

The Evaluation of In-Vehicle Adaptive Systems

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Abstract. Although research on adaptive systems has begun only recently, studies have shown the benefits of using adaptive systems. However most of those studies have examined systems with and without adaptive qualities, disregarding additional factors that may influence the interaction. This study presents a first step towards a more comprehensive evaluation of adaptive systems. We assert that adaptive systems should be examined with regard to different types of tasks, different situations and using various users to be able to determine the conditions in which adaptivity will be beneficial. A preliminary study evaluated adaptivity when performing routine and infrequent tasks. The study showed that adaptivity is beneficial for routine tasks, and that adaptivity impairs performance of infrequent tasks. The study proposes a method to calculate the point at which adaptivity ceases to be beneficial as a function of the relative frequencies of different tasks and provides a starting point for a more comprehensive understanding of the subject.

1. Introduction

Adaptive user interfaces (AUI) are designed to support users in performing their tasks by adapting to their individual characteristics. AUIs can facilitate user performance, make the interaction more efficient, improve ease of use and assist the user in overcoming information overflow and help them use complex systems [2]. However, adaptation has also some limitations, usually related to usability problems, as the user her/himself is an adaptive “system”. Such problems include: lack of control the user may feel regarding the system appearance or functions [6], [7], lack of consistency [8], [9], [11], and lack of transparency and predictability [6], [7]. In addition to these problems, [7] suggested two other problems. First, the adaptive system might place demands on the users’ attention, therefore reducing the capability to focus on the system’s main task. He referred to this problem as Unobtrusiveness. Secondly, he mentioned that the adaptive system might impair the user’s breadth of experience because some types of adaptive systems assist the user by acquiring

information or perform parts of the task instead of the user. Therefore, users may become less knowledgeable in a certain domain (i.e. knowledge degradation). This may also lead to over reliance on the system by the user who believes that the choices made by the system are always relevant and good [5], [7].

Given that adaptive systems have the limitations mentioned, it is valuable to demonstrate that adaptivity indeed improves the interaction with the system, and under what circumstances such an improvement will occur. Therefore, the evaluation of such systems is of great importance and should be as comprehensive as possible.

Our evaluation of the benefits of adaptivity will focus on adaptivity in in-vehicle telematic systems. These systems are now standard equipment in high-end cars. They combine a variety of functions in a single user interface, including access to the navigation system, traffic advise, entertainment (CD, radio, satellite radio, MP3, etc.), climate control, communications (cellular phone, SMS, email access, web access, etc.). The population of drivers is a highly diverse user population in terms of age, cognitive abilities, skills, computer experience, etc., and it therefore is very appealing to adjust systems to the properties and preferences of the individual driver. One way to achieve this goal would be by incorporating adaptive functions in such systems. These functions need to meet two basic requirements: 1. They should facilitate the interaction with the system and improve driver satisfaction with it. 2. They should not increase the distraction (and consequent safety problems) caused by the system, and should ideally even lower distraction. A number of papers have addressed the use of adaptivity in in-vehicle devices (e.g., the “adaptive route advisor” by [10]).

1.1 The Evaluation of Adaptive Systems

The evaluation of AUIs refers mainly to the effectiveness of the systems and whether they meet usability criteria. The effectiveness is usually determined by the quality of the information the system provides, its accuracy, performance time and users’ subjective evaluations. This of course depends on the specific characteristics of the adaptive system. The extent to which these systems meet usability criteria is usually evaluated through traditional HCI usability variables such as consistency, transparency, learnability, predictability etc. To date, the evaluation of adaptive systems is still in its infancy and only few studies have evaluated such systems empirically. Additionally, most studies up to now compared an adaptive and a non-adaptive system on a number of variables, examining whether the adaptive system has some advantage over the non-adaptive system (e.g., [3], [4], [6] [12], and [13]).

The evaluation of adaptive systems needs to cope with a number of problems that are particularly crucial in this context. First, the benefits and limitations of using adaptivity are likely to appear only after fairly prolonged use. Short experiments or observations may fail to provide an adequate picture. Second, the dynamic changes in system properties that result from adaptivity may have differential effects in different situations, while performing different tasks and on different users. For instance, adaptivity may be more beneficial for complex tasks. Similarly, while some users may consider adaptivity to have advantages, others may find it confusing and prefer to have it turned off. Therefore, the evaluation might consider properties of the user,

the task and the situation, since it is not enough to establish for a specific system whether the adaptive version is better compared to the same system without adaptivity. Additionally, there are various types of adaptive systems, ranging from systems that support system use, like adaptive menus, to systems that support information acquisition, such as adaptive filtering systems (see [7]). Fig. 1 presents the variables we claim influence the interaction with an adaptive system and therefore should be considered when evaluating a system.

