Context-Aware Team Task Allocation to Support Mobile Police Surveillance

Jan Willem Streefkerk, Myra van Esch-Bussemakers, and Mark Neerincx

TNO Human Factors, Kampweg 5,
3769 DE Soesterberg, the Netherlands
{j.w.streefkerk,myra.vanesch,mark.neerincx}@tno.nl

Abstract. To optimally distribute tasks within police teams during mobile surveillance, a context-aware task allocation system is designed and evaluated with end-users. This system selects and notifies appropriate team members of current incidents, based on context information (officer availability, officer proximity to the incident and incident priority) and decision rules. Eight teams of three experienced police officers evaluated this system in a surveillance task through a virtual environment, comparing it to a non-adaptive system. Task performance, communication, workload and preferences were measured. Results show that team communication, decision making and response times improve using the adaptive system and that this system is preferred. We conclude that context-aware task allocation helps police teams to coordinate incidents efficiently.

Keywords: Context-aware computing, mobile computing, police surveillance, task allocation, notification.

1 Introduction

To work efficiently as a distributed team, mobile police officers need to coordinate actions together. During surveillance, current incidents require fast and accurate responses from available team members. However, keeping track of availability and appropriately allocating tasks to team members is challenging in such a distributed work environment [1, 2]. In addition, unwanted interruptions can cause distraction [3], e.g. a colleague requesting assistance while you are talking to a violent suspect. This results in increased response times and potentially dangerous situations. What is needed is a system that supports team decision making and task allocation and provides appropriate notification to team members (e.g. on current incidents).

In this study, a support system is designed that provides advice on task allocation (which team member can handle which incident best) based on officer availability, task priority and officer proximity to the incident location. Selected team members are notified using appropriate notification styles (timing and presentation of notifications) to limit interruptiveness of notifications [4]. This team task allocation support is evaluated in a surveillance task with police teams, addressing the following questions: 1) how can user availability, task priority and proximity be used for team task allocation support and 2) what are the effects of this support on police team task performance, workload and subjective judgments? We expect that this support will improve

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task allocation and task performance, result in less team communication and positive user preferences. Based on this study, implications for the design of mobile professional support systems are discussed.

1.1 Previous Research on Task Allocation

Employing mobile technology in operational domains aims to increase shared situation awareness and enable flexible decision making, for example for soldiers (e.g. Network Centric Warfare; [5]) and first responders [6]. These efforts explicitly visualize team information in geographical overviews [2] or using mobile awareness cues [7]. Such designs for activity awareness in mobile computer-supported cooperative work (e.g. [8]) lead to increased team performance and awareness as well as reductions in mental workload [2, 9]. However, users still have to integrate information from a small mobile display, straining their cognitive resources. In addition, these awareness displays do not directly support task allocation.

To realize efficient task allocation support systems, such systems have to be aware of team members' activities and locations. Currently, mobile context-aware services adapt information presentation to dynamically changing user needs or changes in the work environment (e.g. [10]). Mobile context-aware information delivery was proposed for fire-fighters [11, 12] and construction workers [13]. In the police domain, an in-car support system was proposed to improve task allocation between the emergency room and police officers in the field, based on police officers' current tasks [14]. However, as no user evaluations were reported, it is not clear whether these systems actually support decision making and task allocation.

Using context information to optimize task allocation falls within the area of Augmented Cognition, which seeks to model the user and use context to dynamically adapt the user-system interaction. For example, in the naval domain, tasks were allocated dynamically to human operators or to an automated system based on task information (e.g. priority and number of radar contacts) or physiological measures assessing workload [15]. On the downside, some authors argue that such high levels of system automation are not advisable in time-critical environments [16]. Still, few empirical users studies address automated task allocation in mobile, operational domains [15, 17].

In the current study, a prototype system is designed that not only visualizes team information to support activity awareness, but also advises team members about appropriate task allocation. Although some studies have focused on task allocation and notification in the police domain [14, 18], such support has not yet been realized for mobile police officers. To assess how this task allocation support prototype effects police team performance, the prototype is evaluated with police end-users in a virtual environment. This allows users to experience the adaptive system within the task flow and facilitates control over external variables [17, 19].

2 Designing Team Task Allocation Support

Following a concise analysis of police team surveillance based on police interviews [2], a task allocation support system was designed and implemented. Based on a set of decision rules (on officer availability, incident priority and officer proximity), this system distributes incidents optimally over team members.

2.1 Police Team Surveillance

Police officers on surveillance work together as distributed, ad hoc teams. When an incident occurs, they communicate with colleagues to determine who should handle which incident. For this process to work efficiently, they have to be aware of location and priority of current incidents as well as location, identity and availability of colleagues.

