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ANALYZING THE POTENTIAL OF GRAPHICAL BUILDING INFORMATION FOR EMERGENCY RESPONSES: TOWARD A CONTROLLED EXPERIMENT

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Research in Progress

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Abstract

Improving the efficacy of emergency agencies like fire departments is receiving increased attention in academia and practice. In recent times, novel firefighter information technologies like digital plans and augmented reality systems have been proposed to better support the work of firefighters. These technologies, however, mostly result from technology-driven approaches and run a risk of failing the actual needs of the users. In this paper, we present the design of a controlled study to more rigorously examine firefighters' needs for information. Considering the search and rescue task during a building fire as an exemplary case, we first identify informational potentials to support the work on site. Based on theories of situation awareness and cognitive science, we then hypothesize that graphical building information can facilitate the search and rescue task. To examine the hypotheses, we propose the design of a controlled, yet realistic laboratory experiment that was developed in cooperation with a Bavarian state firefighting academy. During the experiment, firefighter squads will be provided with different kinds of building information and evaluated with respect to their task performance. The results of the experiment are expected to provide implications for the design of novel firefighter information technologies and firefighters' working routines.

Keywords: Firefighter information technologies, Situation awareness, Cognitive science, Laboratory experiment.

1 Introduction

As a response to significant disasters such as terrorist attacks, earthquakes, hurricane strikes, or wildfires, improving the effectiveness of emergency responses is receiving increased attention in academia and practice (Lee et al., 2017, Pfeifer et al., 2004). During the last years, multiple strategies have been developed to enhance the organization of fire and rescue departments and to optimize their response processes. One of those strategies is to equip firefighters with new and emerging information technologies in order to increase their situation awareness and hence support the making of critical context-dependent decisions on site. Innovative information technologies such as digital plans (Johnson, 2005, Takahagi et al., 2015), intelligent protective clothing (Smart@fire, 2016, Salim et al., 2014), augmented reality (Klann and Geissler, 2012, Bretschneider et al., 2006), on-site emergency response information systems (Yang et al., 2009, Ha, 2012), or unmanned aerial vehicles (van Persie et al., 2011, Barrado et al., 2010) are supposed to help gathering, sharing, and presenting real-time information about the emergency site. Augmented with such novel information technologies, firefighters should theoretically be able to better understand the situation and the capabilities of available resources.

Looking at the assessment of those novel information technologies in practice, however, a recent study showed that most of them are perceived rather skeptically and are hardly disseminated (Schlauderer et al., 2016). One supposed reason for this is that the use of novel information technologies is mainly proposed based on their innovative features and the presumably resulting functional potential to support emergency response processes. Such mainly technology-driven approaches tend to neglect the specific nature of emergency responses, which impose tight usage constraints. Although information technologies are hence delicate artifacts for firefighters, literature hardly discusses if and under which circumstances a novel information technology might be viewed as beneficial by them. To the best of our knowledge, the only recent study addressing this issue was done by Weidinger et al. (2017). Among others, this study identified potential key factors for the acceptance of novel firefighter information technologies, and confirmed the skeptical assessment of such technologies in practice.

To ensure that firefighter information technologies indeed meet the needs of the intended users, it appears thus necessary to investigate more rigorously, (i) which kinds of information are effective in enhancing the situation awareness of firefighters and (ii) how technologies should be designed to deliver the respective information in an effective and efficient manner. With the study proposed in the paper at hand, we intend to contribute to the closure of this literature gap. Focusing on the provisioning of information about a building on fire and the location of a victim inside, which has been chosen as the study object because the search and rescue of victims is the subject of typical daily operations, we examine the following research questions: *"Can the presentation of a graphical plan of a building and the location of a victim during the mission briefing improve firefighters' search and rescue tasks compared to a verbal description? Does the continuous availability of a graphical plan during the mission further improve firefighters' search and rescue tasks?"* To achieve rigorous results, we intend to conduct a controlled experiment, in which we provide firefighter squads with information about the building and the victim inside in different formats. The experiment shall be conducted in cooperation with a Bavarian state firefighting academy, which will make available a building that has been designed for fire training purposes and resembles a typical small apartment house in Germany. The experiment design is guided by findings from cognitive science, which imply that in many contexts graphical information can be better recalled and comprehended than verbal information, and that continuous instead of punctual access to such information can additionally reduce the risk of cognitive overload.

