention to the pattern
Dispatcher: No, that's not the point. I was too late for the factory
Observer: Yes, indeed, but it was my mistake that I was too late with searching the large building. I didn't pay attention to it. Next time, I will
Dispatcher: Yes, that is very important

Here, team members clarify their roles and responsibilities. The conclusion is that the poor performance was due to the observer's fault to be too late with sending the message about the large building in danger that caused the dispatcher to be too late with allocating units. This emphasizes the interdependency of the members and the importance to provide information on time. Hence, team knowledge of each other's informational needs is developed. In the between condition, team members do not have to perform fire-fighting tasks, so they can spend their time solely to evaluate. In the following example, team members tell each other what went wrong in the past scenario (Team 19, between Scenario 1 and 2):

Dispatcher: It's difficult. Well we shall see how we are going to do it
Observer: Yes, this was the just the first one
Dispatcher: Yes
Observer: I had to search for the factory
Dispatcher: Yes
Observer: But I lost the factory
Dispatcher: I didn't recognize a pattern yet
Observer: I had it quickly. However, it took a while to find the factory

When team members evaluate a novel scenario, they can track down that the pattern in a series of small buildings is incorrect (Team 16, between Scenario 10 and 11):

Observer: The sector was different from what you expected
Dispatcher: Oh...
Observer: It was in sector II and not in sector I
Dispatcher: Yes, I cannot see that always
Observer: That's why it went wrong. The pattern wasn't right, so...

This type of communication makes team members aware of the fact that they may have encountered a novel situation. Based on this knowledge, team members can determine the new pattern together.

Determining strategies. Team members may inform each other about the best strategy in general (Team 5, Scenario 2, Period 10):

Dispatcher: We have to take care that we find the pattern as soon as possible so that we can send very quickly units to the large building, because I just have only six units
Observer: Okay

Here, the dispatcher's strategy is to perform the activities as soon as possible, which emphasizes that the large building in danger must be found directly when the pattern is recognized. Based on this knowledge, the observer may be more aware that the fire search must begin as soon as possible. In novel
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scenarios, it is important that team members determine the new patterns in a series of small buildings. In the following example, team members cooperatively determine the new pattern (Team 6, Scenario 15, Period 6 to 7):

Observer: Well, there is again a house in sector I. I hope that if another thing is gonna burn in sector I, soon a factory will be in danger in sector III. Otherwise I have to search again all the large buildings on the map.
Dispatcher: Thus, the new pattern is that it is gonna be a fire above or below the sector with the pattern?
Observer: Yes, I think so
Dispatcher: Let's hope so
Observer: Yes
Dispatcher: Great, give it to me quickly

The observer expresses his or her expectation of the sector in which the large building in danger will be on fire. The dispatcher generalizes this such that it can be applied to other scenarios as well. In other words, an alternative pattern is hypothesized that can be tested. Somewhat later, the observer finds the large building in the sector that was expected based on team members' alternative pattern. This confirms team members' hypothesized pattern.

Team knowledge. An important team knowledge element is knowledge of each other's task. In the following example, the observer is informed about the number of periods that the dispatcher needs to allocate units in time (Team 6, Scenario 2, Period 6 to 7):

Observer: Again a hospital in the tenth period. Meaning that the units must on their way by now
Dispatcher: No, in the next period
Observer: No, in this period, because you need three periods before the units are present
Dispatcher: No, when I send units in Period 8, then they are present in Period 10
Observer: Are you sure?
Dispatcher: Yes

The importance of this type of communication is that the observer develops a profound understanding of when tasks of the dispatcher take place. The observer may also develop an understanding of the consequences for his own task execution; to be in time in Period 8, the search after the large building in danger must be finished at least in the middle of Period 8. This way, team members develop detailed procedural knowledge of each other's task sequence. Team members may also inform each other about each other's informational needs (Team 1, Scenario 1, Period 4):

