Evaluating the effect of automatic display management on user performance in a Smart Meeting Room

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Abstract: Multi-display environments provide users with a large number of (semi-)public and private displays. Selecting what information to present on which display here becomes a real issue, especially when multiple users with diverging interests have to be considered. This especially holds for dynamic ensembles of displays. Therefore, automatic assignment strategies might be useful, if they are able to provide the required assignment precision.

We claim that it is possible to define such strategies, at least for certain usage situations. We propose a specific strategy and show that it is able to assist users in solving specific tasks in multi-display environments at least as effectively as conventional manual assignment, while at the same time significantly reducing the number of required interactions. Our claims are based on user performance data collected in the scope of a comparison study.

1 Introduction: Managing Multi-Display Environments

Multi-Display Environments\(^1\) support collaborative problem solving and teamwork by providing multiple display surfaces for presenting information. Typical examples for such environments are meeting rooms, conference rooms, and “mission control centers”.

One difficult task here is the Display Mapping problem – that is, deciding which information to present on what display in order to optimally satisfy the users’ needs for information. While this task is more or less trivial in single-user, single-display situations, it becomes challenging in multi-user, multi-display settings: Users and displays are spatially dispersed so that the visibility of (semi-) public and private displays varies across users. Also, information needs may vary across users, so that finding the “best” assignment of information to displays becomes a typical optimization problem.

Optimization problems are solved by defining an objective function \(q(x)\), the “quality” to maximize, and then applying a suitable optimization algorithm to compute \(x_{\text{max}} = \arg \max_{x \in X} q(x)\).

In this setting the Display Mapping problem gives rise to two subproblems:

\(^1\)See e.g. the UbiComp 2004 workshop on Ubiquitous Display Environments [FKK04] or the Ubicomp 2006 workshop on next generation conference rooms [ea06].
• What is a suitable definition for \( q(x) \)? I.e., what is the objective function to be maximized in order to achieve an optimal (or at least: satisfactory) solution for the Display Mapping problem?

• How should the computation of \( x_{\text{max}} \) be distributed across the members of an ensemble of displays? – This is especially interesting, when dynamic ensembles have to be considered (e.g., portable projectors carried into a meeting room, etc.).

A possible answer to the second question has been given in e.g. [HGK06]. Focus of this paper is the first question: showing that it is indeed possible to define a quality function that enables automatic display assignment in a multi-display, multi-user, multi-document setting. We propose a specific version of \( q \) for which we claim that it provides satisfactory solutions. In order to substantiate our claim, we have carried out an evaluation experiment that investigates the effect of an automatic assignment on user performance and satisfaction, in comparison to a manual assignment.

### 1.1 The Need for Automatic Display Mapping

Why do we need automated display mapping? – Could not the users just do the assignment manually, using a suitable interactive interface, resolving conflicts by social protocols (negotiations)? One example for such a manual display assignment are the ModSlideShow system [CLB+03] and the PointRight software developed for Stanford’s Meyer Teamspace [JHWS02], which are designed to manage presentation slides on multiple displays. For assignment of content to displays, meeting participants drag-and-drop presentations from their note books to any of the available displays.

However, manual display assignment has to cope with the following conflicts:

1. **Interest conflicts** between users might be solved faster by computer supported negotiation mechanism: Morris et al. [MRS+04] have already observed that social protocols do not always suffice for coordinating the use of shared resources, such as display surfaces, in teams – even in relatively simple situations. They advocate the development of specific strategies for automatizing the negotiation process.

2. The need for **dynamic realignment** of Display Mapping is caused by topic changes in the user population – in this situation, the user’s focus of attention will be on the changing topic rather than on convincing the display infrastructure to change the topic.

3. In a dynamic multiple display environment, the **user might not be able to know** the displays currently available to him. With dozens to hundreds of possible display configurations, the user might want to rely on the infrastructure to select the best choice for him.

Therefore, an automatic display assignment might be helpful in multi-display environments, specifically in multi-user settings. However, to our knowledge, it is not known if
suitable automatic assignment heuristics do exist. Although there is substantial research in
multi-display environments, the development of an automatic display assignment has not
been addressed.

Next, we discuss the basic properties of a quality measure – \( q(x) \) – that can be used for
solving the display mapping problem.

## 2 Defining Optimal Display Mapping

### 2.1 The Basic Concept

In order to enable an automatic assignment of documents to displays for a team of users,
we need an explicit notion of the “quality” of a given display mapping. In our current
proposal for such a quality measure, we aim at considering the following heuristics:

**Spatial Layout:** For documents of high importance to a user, displays should be preferred
that provide a good visibility for the user.