The results of our study provide indications in how far graphical building information is effective in enhancing the situation awareness during search and rescue operations. As shown in Figure 1, our proposed study constitutes only the first step in a larger research endeavor. The results of our study are supposed to provide an empirically grounded basis for the design of corresponding information technologies. Depending on the results, the information is supposed to be implemented in digital plans, on-site emergency response information systems (that could be used to present the information punctually during mission briefings), or augmented reality devices (that could be used to present the information continuously during the mission). The results gathered in the emergency response domain might also complement findings on the effectiveness of different kinds of information from the field of cognitive science. So far, it has not been investigated yet in how far existing findings also apply to emergency response processes, which – amongst others – differ with respect to the level of stress, the timing constraints, the margin for error, and the level of certainty.

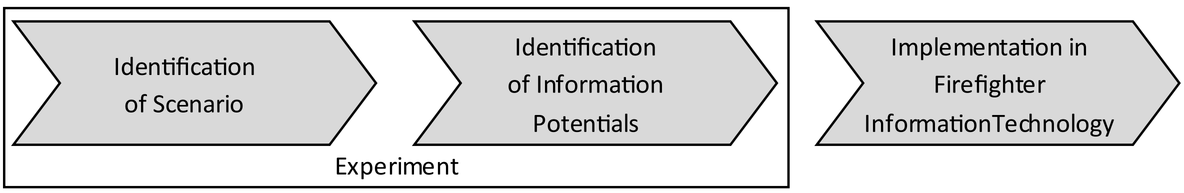

Figure 1. Research Agenda

We proceed as follows: in section 2, we develop the hypotheses and the research model that underlie the design of our experiment. In section 3, we present the design of the experiment in detail. The expected contributions to academia and practice are discussed in section 4.

2 Hypotheses and Research Model

In this section, we elaborate on the theoretical background of our study. First, we develop preliminary assumptions from theories of different research disciplines in section 2.1. In section 2.2 we deduce our research hypotheses and build a research model that will be tested in our experiment.

2.1 Development of Hypotheses

Firefighters face the challenge of making time-critical decisions in a dynamic environment. Supporting firefighters' work in such a context considerably depends on providing sufficient information about the situation. Based on such information, firefighters can gain so-called situation awareness (Endsley, 1995, Endsley, 2000). Considering situation awareness as an abstract construct, it is applicable and relevant to various domains, in which critical decisions must be made. Besides soldiers or pilots, it also applies to emergency responders like firefighters. The construct is described as the result of a three-level process from the perception of environmental elements to the comprehension of their meaning to their projection in the near future (Endsley, 1995). In the perception phase, one must perceive the characteristics of the relevant elements such as the status, attributes, and dynamics. In the comprehension phase the perceived, disjoint elements must be assembled in the sense of creating patterns to develop a holistic understanding of the environment. Finally, based on perception and comprehension, it is possible to make predictions in the short term about the elements in the environment. All levels, especially perception, rely on effective information in terms of quantity and quality. Amongst others, information technologies – in our context firefighter information technologies – can deliver such information. However, research on situation awareness in the emergency management domain mainly concentrates on higher levels of severity, e.g. the handling of extraordinary disasters or the coordination of multiple agencies (Pagotto and O'Donnell, 2012, Ley et al., 2012). Situation awareness in the daily routines of firefighters, as we want to examine it in our experiment, has hardly been in the focus of research. To bridge this gap, we intend to address the problem of providing information in appropriate quantity and quality in everyday-scenarios. Based on this information, the different levels of situation awareness can be achieved, potentially resulting in higher performance and better decisions.

To identify how this information can be provided, we studied potentially relevant concepts of cognitive science. We wanted to identify potentials for effectively presenting information to humans in a general context. Various studies in this field show that graphical information can be superior to other forms of presentation, such as written words or natural language. On the one hand, graphical information can be better recalled than written words (Kaplan et al., 1968, Paivio et al., 1968, Sampson, 1970). A reason for this is the different encoding of words and pictures. According to Kaplan et al. (1968), pictures are double-coded (i.e., both verbally and graphically), which leads to better recallability due to the association with words. On the other hand, Larkin and Simon (1987) show that diagrams enable better comprehension because of the support of numerous perceptual interferences and the grouping of related information. Furthermore, the combination of graphical and verbal information seems to be beneficial (Mousavi et al., 1995). This especially applies to inexperienced persons (Mayer and Sims, 1994). Firefighters who do not have any previous knowledge about the building they are operating in can be characterized as such inexperienced persons.

