Quantitative Evaluation of Workspace Collaboration

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Abstract

In this paper we propose an analytical approach based on models of human performance to evaluate workspace collaboration. Our results indicate that the approach: 1) facilitates the fine-grained analysis of workspace collaboration; 2) provides quantitative estimates of collaborative actions executed in shared workspaces; and 3) affords comparing alternative designs using dimensions of team performance derived from the quantitative estimates.

Keywords: Workspace Collaboration, Workspace Usability, Quantitative Analysis.

1. Introduction and motivation

Collaborative technologies place many challenges to usability evaluation, motivated by the number of users necessary to participate in the evaluation processes and the required control over variables related to the group, the task, the context, and the technologies [5]. The cost and complexity of usability evaluations may be impeding the emergence of more successful groupware designs, highly usable and useful to individuals, teams, and organizations.

In this paper our research interest is in reducing the complexity of usability evaluation for groupware that supports people working synchronously and mediated by shared workspaces. Synchronous shared workspace collaboration (workspace collaboration, for short) requires a significantly high level of interdependence and workspace awareness because individual actions affect the outcomes of the other team members [9].

This particular type of groupware poses even more challenges to groupware usability evaluation caused by the requirement to analyze the low-level details of individual and collaborative actions, usually performed in very dynamic contexts. Furthermore, the impact of small design decisions is much higher in workspace collaboration than in other contexts, where the focus may be on more abstract activities, such as group decision making.

Several analytical techniques from the HCI (Human-Computer Interaction) field, and thus focused on single user interactions, already address the two concerns described above: reducing complexity and giving attention to detail. For example, the GOMS (Goals, Operators, Methods, and Selection Rules) family of techniques [6] relies on models of human performance to analyze fine-grained usability problems. From these techniques, we are particularly interested in the KLM (Keystroke-Level Model) [3,4], because it is relatively simple to use and has been successfully applied to evaluate many single-user designs [6].

In this paper we expand previous research on the possible benefits of using models of human performance to provide additional insights about workspace collaboration, not covered by other evaluation methods [1]. The advantages of this approach emerge from the following characteristics of human performance models:

- Afford studying alternative designs without the participation of users or the development of prototypes, which may reduce design time and effort;
- Elucidate the assumed capabilities and mechanisms of the human processing system, which may be instrumental to develop more useable groupware tools;
- Offer quantitative estimates of human performance, which may be extrapolated to groupware interaction;
- Address the fine-grained details of workspace collaboration, which may be used to optimize overall team performance.

The paper is organized as follows. We start with a discussion of related work. Next, we describe a case of workspace collaboration. We analyze the case using our proposed approach. Then, we evaluate and compare an alternative design, and discuss the benefits and limitations of our approach. We finish with a summary of contributions and future work.

2. Related work

Several methods have recently emerged with the purpose of reducing the complexity and cost of groupware usability evaluation. However, most of these methods either rely on high-level task analysis or depend on inspections performed by multiple expert evaluators. Examples of these are Collaboration Usability Analysis (CUA) [11], Groupware Walkthrough [12], and Groupware Heuristic Evaluation [2], all of them sharing a common framework called "mechanics of collaboration."

It is interesting to compare the CUA and human performance model approaches. Both analyze tasks using hierarchical decompositions but with significant differences in the intended level of detail. CUA reduces collaboration tasks to the mechanics performed by users in shared workspaces, such as writing a message or obtaining a resource. Human

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performance models decompose tasks at a much lower level of detail; for instance, KLM analyses tasks at single keystrokes. Single keystrokes are most times unrelated to collaborative work, notably when group decision making is involved, which is a strong argument in favor of high-level approaches such as CUA. However, we hypothesize that sometimes the designer may find it necessary to optimize the effort applied by users in low-level tasks.

The application of human performance models to the groupware context is, nonetheless, very rare in the literature, and nearly inexistent for workspace collaboration. DGOMS (Distributed GOMS) [8] is an extension of GOMS to the group level of analysis that successively decomposes group tasks until individual tasks can be identified. A communication operator is then defined to coordinate individual tasks executed in parallel. Therefore, this approach does not address workspace collaboration but coordinated work. A similar approach is also suggested in a recent study of GOMS applied to a complex team task [7]. The task involved several users monitoring a display and executing actions in a coordinated way via a shared radio communication channel. As in the previous case, the study does not address workspace collaboration.