Efficient task allocation is threatened by two problems. First, police officers currently have no overview of availability and location of team members. This makes it often unclear who is available to handle an incident, potentially resulting in miscommunications or incidents that remain unattended. Second, team members communicate using radio transceivers over an open channel. For officers who are handling a critical incident, not all communication is directly relevant and might cause unwanted interruptions. Busy police officers have been observed to turn off their radios. However, they still need to be aware of other high priority emergency situations (e.g. when colleagues are requesting assistance).

To address these problems, a mobile support system is designed that is aware of team members' location and availability (handling an incident or not) and the priority of the incident (high or low). This information is acquired from location tracking data, user responses and established incident categorizations in the police domain. Based on this knowledge and a set of decision rules, the system selects the most appropriate team member(s) to handle the current incident. These team members receive a notification message with task allocation advice (i.e. "John and Mary can handle the burglary incident best"). As in previous work [4], the presentation style of these messages (information density and auditory salience) is adapted to limit unwanted interruptions. The prototype uses the following decision rules:

1. *Priority*: high priority incidents require the nearest two available officers as soon as possible while low priority incidents require the nearest available officer.
2. *Availability*: if the nearest officers are busy with a lower priority incident, they should switch to the new incident. If they are busy with a higher priority incident, they should finish that incident first.
3. *Notification*: if officers are selected to handle an incident, the full incident message is presented with a salient notification sound. If they need to be aware that an incident is waiting for them, the system presents an indicator with a less salient sound. If they are not selected to handle the incident, an indicator is presented without sound.

2.2 Prototype Implementation

A prototype support system is implemented for experimental purposes using a simulated Personal Digital Assistant (PDA) on a touch screen monitor. It provides a geographical north-up map with icons indicating team members' location, identity (name) and availability (red icon means busy, green icon means available) as well as the

Fig. 1. PDA screenshots showing the geographical map with the officer's location (*left*), an incident message (*center*) and the task list (*right*)

location of incidents. The map is centered on the users' location and can be dragged to reveal the rest of the map. See Fig. 1 for screenshots of the application.

Incident messages are displayed as full text messages with two buttons to "Accept" or "Ignore" the incident. Accepted messages move to the task list and can be checked off when the incident is finished. User actions ("Accept", "Ignore", "Finish") are used to infer user availability. Indicators are presented as small clickable icons in the lower right corner of the screen, opening the incident message when clicked.

3 Evaluation

In this study, police teams performed a surveillance task through a virtual city environment. The task allocation support system presented low or high priority incident messages. At these moments, team members negotiated who would handle which incident, navigated to the incident location and handled the incident. Task allocation advice, notification presentation and communication were manipulated, creating two conditions (adaptive and control). Effects on task performance, workload and subjective ratings were assessed between the two conditions.

3.1 Method

Participants. Eight teams of three police officers (20 male, 4 female, mean age = 33.0 years, SD = 9.9) participated in this study. All team members were experienced police officers (average 11.2 years of experience) and had collaborated previously with each other on surveillance. They used personal computers on a daily basis and only two teams used a PDA for police work.

Surveillance Task and Incident Handling Task. Teams performed the surveillance task and incident handling task through a virtual city environment [20]. The surveillance task required them to collect a maximum of 30 targets, represented by barrels that appeared at random locations throughout the environment.

The incident handling task was a time-paced, scenario-based task. At predetermined moments during the surveillance round, the system presented in total twelve incident messages to the team. Six incident messages indicated high priority incidents, which had to be handled by two colleagues together. The other six indicated low priority incidents, which could be handled by a single team member. Team members suspended the surveillance task to read the incident message and communicated with colleagues (using a headset) who would handle this incident. The selected team member(s) responded to it (using the "Accept" or "Ignore" buttons below the message) and navigated to the incident location as fast as possible (see Fig. 2). Handling the incident consisted of reading and memorizing the incident description on screen. When done, they checked the incident off the task list and returned to the surveillance task. Participants could decide for themselves when to attend to each message, whether or not to accept an incident and which of their colleagues to approach for assistance.

Experimental Design. A within-subjects design was employed with two experimental conditions (adaptive or control). In the adaptive condition, the system provided task allocation advice and adaptive notification following the decision rules. Team members could choose to communicate with all team members or selected team members only (closed channel). In the control condition, full incident messages were presented to all team members without task allocation advice and the communication channel was open to all team members.

Two similar experimental scenarios (equal duration, number and type of incidents) were established in cooperation with two experienced police officers to maximize external validity. All teams experienced both conditions and the presentation order of the conditions and scenarios was counterbalanced across teams to avoid order effects.

Measures. Before the experiment, age, gender, (mobile) computer experience and police experience were assessed using a questionnaire. Furthermore, spatial ability was assessed in a computer-based spatial rotation task [21].