**Temporal Continuity:** When considering a display for a document, the system should
prefer already existing assignments.

**Semantic Proximity:** Related documents should be presented close to each other to sup-
port the user in analyzing the semantic correlation between the documents. (Semantic
proximity is not yet part of our implementation.)

Let \( D, U, Y \) be the sets of documents, users, and displays, respectively. Then, a **display
mapping** is a function \( m : D \rightarrow 2^Y \), which assigns documents to sets of displays. For
a given document \( d \in D \), \( m(d) \in 2^Y \) gives the set of displays document \( d \) is assigned
to. \( m(d) \) is a set of displays, as it sometimes clearly makes sense to assign a document to
more than one display.

The overall quality of a display mapping \( m \), given a previous mapping \( m_0 \), is then given by
a function \( q(m, m_0) \), which consists of three components: \( q_s(m) \), measuring the spatial
quality, \( q_t(m, m_0) \), measuring the temporal continuity (with respect to a previous mapping
\( m_0 \)), and \( q_p(m) \), measuring the semantic proximity. In general, \( q(m, m_0) \) may be an
arbitrary complex function of \( q_s, q_t, q_p \). However, we currently only consider a linear
combination, so that

\[
q(m, m_0) = \alpha q_s(m) + \beta q_t(m, m_0) + \gamma q_p(m). \tag{1}
\]

The relative weights \( \alpha, \beta, \gamma \in [0..1] \) balance the influence of the three components. (We
currently use the ad-hoc choice \( \alpha = 1 \) and \( \beta = 0.1 \). This choice worked for our trial, but
definitely this should be based on additional research.)

We will now briefly look at the component functions.
2.2 \( q_s \) – Spatial Quality

Let \( \text{impt}(d, u) \in [0..1] \) denote the importance of the document \( d \) to a user \( u \) and let \( \text{vis}(y, u) \in [0..1] \) the visibility of display \( y \) by user \( u \). Then the spatial quality achieved by a mapping \( m \) can be defined as

\[
q_s(m) = \sum_{d \in D, u \in U} \text{impt}(d, u) \cdot \max_{y \in m(d)} \text{vis}(y, u)
\]

(2)

This definition represents the above spatial heuristic: in a good mapping, documents with high importance (for specific users) should be assigned to displays with high visibility (for this user). In addition, if a document is assigned to multiple displays, only the best one for a given user is considered when computing the quality for this user (this is the “\( \max \) \text{vis}” term).

As a first approximation to computing \( \text{vis} \) we have chosen Lambert’s law of reflection, which gives the visibility as cosine of the angle between the display’s surface normal \( n_d \) and the user’s forward vector. A similar approach has been taken by the EasyLiving Geometry model [BS01].

Note that deriving a reliable estimation of \( \text{impt} \) in general may be a substantial challenge – however, there may be additional informations available that can be used as a surrogate (such as an agenda item listing a responsible person with a number of associated documents, etc.). In our test, we have used a manual importance assignment.

There are two possible extensions to \( q_s \) that we will not consider here:

- Steerable projectors – displays that are able to choose between different display surfaces – introduce another level of complexity. Basically, \( \text{vis} \) is decomposed into two components, measuring the visibility of the surface by the user and the projection quality on the surface by the steerable projector. Also, a surface mapping assigning projectors to surfaces has to be introduced. A definition of \( q_s \) considering this aspect can be found in [HGK06].

- For the different roles that a document may have for a user, the visibility \( \text{vis} \) may have quite different meanings. For instance, for a speaker, \( \text{vis} \) may relate to the physical distance between himself and the presentation slides, rather than to the visual perceivability of the slides. So, in general \( \text{vis}(y, u) \) should be written as \( \text{vis}_{\text{role}(u,d)}(y, u) \): Depending on \( \text{role}(u,d) \), different interpretations for \( \text{vis} \) can be selected.