Dispatcher: On the moment that a large building is burning...
Observer: Yes
Dispatcher: Don't give me too much information about apartment buildings, because it gets so unclear
Observer: Yes, I will

The dispatcher explicitly tells the observer when and what information is not needed to provide. Sometimes dispatchers are more direct (Team 6, Scenario 6, Period 9):

Dispatcher: That's why I need to know all those things as soon as possible, at least before Period 8

In the following example, the observer takes the initiative to ask the dispatcher in which way the information must be provided (Team 3, Scenario 12, Period 2 to 3):

Observer: What is better? If I say house A in sector IV or do you want it otherwise?
Dispatcher: You only have to mention house A, I can see the sector number on my screen
Observer: Are you sure?
Dispatcher: Yes
Observer: What kind of display do you have? Don't you have a map of the city, like me?
Another example in which team members develop a common understanding of the way information must be exchanged is (Team 5, Scenario 1, Period 3):

Observer: I shall try to send only messages when something changes in the city
Dispatcher: Yes please
Observer: Because I think you’re gonna get crazy if I send you 10,000 messages
Dispatcher: No, only send me the most important messages
Observer: Even not small houses?
Dispatcher: Yes, but I would like to have the apartment buildings
Observer: Okay

**Situation knowledge.** Situation knowledge includes the exchange of information concerning the pattern or changes in the pattern of small buildings and predictions of the large building in danger (Team 5, Scenario 2, Period 6):

Observer: Yes, I... there will be a pattern soon, because there comes a house in sector III
Dispatcher: Apartment building, house, apartment building
Observer: Indeed

Team members may help each other in predicting the sector of the large building in danger (Team 5, Scenario 3, Period 6):

Observer: ...and now we have a new apartment building in sector IV
Dispatcher: Yes, sector IV, apartment building, apartment building
Observer: Yes
Dispatcher: What do we have here?
Observer: A house, or an apartment building, I guess
Dispatcher: In sector I
Observer: An apartment building, a hospital is coming up

In novel situations, team members must reveal that the pattern in a series of small buildings is incorrect (Team 5, Scenario 9, Period 7):

Observer: It is gonna be a factory
Dispatcher: Fortunately
Observer: Oops, I can’t find it, I think it is in a different sector, now I have to search
Dispatcher: Maybe it is in sector III, the sector besides the one we normally expect
Observer: Yes, indeed
Dispatcher: Thus, when we have a factory or hospital in sector IV, we have to search in sector III

Here, situation knowledge is transferred about the sector.

4.3.3 Summary and conclusions unrestricted communication

The purpose of the cognitive team task analysis of this section was a) to determine what additional teamwork is introduced when team members have the opportunity to communicate unrestrictedly, b) which knowledge is needed to perform this teamwork successfully, and c) what knowledge is transferred when team members communicate unrestrictedly. In the following paragraphs, these subjects will be discussed separately.
When team members have the opportunity to communicate unrestrictedly, several teamwork tasks are introduced. Based on the literature we determined that team members might use their opportunity to communicate unrestrictedly for performance monitoring, evaluation, and determining strategies. Performance monitoring helps team members to adjust the task execution immediately. Team members watch each other's task execution, provide feedback, and give advice to optimize task performance. Observational studies in the military field have shown that good performing teams engage more often in performance monitoring than poor performing teams (McIntyre & Salas, 1995). Blickensderfer et al. (1997b) assert that communication is beneficial for team self-correction. Two important phases can be distinguished in team-self correction discussions. In the one phase, team members look back and evaluate their past performance. In the other, often subsequent phase, team members look ahead and determine strategies to improve performance for the next time. Although the value of this type of discussions is especially described in terms of improving teamwork (e.g., more implicit coordination, and performing activities in sync) it can be argued that such discussions are also important to develop strategies to handle unexpected problems in novel situations. Stout et al. (1996) theorized that this so-called strategizing is especially important in order to develop commonly hold strategies. In flight simulator studies, Orasanu (1990, 1993) showed that teams committed fewer flight errors when the members used the low workload periods to communicate about task strategies and plans. Taken together, these studies assert that unrestricted communication may have a positive effect on performance.