During the experimental sessions, task performance on the surveillance task was measured as the *total distance traveled* and the number of *targets* collected. Task performance on the incident handling task was measured as the *response time* to incident messages, *errors* in decision making, *incident handling time*, *total time on task* and recall of incident *details*. Furthermore, the number of *communication utterances* on task allocation between team members was counted. These variables were measured per team and averaged over incidents.

Subjective judgments were collected individually using questionnaires and rating scales. After each session, experienced *workload* was measured using the RSME [22] and judgment on *own performance* and *team performance* was measured with a six-item team effectiveness scale. After both sessions, team members were asked individually to compare both experimental sessions. On the *preference* questionnaire they indicated which of the two prototypes they would prefer in their daily police practice regarding task allocation advice, presentation of the messages and team communication.

Fig. 2. The virtual environment with an incident location (*left*) and a police officer behind the experimental setup (*right*)

Apparatus. Participants were seated behind two 17” monitors, one above another. The top monitor displayed the virtual environment and the incident details. Participants moved through the environment using a game controller. The bottom (touch-screen) monitor displayed the simulated PDA and communication interface (see Fig. 2). To avoid overhearing each other, city background noise was played over the headset. While navigating through the environment, the PDA was blanked out to avoid overreliance on the geographical map.

Procedure. In total, the experiment took about three hours to complete. First, the personal characteristics questionnaire and the spatial ability test were administered. Participants received instructions on both tasks and familiarized themselves with navigation and incident handling in two short practice scenarios (control first, adaptive second). In the control condition, participants were instructed to follow the set of decision rules for task allocation (see paragraph 2.1), while in the adaptive condition the system provided task allocation advice. The two experimental sessions took about twenty minutes each, after which the RSME, the performance and detail recall questionnaires were administered. After both sessions, the preference questionnaire was administered.

3.2 Results

Data on all performance variables was averaged and compared per condition using t-tests for repeated measures. Means for all variables are presented in Table 1. For response time, decision errors and navigation efficiency, follow-up analyses per priority level (high or low) were performed. Subjective judgments were analyzed using non-parametric tests. Multiple regression analyses were performed on performance measures, communication and workload with age, spatial ability, education, computer experience, police experience and game experience (averaged over teams) as predictor variables.

Surveillance Task Performance. The difference in total *distance* traveled between de adaptive and control condition approached significance ($t(7) = 2.13$, $p = 0.07$). Less distance was traveled in the adaptive condition. On average, more *targets* were collected in the adaptive condition (M = 18.5) compared to the control condition (M = 17.4). However, this difference was not significant ($t(7) = -0.44$, $p = 0.67$).

Regression analysis showed that variance in distance traveled was significantly predicted by age (R^2 adj. = 61%, B = 8956, $p < 0.05$) and variance in targets collected was also explained by age (R^2 adj. = 64%, B = -0.5, $p < 0.05$); younger teams collected more targets and traveled less distance in the control condition. In the adaptive condition, no significant predictors were found on these variables.

Incident Handling Task Performance. *Response time* to incident messages was slightly lower for the adaptive condition, however not significant. This can be explained by the extra line of message text (with the task allocation advice) that had to be read in this condition. When response times were analyzed separately for high and low priority messages, the interaction effect of condition and priority approaches significance ($F(1, 7) = 4.32$, $p = 0.076$; see Fig. 3). In the control condition response time to low and high priority incidents is almost identical, while in the adaptive condition, participants' response time differs between low and high priority incidents.

Both *incident handling time* and *total time on task* did not differ significantly between the adaptive and the control condition. Regression analysis showed that variance in incident handling time was also predicted by age (R^2 adj. = 91%, B = -5.37, $p < 0.01$) and variance in time on task in the control condition was predicted by age (R^2 adj. = 65%, B = -4.92, $p < 0.05$); younger teams took more time than older teams. This effect was not present in the adaptive condition.

The number of *decision errors* on task allocation was lower in the adaptive condition (M = 3.4) than in the control condition (M = 5.0), approaching significance ($t(7) = 2.09$, $p = 0.07$). Analyzed separately for high or low priority incidents, no significant interaction effect was found (see Fig. 4). The adaptive support helped teams to reduce decision errors.

The number of *details recalled* was slightly higher in the adaptive condition than in the control condition (see Table 1), however not significant. Regression analysis showed that variance in detail recall in the control condition was predicted by age (R^2 adj. = 59%, B = -0.34, $p < 0.05$); older teams recalled less details. However, in the adaptive condition, this effect was not present.

Communication. The number of *communication* utterances on task allocation differed significantly between conditions ($t(7) = 4.17$, $p < 0.005$). In the adaptive

Table 1. Means on the main performance variables (TG = targets, RT = response time, DE = decision errors, HT = incident handling time, TT = total time, Com = communication utterances, Det = details recalled and WL = workload) for the control (*Co*) and adaptive (*Ad*) conditions. * significant at p < 0.05, **bold** indicates a trend approaching significance.