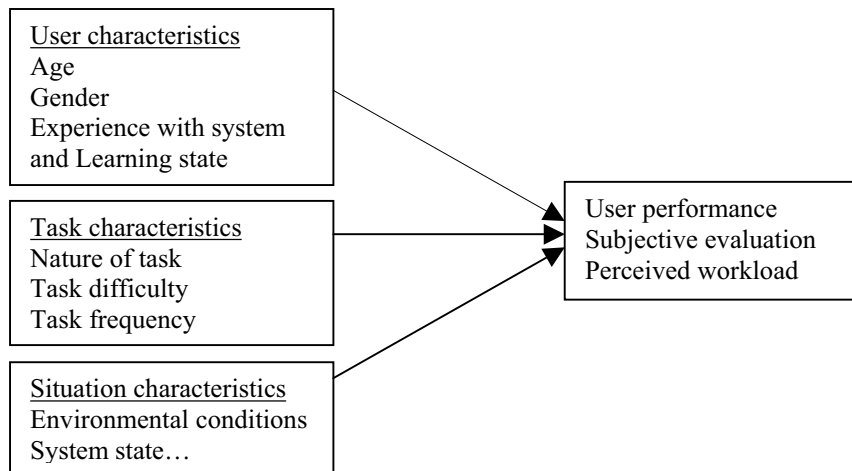


Fig. 1. The variables assumed to influence the interaction with an adaptive system

We assert that a framework describing the conditions in which adaptivity will be most beneficial should be generated and examined. Such a framework requires the evaluation of adaptive systems in a number of steps. The first step should examine adaptivity when performing different types of tasks, such as routine and uncommon tasks, tasks with different levels of difficulty, etc. The second step should examine adaptivity in different situations, such as different environmental conditions. Finally, the third step should evaluate system use by various types of users differing in age, level of expertise with the system, etc. We claim that the frequency at which a task needs to be performed has major influence on the degree in which the system will be beneficial.

1.2 Task Frequency

The aspect of task frequency has been examined before in other domains, such as adaptable systems and mainly in the study of automation, but has not yet been examined with relation to adaptive user interfaces. Previous research has raised the value of task frequency. [1] For example, compared two interfaces. In one interface the user can customize all the items in the menu (the user adds all features to the menu) for both frequent and infrequent tasks he or she will need to perform. In a second interface the user customizes only the features necessary for the more

frequently performed tasks (the user needs to switch to the full interface to perform infrequent tasks). [1] Found that when users perform a task infrequently, adding all items is not always as efficient as adding only those from the frequent task. Adding infrequently used items depends on a number of factors including the number of infrequently used features, where these features will be located in the menus, the ratio at which the infrequent features will be used compared to the frequent features and the user's expertise.

1.3 The Study

This paper will describe a step towards developing a framework for evaluating adaptive systems by examining the first variable we assert influences the interaction. We assert that adaptive systems should be more beneficial to the user when performing routine and frequent tasks. On the other hand, when the user is required to perform an uncommon and infrequent task, the adaptive system will most likely cease to be advantageous and even may become a burden on the user. The purpose of this paper is to discuss the issue of task frequency and more specifically to provide a method to calculate the point from where adaptivity will no longer be beneficial and may impair performance.

2. Method

2.1 Participants

Twenty engineering students at Ben-Gurion University of the Negev, Israel, served as paid participants in this study.