3. Case description

We now present a case of workspace collaboration that will be central in our analysis. The case refers to a collaborative game where players draw either vertical or horizontal connections between adjacent pairs of points in a board. The game is over when the board is filled with connections, but players must observe this rule: if a player, Sophie, is an expert in drawing vertical connections, then she must consider adjacent pairs of points that contain, at least, one horizontal connection to a third point. Charles's behavior, an expert in horizontal connections, is analogous.

For illustration purposes, the board is characterized by a square arrangement of contiguous cells, numbered 1 to 9, and by an initial state that contains at least one horizontal and vertical connection lines (see Figure 1).

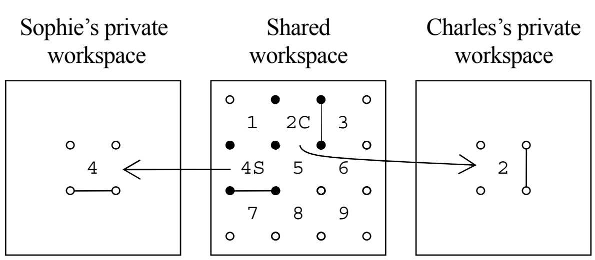

Figure 1. Cell reservations and ownership letters

The groupware tool that supports this game features a shared workspace for displaying a public up-to-date view of the board, and private workspaces where players can connect cell points. To simplify our analysis, we restrict player interactions to a mouse with a button.

In order to connect points, players must first reserve the points by selecting and dragging the corresponding cell into the private workspace. Afterwards, the modifications on the cell are made public when the cell is moved back to the shared workspace.

To minimize inadvertent selections of reserved cells, the shared workspace provides awareness by displaying a letter, next to the cell number, that identifies the current owner (see Figure 1). Additionally, the groupware tool impedes concurrent reservations of the same pairs of adjacent points. For example, if two players select vertically or horizontally neighbor cells (or the same cell), and simultaneously try to reserve them, then only one player will accomplish the cell reservation, while the other is notified that the cell cannot be reserved.

It is expected that the cells remain reserved for a small amount of time due to the expertise of the players and their eagerness to accomplish the shared goal.

To demonstrate why this case concerns workspace collaboration, we can consider that, to quickly connect all pairs of adjacent points, the team must work in harmony: the more horizontal connections exist, the more vertical connections can be drawn, and vice-versa. Conversely, if one player stops drawing connections, the other player will soon also stop. For example, if Sophie arrives late to a situation where the board only has one vertical connector, then Charles is capable of drawing at most four horizontal connections, while being idle for the rest of the time. In other words, the actions of the team members (the players) are intertwined, this being a distinctive feature of workspace collaboration [9].

4. Analytical evaluation

The analysis starts with a characterization of the collaborative environment in terms of goals and actions. In this game, players pursue *individual goals*: to draw connection lines as fast as possible. At the same time, they are conscious of team performance towards the *shared goal*: to quickly connect all adjacent points in the board.

In this case, team work results from a combination of individual and collaborative actions. *Individual actions* correspond to drawing vertical and horizontal connections, which, due to their similarity, can be generically identified by `DRAW`. *Collaborative actions* are related to moving a cell from the shared into the private workspace, and vice-versa. These actions, named `RESERVE` and `RELEASE`, involve the shared workspace and are required to coordinate work and prevent conflicts.

The case analysis proceeds with detailed descriptions of individual and collaborative actions that players can perform using the groupware tool (see Table 1). These individual and collaborative actions are intertwined and under the control of the groupware tool, which means that their design can influence individual, and especially, team performance.

Table 1. Individual and collaborative actions

Action	Description
RE-SERVE (collab.)	The player: 1) locates a cell in the shared workspace; 2) presses the mouse button over the cell; 3) moves the mouse cursor to the private workspace; and 4) releases the mouse button
DRAW (individ.)	The player: 1) locates a cell point in the private workspace; 2) presses the mouse button over the point; 3) moves the mouse cursor to the adjacent point in the cell; and 4) releases the mouse button
RE-LEASE (collab.)	The player: 1) locates a cell in the private workspace; 2) presses the mouse button over the cell; 3) moves the mouse cursor to the shared workspace; and 4) releases the mouse button

4.1 Predicting execution times

The case analysis proceeds with a usability evaluation with the KLM (Keystroke-Level Model) [3,4]. This model provides quantitative predictions of human performance based on the action descriptions in Table 1. In the KLM each action is converted into a sequence of mental and motor operators whose execution times have been validated in psychological experiences [3,10].