Altogether, while those insights are well grounded in the field of cognitive science, it remains unclear if they also hold in the special domain of firefighters. The fact that a person can better recall graphical information in an unstressed, quiet environment might not be straightforwardly transferable to the more chaotic scenario of a burning house with lives at stake. Such scenarios are characterized by high emotional strain due to the urgency of the situation. It thus remains unproven if graphical building information will support firefighters in their search and rescue tasks. If such graphical information will still have a positive influence in this special scenario, will be the first question to be answered in our experiment. We assume that Firefighters provided with graphical instead of only verbal building information will be able to perform their search and rescue task better.

Because of the before-mentioned special characteristics of the firefighter domain, there is an increased danger of so-called cognitive overload (Mayer and Roxana, 2003). This means that a person's cognitive abilities do not suffice to process the given information. Visualizing the hectic conditions of a critical emergency with countless environmental impressions, firefighters could more quickly experience such a cognitive overload. In this case, they might not be able to memorize the information that was given to them at a certain point in time. Because of this, we further assume that having continuous access to the graphical building information - which represents a higher degree of graphical information - might be better than having to memorize it. Consequently, we hypothesize that firefighters provided with continuous instead of only punctual graphical building information will be able to perform the task better.

2.2 Research Model

Building upon the theoretical background, we propose a research model to summarize our hypotheses. In particular, the research model helps us to examine to what extent the provisioning of punctual or continuous graphical information supports the firefighters in fulfilling their task. Referring to our assumptions, we expect that the use of a graphical notation will increase the usability of the provided information for firefighters. In general, usability is determined by three different aspects (Frøkjær et al., 2000, ISO/IEC, 1998): the effectiveness, i.e. the accuracy with which a task is fulfilled, the efficiency, i.e. the effectiveness in relation to the effort needed to complete a task, and the satisfaction, i.e. the users' comfort when performing a task. Accordingly, we formulate our hypotheses as follows:

- **H_1**: Firefighters provided with a higher degree of graphical building information will be able to perform the task more accurately.
- **H_2**: Firefighters provided with a higher degree of graphical building information will need less time to perform the task accurately.
- **H_3**: Firefighters provided with a higher degree of graphical building information will be more satisfied while performing the task.

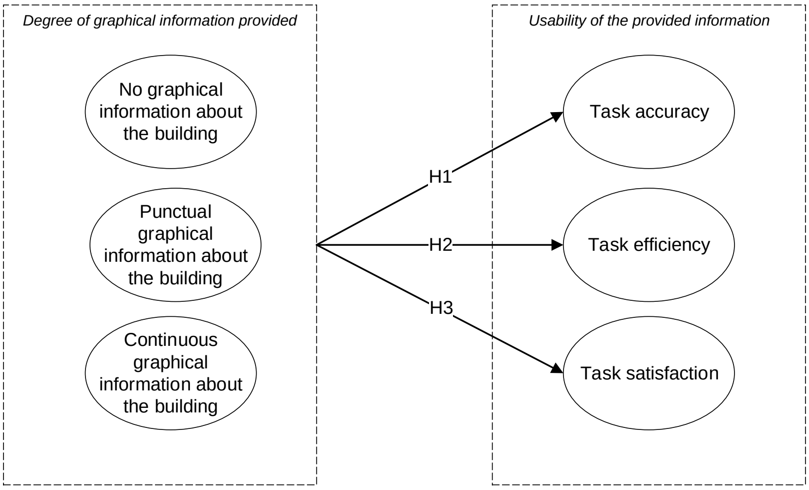

Figure 2. Research model

Figure 2 summarizes our research model. In the following, we provide more information on how we measure the model constructs, the design of our experiment and information about the participants.

3 Experimental Design

To examine the hypotheses, we intend to conduct a controlled experiment with several firefighters as subjects. Hypotheses H_1 and H_2 will be tested in the experiment itself. The following section describes this in detail. Hypothesis H_3 will be tested in interviews that we are going to conduct following the experiment. Those are explained in section 3.2.