2.2 Apparatus

An experimental system, which consists of two subsystems, was developed: a driving simulator and a telematic system simulating in-vehicle devices. The system was PC based and was developed in Visual Studio.Net 2003. It displayed a road scene on a 21-inch monitor located in the center of the participant's visual field. The simulator showed a two-lane curved road without additional traffic. The car position in the lane was controlled through a steering wheel and it drove at a constant speed of approximately 30 km/h. The in-vehicle telematic system was simulated through a visual display (16 cm wide X 9 cm high) that was displayed on a separate 15-inch screen to the right of the driving simulator screen. The telematic system included three subsystems: a communication system (including SMS, Outlook, News Updates), an entertainment system (including radio and CD) and a navigation system (including traffic updates). Participants controlled the telematic system using buttons located on

the steering wheel (left, right buttons for navigation in the telematic system and a button for selection). The integrated system was connected to an output data file that contained data on driving performance (the driver's steering actions and lateral lane position were recorded every 200 mSec) and on task performance with the telematic system. To assess the drivers' subjective evaluations of the system they were asked to respond to three questionnaires, one at the end of each drive.

2.3 Experimental Design

A 2 X 3 X 5 X 2 between-within experimental design was employed. The between subject variable was the manual condition compared to the adaptive condition. The within-subject variables included: the number of drives (2 routine and 1 uncommon drive), 5 tasks (traffic updates check, SMS reading, news updates reading, e-mail checking and CD change) and 2 occurrences of all tasks (first, second). The dependent variable was the performance with the telematic system. Performance time was measured in milliseconds for all participant actions with the telematic system.

2.4 Procedure

Participants were requested to perform tasks with the telematic system while driving the car. The experiment began with an introduction drive in which the user became acquainted with the system and the tasks in the manual mode. After completing the introduction drive, participants drove 2 routine drives and 1 uncommon drive. Each routine drive included 12 tasks the user was asked to perform (5 tasks that occurred twice and additional 2 tasks in which lane shifts were required). The uncommon drive included 3 uncommon tasks in addition to the routine tasks. Ten participants performed the tasks in the manual mode and ten in the adaptive mode. During the drive the participants received a text message in the top section of the telematic system that specified the required task. For example, the system notified the participant that she received an SMS message and she was requested to reply with a message "I'm driving". In the manual condition, the participants were requested to reply manually by typing their reply on a virtual keyboard. In the adaptive condition, the system automatically sent the participants' usual response. The text messages were always accompanied by an auditory message. The appearance of the next task was conditioned on the successful completion of the previous task. All 4 drives (introduction, 2 routine and 1 uncommon) took place in one experimental session that lasted about 90 minutes, with 5-minute breaks between the drives and time for filling out the questionnaires. The participants performed the following tasks with the telematic system: Receiving an SMS message and sending a reply, reading e-mail from the inbox, receiving news updates, receiving traffic updates, and changing from radio to CD. The participants received some instructions prior to their drive, informing them about their regular use of the telematic system.

3. Results

Performance time was measured in milliseconds as the time from the moment the message appeared on the screen until the participant completed the task. Performance time was analyzed for two types of tasks:

1. Constant tasks: tasks that did not include uncommon actions and therefore did not change along the three drives. These tasks included checking traffic updates, checking news updates and one instance of reading an email message.
2. Changing tasks: tasks that included uncommon actions during the third drive. These tasks included the 2 SMS messages received and one instance of checking email in which the participants were required to change the user in the inbox.

Analyses on both tasks used a 2-way ANOVA with repeated measures on the number of drive variable (3 drives). The between factor was adaptivity (Manual and Adaptive).

The results of the ANOVA performed on the constant task showed an interaction Adaptivity X Drive ($F(2, 28) = 5.99, p < 0.0001$). Fig. 2 presents the results. The results show that in all drives performance times were better in the adaptive condition, although they significantly improved in the third drive in the manual condition.

The results of the ANOVA performed on the changing tasks showed an interaction Adaptivity X Drive ($F(2, 28) = 74.45, p < 0.0001$). Fig. 3 presents the results. The results show that in the first two drives, which include the routine tasks, performance times in the adaptive condition were much faster, while in the third drive, where the tasks were infrequent, performance times in the adaptive condition were significantly longer, compared to the manual condition.

We propose that an additional factor related to the frequency of the task relates to the ratio at which routine and infrequent tasks occur. The greater the ratio of the routine tasks to the infrequent tasks, the more adaptivity should be beneficial. The calculation of the costs and benefits of adding adaptivity to a system can be demonstrated on the results of our experiment.