The qualitative analysis of the verbal protocols shows that performance monitoring, evaluation, and determining strategies can be distinguished in the fire-fighting task. Performance monitoring takes place by informing each other about what one is doing during fire fighting. This allows team members to watch each other's performance. For example, when the dispatcher mentions how many units he or she wants to allocate, the observer can verify whether this is the right amount. Team members may also provide each other with feedback or give advice to improve performance further. Evaluation seems to take place typically during the relatively low workload periods in the fire-fighting task. The performance outcome is judged and team members jointly analyze the causes of the good or poor performance. For example, team members conclude that their poor performance is due to the dispatcher who was too late with allocating units. Further evaluation might reveal that this was caused by the observer being too late with sending the message about the large building in danger. Finally, team members determine strategies together. For example, team members determine that the pattern must be recognized as soon as possible or that a series of fires in small buildings forms a new pattern from which the type and sector of the large building in danger can be predicted. In conclusion, based on the examination of the verbal protocols we believe that team members that have the opportunity to communicate without restrictions use this opportunity to monitor each other's performance and jointly evaluate and determine strategies in the fire-fighting task.

Knowledge

Based on the literature and the verbal protocols we concluded that when teams have the opportunity to communicate unrestrictedly, three additional teamwork tasks (i.e., performance monitoring, evaluation, and determining strategies) are introduced in the fire-fighting task. Now, the question is whether the knowledge that is needed to perform this teamwork in the fire-fighting task is similar to what researchers expect to be important for shared mental models. Just as with the restricted condition, we compared this. The starting point is the four team knowledge elements described by Cannon-Bowers et al. (1993):
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1. **Equipment knowledge.** Team members do not need equipment knowledge for performance monitoring, evaluation, or determining strategies.

2. **Task knowledge.** For performance monitoring it is important that team members know the current state of the progress made on the task. Knowledge of the past performance on the task is needed for evaluation. In order to determine strategies, team members must also know the past performance and know that different strategies lead to different performance outcomes. Knowledge of strategies is needed to compare strategies and decide on which one is the best.

3. **Team interaction knowledge.** To determine team strategies, team members need team interaction knowledge that describes which way information exchange can take place. This includes knowledge describing that information exchange can take place each period or only when there are changes in the number of units needed.

4. **Team members’ characteristics.** The knowledge we determined for the teamwork that is introduced when team members communicate unrestrictedly in the fire-fighting task does not include knowledge of the characteristics of the team members.

Besides these four knowledge elements, Blickensderfer et al. (2000) also assert that it is important to have common knowledge of the goal. In the fire-fighting task, team members need to know that the goal is to save as many potential casualties as possible. It is also important that team members translate this knowledge in terms of how fire fighting should ideally take place and what optimal performance is. This knowledge is needed to be able to determine whether the present (performance monitoring) or past (evaluation and determining strategies) performance is such that it can be improved. Finally, in the unrestricted condition, it is important that team members have up-to-date situation knowledge. With the help of this knowledge team members are able to evaluate the performance and determine strategies jointly. Team members must, for example, know that there are novel scenarios in which the pattern does not predict the sector and the type of the large building as usual. Based on this knowledge, team members can determine new strategies together.

**Knowledge transfer**

We hypothesized that unrestricted communication fosters the knowledge team members have in their shared mental models. Based on the literature, we defined several categories in which communication can be classified. The verbal protocol analysis shows that for each of the categories we determined, knowledge is transferred. Unrestricted communication seems to be especially important to refine members’ team knowledge into specific procedural rules of how to perform teamwork in the fire-fighting task. For example, instead of knowing that it is important to exchange information in time, team members develop knowledge that it is important to exchange information in one period. Because team members know more specifically when information is important to exchange, they are more able to coordinate implicitly. Unrestricted communication gives team members also the opportunity to develop up-to-date knowledge of the ongoing performance and situational developments. This commonly held knowledge helps team members to engage in performance monitoring, evaluation, and determining strategies.