An important KLM requirement is that modeling applies to expert error-free behavior only. This is met in our game since the players are highly trained in drawing connections and in using the groupware tool.

To exemplify the conversion from a detailed textual description into a KLM representation, consider the RELEASE action in Table 1. In steps 1 and 2, player Sophie locates a worked cell in her private workspace; this is converted into the M operator. Then, she moves the mouse cursor over the cell, a P, and presses the mouse button, a K. In step 3 she moves the mouse cursor to the shared workspace, an operation that is translated into a P, without a preceding M since there is no need for finding the workspace. In step 4 Sophie releases the mouse button, K. The total predicted time for the execution of the RELEASE action is obtained by adding the individual times of the KLM operators, which for MPKPK gives 1.2+1.1+0.1+1.1+0.1 = 3.6 seconds.

Interestingly, the KLM models for all the actions in our case are essentially a sequence of MPKPK operators, hence the predicted times are the same. This suggests that the required human skills for drawing a connection between two points are very similar to those needed for moving a cell between workspaces, which seems plausible if we consider Fitts's Law, the sizes of the objects, and the distances between them [3].

The previous time estimates apply to actions as if they were unrelated. To reveal goal achievements (individual and shared) in this collaborative environment it is necessary to understand how work is carried out with the groupware tool. We start with an analysis of individual behavior and then proceed with an evaluation of team performance towards the shared goal.

4.2 Focusing on the individual goals

Given an appropriate cell in the shared workspace, each player accomplishes individual goals by following one of two possible sequences of actions, shown in Table 2. Sequence S1 corresponds to drawing a single connection in a cell. The sequence of actions S2 applies to cases where two line connections can be drawn in the same cell.

Table 2. Sequences for achieving individual goals

S#	Actions	Time (s)	Collab.	Individ.
S1	1) RESERVE 2) DRAW 3) RELEASE	3.6 + 3.6 + 3.6 = 10.8	7.2/10.8 = 67%	3.6/10.8 = 33%
S2	1) RESERVE 2) DRAW × 2 3) RELEASE	3.6 + 3.6 × 2 + 3.6 = 14.4	7.2/14.4 = 50%	7.2/14.4 = 50%

The data in Table 2 is quite interesting because it shows that collaborative actions, RESERVE and RELEASE, are more costly (7.2s; 67% of total predicted time) than the individual action of drawing a connection line, DRAW, that characterizes sequence S1. It is therefore likely that the groupware designer admits that players will avoid such situation and instead prefer sequence S2, due to its lower collaboration overhead (50%) and small increase in execution time (14.4s versus 10.8s), especially when compared to two, instead of one, line drawings per cell reservation.

4.3 Focusing on the shared goal

Based on the previous analysis of individual behavior we can now evaluate team performance towards the shared goal. We start by defining a *goal unit* as a conceptual metric for assessing progress in terms of the shared goal. In the collaborative game, the shared goal is reached when all line connections have been drawn on the board, which gives a total of 24 goal units.

We continue the analysis with a characterization of the sequences of actions along three dimensions, which we think are inherent to workspace collaboration: productivity, opportunities, and restrictions.

The *productivity* dimension measures the number of goal units produced per time unit. The greater the value, the faster the team may progress towards the shared goal. In single-user software design this dimension can be used for measuring individual efficiency. However, with workspace collaboration, team efficiency cannot be determined by simply combining individual efficiencies; we try to capture this with the other two dimensions.

The *opportunities* dimension is related to the intertwined nature of workspace collaboration: if a team member stops, then soon the team will also halt, eventually never reaching the shared goal. This suggests that collaboration among team members is bound by opportunity dependencies created by the achievement of individual goals. The measurement unit for this dimension is new goal unit opportunities potentially created per time unit. The greater the opportunities, the faster the team may progress.