	Distance	TG (#)	RT (s)	DE (#)	HT (s)	TT (s)	Det (#)	Com (#)	WL
Co	**383425**	17.4	11.0	**5.0**	70.1	129.5	16.9	***33.2**	49.3
Ad	**332734**	18.5	13.5	**3.4**	67.0	123.6	17.5	***23.3**	51.0

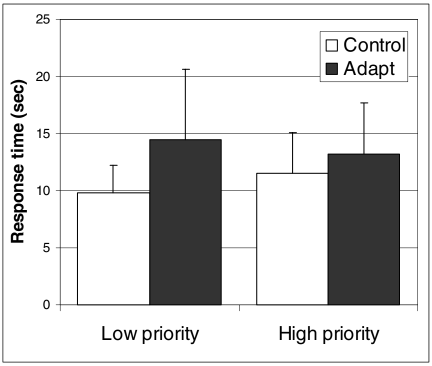

Fig. 3. Response times to low and high priority incident messages

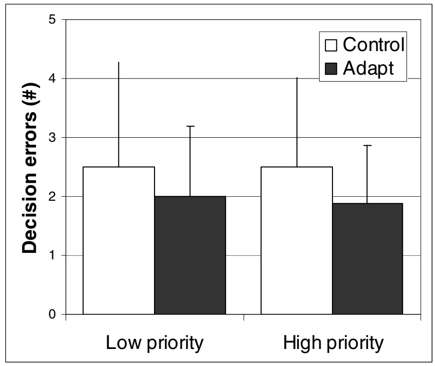

Fig. 4. Number of decision errors on low and high priority incidents

condition, team members communicated less on task allocation than in the control condition (23 and 33 utterances respectively). When they had the choice between open or closed channel of communication in the adaptive condition, informal observations showed that almost all teams preferred and used an open channel.

Workload. There was no significant difference in *workload* between both conditions. Regression analysis showed that workload in the control condition was predicted by spatial ability (R^2 adj. = 89%, B = -5.80, $p < 0.05$), game experience (B = 14.8, $p < 0.05$) and education (B = 8.06, $p < 0.05$); participants with high spatial ability and less game experience indicated lower workload ratings. Workload in the adaptive condition was also predicted by spatial ability (R^2 adj. = 84%, B = -5.17, $p < 0.05$) and game experience (B = -8.18, $p < 0.05$), but showed that participants with *more* game experience indicated lower workload.

Subjective Judgments. The questionnaire items on own performance and team performance showed no significant differences between conditions. Participants did not rate their own performance or team performance differently in one of the conditions. The mean scores on the team effectiveness scale showed a ceiling effect (5.8 and 5.9 for control and adaptive condition respectively).

Participants' *preferences* after both conditions showed that 76% of the participants preferred the adaptive condition in their daily police work because it supported decision making. Half of the participants preferred the adaptive condition because of the lower disruptiveness of messages. However, 58% of the participants found it to be more difficult to divide attention between the PDA and the surveillance in the adaptive condition.

4 Discussion and Conclusion

This study evaluated team task allocation support based on relevant context factors (location, availability and priority). In a surveillance task with experienced police teams, two conditions (with and without context-aware task allocation and notification) were compared. Using task allocation support, less team communication and less decision errors are observed and less distance is traveled. In addition, adaptive notification causes response times to be more varied, appropriate for the priority of the incident. The majority of the officers preferred this support in their daily work, although some found the adaptive system behavior hard to understand. Regression analysis showed that older police officers profited from the support in terms of more details recalled, distance and targets collected and younger officers profited in terms of incident handling time. Our results show that context-aware task allocation support helps police teams in decision making and communication.

Contrary to our expectations, no effects of support were found on time on task, incident handling time and workload; the support does not make police officers faster nor lessen their workload. The time benefits of the task allocation support may be too small compared to the incident handling time (over 120 seconds). In addition, learning to work with an adaptive system might have increased officers' workload. These effects are expected to decrease with prolonged system use. An interesting observation on team collaboration is that without task allocation support, tasks were allocated to whoever called first or loudest. While this may not have been the most appropriate decision, still teams rated team performance very positively.

These results have implications for the design of task allocation support systems on mobile devices. Because the use context (location, availability) can change unexpectedly, task allocation advice may become outdated or wrong. Consequently, the task list must allow team members to pass over incidents or tasks to others. Or task allocation should be dynamically revised, based on the current situation. This is an opportunity to extend the principles of Augmented Cognition to the mobile domain. Further research should focus on the usability and predictability of such dynamic task allocation systems. In ongoing research, we will investigate how teams deal with unexpected breakdowns in task allocation support and what the role is of shared situation awareness in handling such situations.

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