**4.4 Conclusions**

The main purpose to perform the cognitive team task analysis was to reveal whether the psychologically important elements of the shared mental model theory are present in the fire-fighting task. If that is the case, we are confident that the fire-fighting task can be used to investigate the shared mental model
theory empirically. The cognitive team task analysis shows that the fire-fighting task contains team processes that researchers expect to be important for shared mental models.

The first team process is implicit coordination. In the restricted communication condition, information exchange is needed to accomplish the tasks. The analysis revealed further that this information exchange must take place at certain moments in the scenario and under considerable time pressure. Implicit coordination and, therefore, communicating efficiently and effectively is possible and also expected to be beneficial for team performance. Other team processes are concerned with communication as antecedent of shared mental models. The analysis shows that in the unrestricted condition, team members perform several additional teamwork tasks. Team members monitor each other’s performance, evaluate, and determine strategies together. The examples of the verbal protocols give a detailed description of how team members engage in this teamwork and how this fosters the knowledge of team members. Based on the cognitive team task analysis, we conclude that the fire-fighting task contains the psychologically important elements to investigate the shared mental model theory empirically.

Another purpose was to examine whether the knowledge needed to perform teamwork in the fire-fighting task has to be shared among team members. The cognitive team task analysis provides a detailed description of the knowledge needed to perform taskwork as well as teamwork in the fire-fighting task. The knowledge needed to perform the teamwork (i.e., implicit coordination, performance monitoring, evaluation, and determining strategies) in the fire-fighting task is similar to the knowledge that researchers expect to be important for shared mental models. Whether this knowledge must be completely held in common remains a difficult matter. In order to coordinate implicitly, it can be argued that there is a certain overlap in the knowledge of the team members. This especially goes for team interaction knowledge. Knowing when to provide and expect certain information seems to be important. However, as far as it is concerned with task knowledge, such as knowledge of each other’s tasks and task strategies, this is less clear. It can be argued that to coordinate implicitly it is sufficient when team members know which information must be exchanged when. However, it can also be argued that team members have a better understanding of why information must be exchanged when they have knowledge of each other’s task (and thus have several task knowledge elements in common).

For performance monitoring, evaluation, and determining strategies it can also be argued that a certain overlap in team member’s knowledge is needed. Commonly held knowledge ensures that team members interpret the teamwork demands and the situation similarly, which ensures that team members provide each other with information, suggestions, or alternative courses of action that are both expected and can be explained by the teammate. Regardless of the knowledge overlap, we conclude that team members need specific knowledge to perform the teamwork effectively.

The verbal protocol analysis shows that communication can be used to foster team member’s knowledge in a shared mental model. Within the communication categories we defined, team members communicate about each other’s task, their informational dependencies, task strategies, changes in the situation, and other knowledge elements expected to be important for shared mental models. The transcriptions of the verbal communication give a detailed insight of how the process of knowledge fostering takes place.

Finally, the cognitive team task analysis provides a clear picture of the relationships between knowledge in shared mental models, team processes, and performance. A good performance can be obtained only when team members perform accurately on their teamwork tasks. It is essential that team members exchange the necessary information in time and apply the right strategies. The cognitive team task analysis shows that team and situation knowledge is needed to perform this teamwork accurately.
Therefore, we assert that team performance is a good indicator of having knowledge in shared mental models. The higher the performance, the better team members’ knowledge in shared mental models.

In chapter 2 to 4, we examined conceptually team processes of teams that perform in complex and dynamic environments. After the theoretical exploration (chapter 2), the description of the experimental team task (chapter 3), and the description of the teamwork and knowledge needed in this task (chapter 4), we now turn to the empirical work of this thesis. In the next chapter, the first two experiments are described in which the effect of cross training on communication and performance is investigated.