2.3 \( q_t \) – Temporal Continuity

Documents should not unnecessarily change their place between two display mappings. Therefore, we penalize display changes for documents. In a display mapping \( m \), a user’s
primary display for a document \(d\) is \(\pi(m, u, d) = \max_{y \in m(d)} \text{vis}(y, u)\). It is that display showing \(d\), which is best visible for the user \(u\). A relevant display change occurs between two mappings \(m\) and \(m_0\), if a user’s primary display changes:

\[
\text{shift}(m, m_0, u, d) = \begin{cases} 
0, & \text{if } \pi(m, u, d) = \pi(m_0, u, d) \\
1, & \text{otherwise}
\end{cases}
\]

Then, \(q_t\) tries to minimize these shifts relative to the document’s importance:

\[
q_t(m, m_0) = - \sum_{u \in U} \sum_{d \in D} \text{shift}(m, m_0, u, d) \times \text{impt}(d, u) 
\]

Here, \(m_0\) is the previous mapping and \(m\) is the mapping to be optimized. (Note the negation in front of the sum: the sum term denotes a penalty, hence we have to take the negative value if we use it in a maximization task).

2.4 \(q_p\) – Semantic Proximity

Semantic proximity is based on two functions: \(\rho(d, d')\), measuring the semantic proximity of two documents and \(\delta(y, y')\), measuring the physical distance between two displays (e.g., Euclidian distance). Based on this, the semantic proximity heuristic \(q_p\) can be defined as

\[
q_p(m) = - \sum_{u \in U} \sum_{d, d' \in D} \rho(d, d') \times \delta(\pi(m, u, d), \pi(m, u, d')) \times \text{impt}(d, u) \times \text{impt}(d', u)
\]

(Again, the sum denotes a penalty, therefore we negate it.)

Deriving a reliable estimation of \(\rho\) in general will be a substantial challenge. However, as in the case of \(\text{impt}\), there may be additional information available (such as an agenda listing a set of documents for a given agenda item) that may be used as a surrogate for semantic distance.

Note that semantic proximity as defined here is an instance of the quadratic assignment problem (a combinatorial optimization problem that is NP-hard).

2.5 Using \(q\)

\(q\) has been defined completely independent from a concrete ensemble of users, displays, documents, and surfaces. It describes the globally optimal behavior for any possible ensemble. Once machinery is available for computing the optimum for \(q\), any ensemble will be able to behave optimally – as far as \(q\) is a correct definition of an ensemble’s global optimum from the user’s point of view.
Next, we describe the experiment we have used for assessing the performance of an automatic display assignment based on $q$ in comparison to a manual assignment.

3 Evaluation of $q$

3.1 Overview

The objective of our evaluations is to answer the following questions with respect to automatic display mapping in general and the definition of $q$ specifically:

- Is it possible to predict and automatically generate a good document display mapping that would satisfy a reasonable subset of users? Are the configurations produced by the algorithm actually useful and sensible to users in multi-display environments? What benefits does automatic content distribution offer over manual distribution?

- Is it possible to develop a universal approach, or do different application domains, situations, and contexts require different assignment strategies (or even a pure manual mechanism)?

In this paper, we focus on an experimental study whose objective has been to assess the effectiveness of an automatic display assignment in comparison to a manual assignment in a multi-user, multi-display environment. Specifically, we have measured the impact of manual vs. automatic display assignment on the performance of a team in solving a semi-cooperative task. In such tasks, the need of cooperation and joint use of information is not evident from the start, but rather arises while working on the task. We think that this kind of aspect pertains to many team processes, specifically in multidisciplinary teams.

The experiment was carried out in our Smart Appliance Lab (cf. Figure 1, left). This environment provides six projection based public displays, arranged in two pairs at three
sides of the room, of which five were used for the experiments (see Figure 1, right).

3.2 Experimental Setup

3.2.1 Goal and Hypothesis

The objective of this experiment was to compare the effect of manual and automatic display assignment on task performance. Our hypotheses is that automatic assignment enables teams to solve their tasks in a shorter time, with less conflicts between team members, and with greater satisfaction.

3.2.2 Procedure

In order to test our hypothesis, we chose an experimental design that allowed us to measure both objective performance data and subjective user satisfaction.

In the experiment, two-person teams had to solve a semi-cooperative set of comparison tasks as fast as possible. The two team members, X and Y, were given different agendas, each containing the description of an individual comparison. For X the task was to compare two documents A and B, for Y the task was to compare A and C. The task was a simple letter comparison, counting the number of differences in the two letter sequences contained in A and B resp. A and C. In addition, X and Y had to report time information and a random key from another document Time. The seemingly unrelated tasks for X and Y were linked into a cooperative task through the shared documents A and Time – see Figure 2 for the documents.