The *restrictions* dimension reflects a possible negative outcome of coordination in shared workspaces: the prevention of conflicts and duplicate efforts (positive outcomes) may slow down or even impede the work of other team members. Restrictions are measured in inaccessible goal units times the duration of the sequence of actions. This unit of measurement emphasizes fast and unobtrusive execution of individual goals: the greater restrictions value, the slower the team may progress, because team members will probably spend more time waiting to proceed.

We are now in position for evaluating team performance toward the shared goal based on the analysis of the sequences of actions S1 and S2 along the three dimensions (see Table 3). As mentioned before, in our case a goal unit (gu) is equivalent to one connection. The main time unit, for convenience, is minutes.

Table 3. Team performance for the initial design

S#	Productivity	Opportunities	Restrictions
S1	1 gu / 10.8 s = 5.5 gu/min	2 gu / 10.8 s = 11.1 gu/min	1 gu * 10.8 s = 0.18 gu.min
S2	2 gu / 14.4 s = 8.3 gu/min	5 gu / 14.4 s = 20.8 gu/min	1 gu * 14.4 s = 0.24 gu.min

The predictions in Table 3 show that S2 is more productive than S1, because S2 takes 14.4s to draw 2 line connections, thus the 8.8 gu/min, in contrast with 5.5 gu/min of S1. Additionally, S2 also compares favorably with S1 in creating new individual goal opportunities for the other team members: 20.8 versus 11.1 gu/min. The reasoning behind the number of opportunities for each sequence of actions is illustrated in Figure 2.

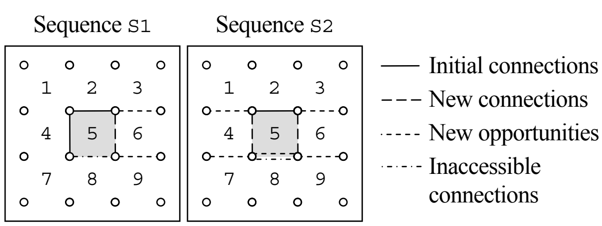

Figure 2. Productivity, opportunities, and restrictions

Using sequence S1 only one vertical connection line can be drawn by Sophie in cell 5, which, in the best case, opens two new opportunities to Charles since he will be able to draw two horizontal connections: the top and bottom lines in cell 6. The missing bottom horizontal line in cell 5 is *not* an opportunity because it was already available via the left vertical connection in cell 5. Actually, this bottom connection is inaccessible to the other players while Sophie is running S1. In sequence S2 up to 5 opportunities can be created after the left and right vertical lines are drawn in cell 5.

The only dimension where S1 is preferable to S2 is in the restrictions to the work of the other team members. The lower 0.18 gu.min of S1, against 0.24 gu.min of S2, is caused by its faster predicted execution time, 10.8 versus 14.4s, since the number of inaccessible goal units during the execution of the sequence of actions is the same in both cases: a single line connection drawing (the bottom horizontal connection in cell 5).

The results in Table 2 and Table 3, which we think are representative of the afforded usability with the current version of the groupware tool, provide a basis for making comparisons with other designs. This discussion will continue in the next section, where a design alternative will be evaluated using the same approach.

5. Alternative design and discussion

Our design alternative for the groupware tool features multiple cell reservations and releases, and awareness information while team members *select* cells in the shared workspace. The motivation for these choices are twofold: a) the impact of collaborative actions in the execution of individual goals can be decreased if the groupware tool allows multiple cells to be reserved or released at once, because more connection lines can be drawn consecutively; and b) cell selections in the shared workspace are faster than cell reservations, which means that awareness information will be more up-to-date.

5.1 Predicting execution times

The new features inevitably imply changes in the *collaborative* actions that characterize the work environment: two novel actions are used for selecting single and multiple cells, SELECT_1 and SELECT_N, and the reservations and releases, RESERVE_B and RELEASE_B, are now a bit simplified. Table 4 shows the new descriptions.