As can be seen in Fig. 3, the mean time required to perform the tasks in drives 1 and 2 (in which only routine tasks needed to be performed) was 43.25 seconds for the manual condition. The use of adaptivity improved the time to 22.63 seconds, so that we can state that introducing adaptivity shortened the performance times to approximately half their value without adaptivity. In drive 3, when non-routine tasks needed to be performed, times remained approximately the same for the manual condition (49.31 seconds) whereas performance time increased to 72.69 seconds for the adaptive condition. Thus adaptivity increased performance times in non-routine tasks by approximately 50%. We do not state that the symmetry in the effects (where adaptivity shortens times for routine tasks by half and raises times for non-routine tasks by half, as well) will be found whenever adaptive systems are evaluated, but it can serve as a convenient first approximation of the effects of adaptivity.

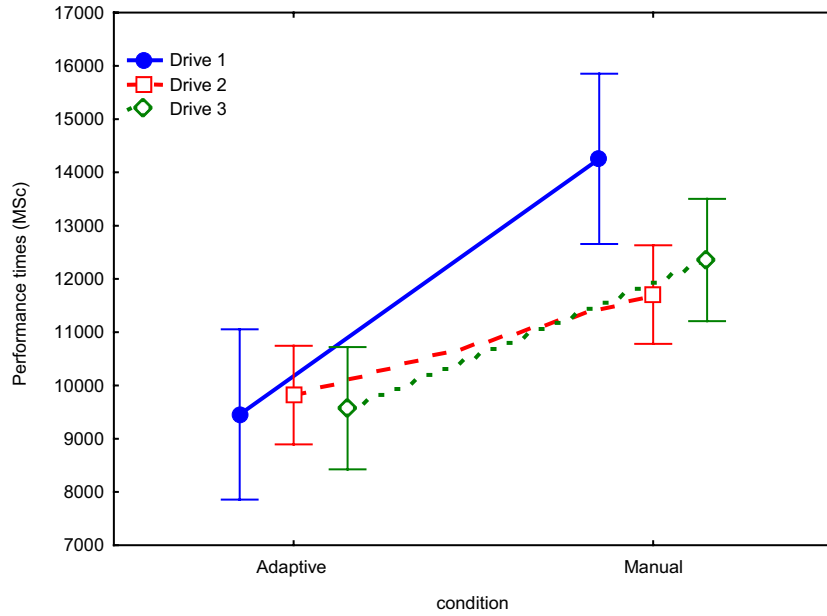


Fig. 2. Mean time to perform constant tasks in the manual and adaptive conditions

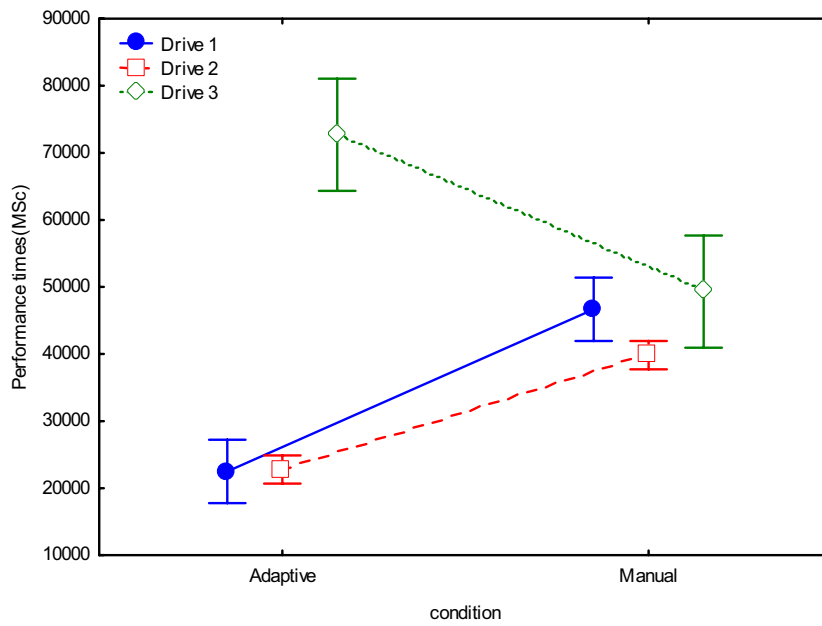


Fig. 3 Mean time to perform changing tasks in the manual and adaptive conditions

It is now possible to compute some estimate for the effects of adaptivity as a function of the proportion of frequent tasks out of all tasks that need to be performed. A measure of the total performance time T_{Total} can be computed from the expression