The seating arrangement used for a team is shown in Figure 1, right. Note that there are two pairs of displays exclusively visible to X and Y, respectively, and one display visible to both X and Y. For the experiments, every participant was given a simple user interface for document assignment. Manually assignment of a document to a display-surface is done through a simple “drag & drop” (Figure 3, right). For automatic assignment, the user just associates an importance value with the documents (Figure 3, left). The optimal document-display assignment is then computed using our goal function $q$. 

![Figure 2: Problem documents, from top left: Agenda, Time, A](image-url)
As the agendas and task descriptions were mutually unknown, the sharing had to be discovered through a conflict in the manual assignment group. (In order to enforce resource conflicts in this simple setting, each document could only be displayed on one display at a time.)

Finally, the teams were assigned to two equal-sized groups, A and M. The teams had to solve two sets comparison tasks in sequence, with a short break after the first set. Group A had to solve the first set using automatic assignment and the second set with manual assignment. The Group M had to solve the first set with manual, the second set with automatic assignment. In the evaluation of the results, we will call the first set “Initial Test” and the second “After Training”, respectively.

<table>
<thead>
<tr>
<th>Summary of experimental design</th>
<th>Group A:</th>
<th>Group M:</th>
</tr>
</thead>
<tbody>
<tr>
<td>First Task Set</td>
<td>Second Task Set</td>
<td></td>
</tr>
<tr>
<td>(Initial Test)</td>
<td>(After Training)</td>
<td></td>
</tr>
<tr>
<td>Automatic</td>
<td>Manual</td>
<td></td>
</tr>
<tr>
<td>First Task Set</td>
<td>Second Task Set</td>
<td></td>
</tr>
<tr>
<td>(Initial Test)</td>
<td>(After Training)</td>
<td></td>
</tr>
<tr>
<td>Manual</td>
<td>Automatic</td>
<td></td>
</tr>
</tbody>
</table>

For each experiment, we recorded the time required for completing the task, the number of interactions with the provided user interfaces, and the solution correctness (percentage of letter differences found). After each task set, the subjects were asked to answer a questionnaire regarding user satisfaction. After both task sets, the subjects were asked to complete a final questionnaire regarding the comparison of the automatic and the manual assignment.

Note that a goal of the experimental design has been to (I) explicitly provoke conflicts between the team members regarding the use of the available display space and (II) to enforce substantial changes in the set of documents currently important for a user. Clearly, display assignment becomes an issue only, once more relevant documents than displays
are available (specifically, if different users have different sets of relevant documents), and once the set of currently relevant documents changes dynamically. In order to achieve these effects with a manageable and reproducible experimental setup, we had to settle with a somewhat artificial experimental design. However, the results we have achieved with this setup are independent from the specific trial task. They are valid in any situation that involves multiple-user and multiple-display scenarios with inherent conflicts and/or dynamics between the team members’ sets of relevant documents.

### 3.2.3 Participants

24 voluntary subjects (19 male and 5 female) were recruited from colleagues and students of our department and the local university. The participants were between the ages of 20 and 41, had at least one year of a Bachelor degree and were used to computer systems. The participants were randomly grouped into 12 teams, from which 6 were randomly assigned to group A, the other ones to group M.

### 3.3 Results

#### 3.3.1 Overview

In the analysis of the experimental data, we have focused on our first research question: is an automatic display assignment able to assist users in solving tasks in multi-display environments in a shorter time and with less interactions as conventional manual assignment? On average all subjects needed 4:28 min to complete one set of a comparison task. When
the teams were using automatic assignment, the average time was 4:08 min, while they required an average time of 4:49 min using manual assignment. The overall average number of interactions was 11.8, where the subjects needed 8.5 interactions on average with automatic and 15 interactions on average with manual assignment. The average solution correctness was 95%, for both manual and automatic assignment.

This indicates that the automatic assignment is superior to manual assignment, regarding time and interactions (a brief statistical validation for this claim is given further below).

An overview of the collected data is shown in the boxplots in Figure 4, 5, and 6. In these plots, “mode” refers to the display assignment mode (manual vs. automatic). In the per-task-set plots, grey lines connect the mean values of the two consecutive task sets of a group (Group A or Group M), black lines connect consecutive task sets using the same assignment mode. So, the boxes in Figure 4, right, have the following interpretation:

- Bottom left unfilled box: Group A, first set using automatic assignment (“Initial Test”).
- Top left filled box: Group M, first set using manual assignment (“Initial Test”).
- Top right, filled box: Group A, second set using manual assignment (“After Training”).
- Bottom right unfilled box: Group M, second set using automatic assignment (“After Training”).