3.1 Controlled Laboratory Experiment

The experiment will take place at the Bavarian state firefighting academy in Würzburg. In this academy, voluntary as well as professional firefighters from all over the state Bavaria are trained in several kinds of firefighter tasks. Using the training facilities of the academy, we will be able to conduct a controlled, yet realistic laboratory experiment. For the design of the experiment, we are following the guidelines given by Cox and Reid (2000).

The experimental scenario was developed in a roundtable session with instructors of the firefighting academy in late 2017. A squad of firefighters will respond to a simulated apartment fire on the second floor of a multi-level building. The building will be represented by the fire training building of the academy (cf. Figure 3). The building emulates a typical residential building with multiple apartments. With remotely controlled gas-fires and fog machines simulating smoke inside the building, the scenario will be designed like a real-world apartment fire. As the task, we selected the search and rescue of a missing person (represented by a dummy) from the apartment. For our experiment, the responding squads will consist of one squad leader and a team of two firefighters. The squad leader commands the task. (S)he will first explore the incident site and then brief the team. The team will be ordered to enter the building, search, and rescue the dummy from a certain room inside the building. Other members that are part of a real-world squad (e.g. the operator of the fire engine) will not be considered in the experiment, which constitutes the virtually only unrealistic element of our experiment.

Figure 3. Fire training building (cf. http://www.sfs-w.de)

The subjects for the experiment will be retrieved from participants of firefighting courses at the academy and composed to squads. The number of participants in that realistic courses is very limited and each Bavarian fire department is allowed to send only a small number of firefighters to such courses each year. This itself results in highly mixed and randomized groups of subjects in the first place. To examine our hypotheses, each squad will be randomly assigned to one of three groups which will all be of equal size (Cox and Reid, 2000). $\mathbf{G_0}$ is the control group. Teams of this group will receive a verbal briefing by their squad leader without any graphical resources. The command will look like this: “There’s an apartment fire on the second floor, one person is missing in the third room on the right-hand side. Your team is going in for search and rescue with the first hose line to the second floor via the main staircase.” $\mathbf{G_1}$ is the first treatment group. The treatment received by this group is a sketch-map of the building that the squad leader will draw and then use as an additional graphical resource to brief the team besides the verbal command. However, the team members will only see this map during the briefing and must not take it along when entering the building. Therefore, they will only have punctual access to the graphical information. **G_2** is the second treatment group. Like in G_1, the treatment received by this group is a sketch-map of the building in addition to the verbal command. Unlike G_1, however, the teams of G_2 will not only be briefed using this map but will also be allowed to take it with them when entering the building. Therefore, they will have continuous access to the graphical information. The map for both G_1 and G_2 will be drawn on paper. For G_2, it will be wrapped in a heat-resistant packaging. As discussed later (cf. section 4), the real-world application of especially the continuous building information will call for the employment of information technology. However, since we want to measure the effects of the information itself in a first step, we use paper as a simple (yet effective) approximation.

To examine H_1, we will compare the task completion rates of the three groups. A task is rated as complete if the team could find the dummy and retrieve it from the building. If the punctual graphical building information increases the task accuracy, the percentage of successful tasks in G_1 will exceed that of G_0. If the continuous information further increases the task accuracy, the completion rate of G_2 will exceed those of G_0 and G_1.

For each squad, we are going to take the time of four different activities. **t_{recon}** is the time needed for the squad leader to explore the incident site. During this period, (s)he will try to get a comprehensive impression of the site by looking at the different sides of the building, questioning attendants, and so on. In G_1 and G_2 (s)he will also draw the sketch-map based on the gathered information during this period. **t_{brief}** is the time needed to brief the team. The squad leader will give the team a rough situation report and issue his/her commands. As pointed out above, the squad leader will have a sketch-map to support the verbal briefing in G_1 and G_2. In G_0 the briefing will be done verbally only. **t_{in}** is the time needed for the team to reach the dummy. This period will start with the team entering the building. The time will be taken once the team radios to the squad leader that they have reached their ordered destination and found the dummy. **t_{out}** is the time needed for the team to get out of the building together with the rescued dummy. This period will directly connect to the end of t_{in} and the time will be taken once both team members and the dummy have left the building.