$$T_{Total} = p_{Freq} (1 - B) + (1 - p_{Freq})(1 + C).$$

where p_{Freq} is the proportion of frequent tasks, B is the benefit from adaptivity for frequent tasks, and C is the cost of adaptivity for non-frequent tasks. Costs and benefits in our case are the degree of change in performance time after introducing adaptivity for frequent and infrequent actions. T_{total} in this case is the ratio between the performance time with adaptivity and without it, so that $T_{total}=1$ when adaptivity has no effect on performance time, $T_{total}<1$ when adaptivity shortens performance times, and $T_{total}>1$ when adaptivity lengthens performance times. In our case we can set $B=C=.5$. The resulting computation is shown in Fig. 4. Clearly, in this very simple case, system performance will benefit from installing adaptivity if the proportion of frequent tasks out of all tasks that need to be performed with the system exceeds 50%.

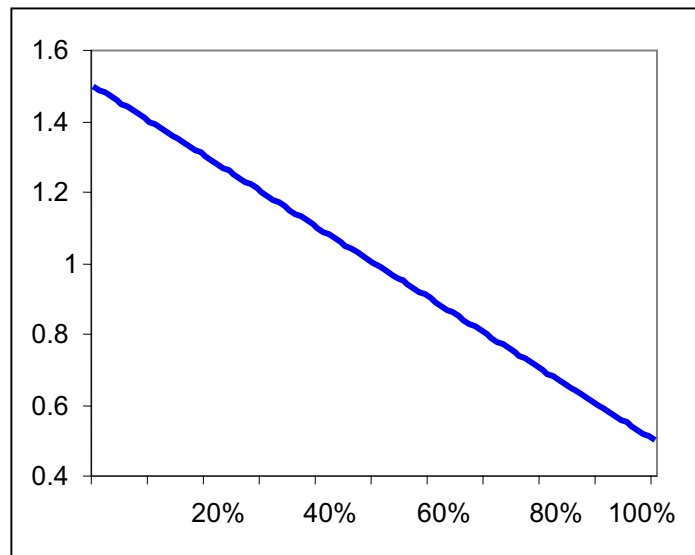


Fig.4. Performance time ratio as a function of the ratios of routine and non-routine tasks. The value 1 represents the performance level without adaptivity. Shorter times indicate faster and therefore better performance.

4. Discussion and Summary

Adaptive user interfaces were shown to be beneficial in empirical studies that compared an interaction concept in an adaptive versus non adaptive version. However, a number of additional factors influence the interaction with adaptive systems and are likely to affect the value of adaptivity. We call for a more comprehensive examination of adaptive systems that should lead to the development of guidelines that specify the conditions in which adaptivity will be beneficial. These conditions should be based on the analysis of the set of tasks that need to be performed with the system, the various usage situations, and the characteristics of the individual users.

Our study is a first step towards achieving this goal. It evaluates adaptivity as a function of the ratio of routine and infrequent tasks. We suggested that adaptivity will be beneficial when routine tasks are to be performed and will impair performance when infrequent tasks arise. The results of our study support our assumptions and showed that indeed adaptivity improves performance of routine tasks and impairs performance of infrequent tasks. We demonstrate that for a given adaptivity algorithm the relative value of adaptivity can be assessed, given the benefits of adaptivity for the performance of frequent tasks, the costs due to adaptivity for infrequent tasks, and the relative frequency of frequent tasks.

This study presents only a preliminary evaluation of the subject. Clearly more experiments are needed to replicate and expand the results. For instance, we assume here that the costs and benefits are independent of the relative frequency of the frequent task. This assumption may hold after prolonged experience in using a system, but may actually require closer scrutiny in the early stages of learning system usage. Future research should examine adaptivity using different frequencies of routine and infrequent tasks. Also, the effects of the different categories of variables that we identified as affecting the performance with adaptive systems should be examined empirically. We hope that by gradually accumulating a set of empirical results on the performance with adaptive systems for different tasks in different usage situations and by different users, we will be able to develop a comprehensive model from which the outcome of installing adaptive functions in a system can be predicted. Such models should have great value for system designers in general. They may have particularly great appeal for the interaction design of e.g. in-vehicle systems, where issues of adaptivity and user performance have major impact both on the appeal of the system to the driver population and the safety of the use of the system.

5. References

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