3.3.2 Interpretation

As can be seen in Figure 4, right, for both task sets the solution time is shorter when using automatic assignment. In addition, Group M was able to solve the task substantially faster in the second set (i.e., when switching from manual to automatic assignment), whereby Group A was not able to improve performance in the second set (i.e., switching from automatic to manual assignment). The number of interactions (Figure 5) is smaller for the automatic method in both sets. Interestingly, the interaction counts within a mode are almost identical in both sets. There was no training effect. This indicates, that the training (due to solving similar task in both sets) had no influence in using the system infrastructure. The training effect was limited to solving the key problem of comparing the letter sequences.

In the manual assignment mode, both groups initially had no idea that they needed to share documents. So they unwittingly “stole” the shared documents from each others “private” displays. It took a couple of interactions until the participants realized that they needed to cooperate and to assign some of the documents to a display visible to both users. This process of realization and negotiation was the reason for confusion and delay (manifesting itself in the higher solution time and interaction counts required in the manual mode). Interestingly, even the Group A did not realize that they had to share documents in the

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2These boxplots show the minimum and maximum values, the 25% and 75% percentiles, the median (horizontal bar inside the box), and the mean (small circle inside the box).
manual task set (second task set for Group A), although they might have been able to discover this fact in the first task set.

In the automatic assignment mode no such conflicts did arise as the system automatically displayed shared documents on a shared screen. If we use the number of interactions as indicator of occurred conflicts, the data shows that with the automatic mode the number of conflicts is considerably smaller than in the manual mode. A detailed survey of the log files showed that documents which had to be shared, very frequently were reassigned in the manual mode. This proves the presumption that resolving conflicts by social negotiation is – in some situations – inferior to a computer supported negotiation, which can be solved by an automatic assignment using a global quality function such as $q$.

### 3.3.3 User Satisfaction

The questionnaires were used for answering our second hypothesis: is automatic display assignment able to improve user satisfaction?

For the questionnaires, we used parts of the technology acceptance model (TAM) [Dav89], mainly the perceived usefulness and the perceived ease-of-use. We included the following items, each to be answered on a scale from 1 (strongly disagree) to 5 (strongly agree):

- The system is easy to use.
- The system helps in solving the task efficiently.
- It is easy to cooperate with the team partner.
- The system helps in solving team conflicts.
- I felt comfortable in using the system.
Table 1: Questionnaire Summary
A = Automatic, M = Manual, 1 = strongly disagree, 5 = strongly agree.
C = Comparison, 1 = Manual strongly preferred, 5 = Automatic strongly preferred

<table>
<thead>
<tr>
<th>Item</th>
<th>Group A</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th>Group M</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th>All Participants</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>M</td>
<td>C</td>
<td>A</td>
<td>M</td>
<td>C</td>
<td>A</td>
<td>M</td>
<td>C</td>
<td>A</td>
<td>M</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>Ease of use</td>
<td>3.9</td>
<td>4.3</td>
<td>3.3</td>
<td>4.2</td>
<td>3.5</td>
<td>4.1</td>
<td>4.0</td>
<td>3.9</td>
<td>3.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Efficiency</td>
<td>4.1</td>
<td>3.9</td>
<td>3.2</td>
<td>4.2</td>
<td>3.0</td>
<td>4.3</td>
<td>4.1</td>
<td>3.5</td>
<td>3.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cooperation</td>
<td>3.7</td>
<td>3.4</td>
<td>3.8</td>
<td>4.0</td>
<td>2.6</td>
<td>4.1</td>
<td>3.9</td>
<td>3.0</td>
<td>4.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conflicts</td>
<td>4.2</td>
<td>1.5</td>
<td>4.3</td>
<td>4.1</td>
<td>1.7</td>
<td>4.4</td>
<td>4.1</td>
<td>1.6</td>
<td>4.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Comfort</td>
<td>3.6</td>
<td>3.7</td>
<td>2.6</td>
<td>4.1</td>
<td>3.1</td>
<td>3.7</td>
<td>3.9</td>
<td>3.4</td>
<td>3.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>3.9</td>
<td>3.4</td>
<td>3.5</td>
<td>4.1</td>
<td>2.8</td>
<td>4.1</td>
<td>4.0</td>
<td>3.1</td>
<td>3.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The final questionnaire had the same items, but with the request to compare both approaches, automatic and manual assignment, on a scale from 1 (manual assignment strongly preferred) to 5 (automatic assignment strongly preferred).