Hypothesis H_2 will be tested by comparing the average times needed to complete the task between the three groups. If the punctual graphical building information indeed increases the task efficiency, the squads of G_1 will on average complete their tasks faster than those of G_0. If the continuous information further increases the task efficiency, the completion times of G_2 will be below those of both G_0 and G_1. Due to the partitioning into four periods, we will also be able to identify in which periods time advantages or disadvantages occur. Table 1 summarizes the experimental design.

Groups	Time Measurements	Test of Hypotheses
G_0: verbal only information G_1: punctual graphical information G_2: continuous graphical information	t_{recon}: investigation (+ drawing sketch map t_{brief}: briefing of the team t_{in}: finding the dummy in the apartment t_{out}: getting the dummy out of the building	H_1: task completion rate H_2: task completion time H_3: interviews (cf. 3.2)

Table 1. Summary of the experimental design

As suggested by Cox and Reid (2000), we will take measures to ensure both internal and external validity of our experiment. To ensure internal validity, we want to make our treatments the only varying factor within the experiment. First, the chosen task allows us to control most surrounding conditions. The time needed to find and rescue the dummy will mostly depend on the teams' orientation capabilities inside the building. Those capabilities may be influenced by our treatments. Looking at other scenarios, there would be many more unknown factors. In a firefighting scenario, for example, the time to find and extinguish the fire would also depend on the teams' hose management, the extinguishing technique, and other factors. Next, the dummy, being the task destination, will be at the same position inside the same room for all teams. This way the length and complexity of the path toward it will be identical. As another measure, the participants will have no prior knowledge about the fire training building and the squads will be separated. This means that none of them will be allowed to watch other squads of the same or another group before its own task. Also, the squads will not know the building or its structure prior to the task. This way all squads will have identical previous knowledge upon entering their task and there will be no learning effect for the teams. Finally, to eliminate interference with our experiment, we will capture several statistical control variables. This will be done by means of interviews after the experiment (cf. 3.2). Several measures shall ensure the external validity of our experiment as well. As stated above, the experiment will be conducted in a fire training building. This building was specifically designed to represent real-world apartment fires in the most realistic way that is achievable under safe and controlled conditions. Several elements of a real-world apartment fire will be simulated during the experiment. Amongst others, there will be real flames from remotely controlled gas-fires, thick smoke from fog machines, and acoustic stimuli like crackling or screams from loudspeakers. Therefore, the overall situation will be comparable to the one in a real emergency. Besides the general situation, also the specific task is realistic. It was designed in a roundtable session with instructors of the academy and represents an every-day task for firefighters. Next, the task will be performed by firefighters that perform this kind of tasks in real operations, as well. The participants will come from both professional and voluntary fire departments from all over Bavaria. Therefore, there will be a great diversity among our subjects. This makes our results transferable to multiple types of departments and regions. Overall, we expect our results to be both internally and externally valid.

3.2 Interviews

Each squad will be interviewed shortly after they have conducted their task. The interviews will consist of two parts. In the first part, we are going to capture general and demographic information from the firefighters. We want to capture several attributes that might have an influence on their task performance besides our treatments. One factor might be the firefighters' experience in their job. We intend to estimate the experience by the number of years they have been working as a firefighter and by the average number of incidents they are responding to per year. Next, we want to ask the firefighters about the type of fire department they are working for. In fact, members of voluntary and professional fire departments perform virtually the same tasks in Germany. There might, however, be differences in the level of training. Finally, we are going to capture the age and gender of our subjects.

In the second part of the interviews, we intend to evaluate the task satisfaction of the participants, as it was mentioned in hypothesis H_3. Due to previous experiences with interviewing firefighters, we want to keep the evaluation as quickly and easily, as possible. As a suitable method to be employed in usability studies, we identified the After-Scenario Questionnaire (Lewis, 1991). This questionnaire consists of three items that we slightly adapted:

- Overall, I am satisfied with the ease of completing the tasks in this scenario
- Overall, I am satisfied with the amount of time it took to complete the tasks in this scenario
- Overall, I am satisfied with the supporting information when completing the tasks in this scenario

Each of the three items is supposed to be assessed by the firefighters on a seven-point scale ranging from 1 (strongly agree) to 7 (strongly disagree). There will also be "not applicable" points outside the scales.