The detailed results of the questionnaire are given in Table 1. The average user satisfaction for the automatic assignment is 4.0, it is 3.1 for the manual assignment. The comparison value is 3.8, which is 0.8 in favor of the auto mode (3.0 would be the neutral value), which could be interpreted as a 40% preference of the automatic system (a value of 5.0 would indicate a 100% preference). Also worth noting are the values for the “conflict” items: Users tend to quite strongly agree with the statement that the automatic systems helps in solving team conflicts, while they tend to quite strongly disagree that the manual system helps.

The distribution of the user satisfaction data (using per-questionaire averages) is shown in Figure 6. The overall user satisfaction is higher in the auto mode, for both task sets. In addition, user satisfaction decreases within a group when switching from auto to manual, while it increases when switching from manual to auto. Interestingly, the user satisfaction relatively increases in the second set for both modes, auto and manual. A possible reason
for this might be, that if the subjects know the task, the cognitive load is lower, which leads to less stress and a higher satisfaction.

The correlation of the subjective user satisfaction with the objective data from the log files confirm our hypothesis that the automatic display assignment is superior to the manual assignment in multi-user, multi-display situations with conflicting and dynamic document sets.

### 3.3.4 Statistical Validation (t-test)

For assessing the statistical validity of the results for solution time $t$, interaction count $i$, and overall satisfaction $s$, we have used a one-sided $t$-test (assuming unknown and not necessarily equal variances for the automatic and the manual test results). The null hypothesis in each case has been that the manual method is at least as good as the automatic method. The alternative hypothesis in each case is that automatic assignment is superior to manual assignment.

The results of test are given below. As can be seen, for all values the null hypothesis can be rejected. For solution time, the result is statistically significant, for interaction count and overall satisfaction it is even highly significant.

<table>
<thead>
<tr>
<th>$H_0$</th>
<th>$H_1$</th>
<th>$H_0$ rejected at level</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t_{man} \leq t_{auto}$</td>
<td>$t_{man} &gt; t_{auto}$</td>
<td>2.5%</td>
</tr>
<tr>
<td>$i_{man} \leq i_{auto}$</td>
<td>$i_{man} &gt; i_{auto}$</td>
<td>0.5%</td>
</tr>
<tr>
<td>$s_{man} \geq s_{auto}$</td>
<td>$s_{man} &lt; s_{auto}$</td>
<td>0.5%</td>
</tr>
</tbody>
</table>

Therefore we conclude that automatic assignment for multi-user and multi-display situations is superior to manual assignment.

A different question is, how much better automatic assignment is. Clearly, the statistically reliable minimal improvement is smaller than the difference between the average values. Here, we have the following results:

<table>
<thead>
<tr>
<th>value</th>
<th>minimal improvement</th>
<th>level</th>
</tr>
</thead>
<tbody>
<tr>
<td>solution time</td>
<td>15 sec.</td>
<td>10%</td>
</tr>
<tr>
<td>interaction count</td>
<td>4</td>
<td>10%</td>
</tr>
<tr>
<td>overall satisfaction</td>
<td>0.57</td>
<td>10%</td>
</tr>
</tbody>
</table>

Due to the comparatively small sample size, the significance level is somewhat weak (5% would be preferable). However, a larger sample size should allow to make stronger statements here, also regarding the size of the minimal improvement. These are ongoing investigations.

(We admit that an “improvement of 0.57 in overall satisfaction” is somewhat difficult to interpret.)
4 Discussion and Outlook

In this paper, we have discussed the problem of assisting teams in effectively using multi-display environments for working together. Our user studies show that – at least for specific scenarios – an automatic display assignment based on the above definition of is at least as good as a manual assignment (in fact, it is even better). Therefore, it proves that it is possible to provide automatic assistance for the user.

Our experimental work indicates that there is indeed a noticeable effect of display assignment methods on team performance, at least for semi-cooperative tasks. An automatic display assignment (i) improves the team effectiveness (measured in time to complete a task), (ii) reduces the level of conflict in the team (i.e., the number of arguments about resource use), and (iii) improves the individual user experience and satisfaction.

To summarize, although there are many open questions, we have shown that automatic display assignment provides a measurable benefit in multi-display environments, at least in some situations. Future investigations will have to show whether this benefit offers the universality and significance required to incorporate it generally into such environments.

References