Hypothesis H_3 can then be tested by comparing the firefighters' average assessments between the three groups. If the punctual graphical building information indeed increases the task satisfaction, the squads of G_1 will on average rate the three items more positively than the ones of G_0. If the continuous information further increases the task satisfaction, the average ratings of G_2 will be above the ones of both G_0 and G_1. We will also be able to identify possible differences between the three items.

4 Discussion and Outlook

To examine the usefulness of various kinds of building information in emergency response processes, we presented the design of a controlled laboratory experiment. Based on theories of situation awareness and findings from the cognitive science domain, we hypothesize that graphical building information will better support search and rescue tasks in burning buildings. The hypotheses were refined and summarized into a research model that we are going to evaluate in a controlled, yet realistic environment. On the basis of the experiment, we expect to identify how punctual and/or continuous graphical building information will increase firefighters' accuracy, efficiency, and satisfaction during search and rescue tasks in a burning building.

We expect the results of our study to have implications for academia and practice alike. For academia, our study creates several avenues for future research. If graphical building information is indeed found to better support firefighters, the corresponding information should be made available using appropriate information technologies. Among the currently discussed firefighter information technologies (Weidinger et al., 2017), two approaches seem to specifically suited for such a goal. Digital plans or on-site emergency response information systems might be a means to support punctual graphical building information during the mission briefing. The provisioning of continuous graphical building information will, however, require the employment of more intricate information technologies. First, the produced sketch-map would have to be copied in real-time. This way, not only each team member could take an instance with him/her, but the squad leader could also keep an instance for his/her duties on site. Second, to access the information inside a burning building, the used medium would have to withstand heat, water, and other influences. Outside a laboratory context, simple paper sheets as used in our experiment would probably not be durable enough to withstand such conditions. However, it would be conceivable to use augmented reality systems that can for example be installed inside the firefighters' breathing masks. This way the information would be protected from outside influences. As such technologies bring additional complexities and limitations with them, they should be evaluated in further experiments. In so doing, it is possible to differ between the effects coming from the underlying information itself (as they are examined in our proposed experiment) and the effects stemming from the use of the technology. As pointed out above, this will also be in the focus of our own future research. Besides the examined task of search and rescue in a burning house, the demand for information in other firefighter tasks could be examined using a similar procedure. From salvage operations in car accidents to forest fires, many scenarios exist, which ought to be analyzed for possible information needs of the users. Based on the results, technologies to provide these kinds of information can be developed and again tested. Such an approach might help to develop technologies that better fit the practical needs of firefighters than the ones resulting from a usually technology-driven approach.

As regards practice, we expect our results to provide an indication whether it is worth investing precious time to produce graphical information in time-critical situations. If the results show that there is an improvement of task accuracy and/or efficiency, firefighters should consider changing the common procedure of getting to work the fastest way possible, even with little information. Instead, it might be wiser to spend more time to improve situation awareness at the beginning of an operation in order to ensure its success. Using efficient information technologies, it could be tried to minimize the time needed to establish situation awareness as best as possible. If, on the other hand, our results show that graphical building information does not deliver significant advantages, this could be seen as a confirmation of the current approach on site. Either way, the experiment can sensitize the participating firefighters for possible advantages but also for disadvantages of additional information during an operation. This way they can be enabled to better assess information technologies that are supposed to support their work and identify those that truly hold this assumption.

Although we implemented several measures to ensure internal and external validity of our experiment, several limitations pertain to our study. First, we are going to provide graphical building information on paper in order to examine the original effects of the additional information. Providing it using a complex medium, such as a tablet computer, might possibly bias these effects. However, using paper-based information is not a reliable option in practice. Also, the experiment is designed to be as realistic as it is possible under controlled and safe conditions – it can, however, not capture all aspects of a real-life operation in every detail. Furthermore, with the search and rescue task in a burning building, we concentrate on a critical every-day, yet specific scenario. The results of our study can, therefore, not simply be transferred to other firefighter tasks.

As the next step of our ongoing research endeavor, we plan to conduct the experiment as described in the paper at hand. If the graphical building information will indeed support the participating firefighters, we plan to implement the information in different kinds of information technology and repeat the experiment using these technologies to provide the information and again examine the results.

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