Table 4. New collaborative actions (times in seconds)

Action	Description and KLM model	Time
SELECT_1	The player: 1) locates a cell in the workspace; and 2) clicks the mouse button over the cell	2.5
	1) M 2) PKK	
SELECT_N	The player: 1) locates a cell in the workspace; 2) presses the mouse button over the cell; 3) identifies a second cell that defines the desired imaginary rectangle; 4) moves the mouse cursor to the cell; and 5) releases the mouse button	4.8
	1) M 2) PK 3) M 4) P 5) K	
RESERVE_B	The player: 1) presses the mouse button over a newly selected cell; 2) moves the mouse cursor to the private workspace; and 3) releases the mouse button	1.3
	1) K 2) P 3) K	
RELEASE_B	The player: 1) presses the mouse button over a newly selected cell; 2) moves the mouse cursor to the shared workspace; and 3) releases the mouse button	1.3
	1) K 2) P 3) K	

Table 4 shows that the predicted time for SELECT_1, 2.5s, is lower than the 3.6s required for the previous RESERVE action (see Table 2), which means that players should experience less time dealing with coordination conflicts. On the other hand, the time to reserve a single cell slightly increases because now it takes a SELECT_1 followed by RESERVE_B, with a total of 2.5+1.3 = 3.8s. We consider this tradeoff acceptable because the time to recover from a reservation conflict is, at least, an order of magnitude greater than the extra 0.2s.

5.2 Focusing on the individual goals

The analysis now focuses on the sequences of actions for achieving individual goals (see Table 5).

Table 5. New sequences of actions

S#	Actions	Time	Collab.
S3	1) SELECT_1 2) RESERVE_B 3) DRAW 4) SELECT_1 5) RELEASE_B	2.5 + 1.3 + 3.6 + 2.5 + 1.3 = 11.2	7.6 / 11.2 = 68%
S4	1) SELECT_1 2) RESERVE_B 3) DRAW × 2 4) SELECT_1 5) RELEASE_B	2.5 + 1.3 + 3.6 × 2 + 2.5 + 1.3 = 14.8	7.6 / 14.8 = 51%
S5	1) SELECT_N 2) RESERVE_B 3) DRAW × n 4) SELECT_N 5) RELEASE_B	4.8 + 1.3 + 3.6 × n + 4.8 + 1.3 = *total*	12.2 / *total* n = 1 → 77% n = 2 → 63% n = 3 → 53% n = 4 → 46%

As expected, if players can *only* select single cells, they will probably prefer reserving those in which they can draw two connection lines using sequence S4, in detriment of S3. This is because in S4 the overhead of collaborative actions, 51%, is lower than the 68% in S3.

However, as the data in Table 5 shows, if players see an opportunity for reserving multiple cells at once, then they will likely use sequence S5 when *at least* four connections ($n \geq 4$) are doable in those cells, because the impact of collaborative actions is *at most* 46%, this being unmatched by any of the sequences S3 and S4.

5.3 Focusing on the shared goal

We now evaluate team performance towards the shared goal based on the previous analysis of individual behavior. Table 6 shows values along our three dimensions for the sequences of actions S3, S4, and for three variants of S5, which are illustrated in Figure 3.

The first rows in Table 6 represent the sequences of actions, S3 and S4, which are less restrictive and offer good opportunities, albeit with lower productivity. The last rows describe the more productive variants of sequence S5, but which are the most restrictive and offer only normal opportunities to the other team members.

Table 6. Team performance for the alternative design

S#	Productivity	Opportunities	Restrictions
S3	1 gu / 11.2 s = 5.4 gu/min	2 gu / 11.2 s = 10.7 gu/min	1 gu * 11.2 s = 0.19 gu.min
S4	2 gu / 14.8 s = 8.1 gu/min	5 gu / 14.8 s = 20.3 gu/min	1 gu * 14.8 s = 0.25 gu.min
S5 a)	4 gu / 26.6 s = 9.0 gu/min	8 gu / 26.6 s = 18.0 gu/min	4 gu * 26.6 s = 1.8 gu.min
S5 b)	6 gu / 33.8 s = 10.6 gu/min	10 gu / 33.8 s = 17.8 gu/min	6 gu * 33.8 s = 3.4 gu.min
S5 c)	8 gu / 41.0 s = 11.7 gu/min	13 gu / 41.0 s = 19.0 gu/min	9 gu * 41.0 s = 6.2 gu.min

We end the analysis of the design alternative by noting that the S5 variants in Figure 3 are ideal cases and that actual team performance depends upon the evolving state of the board. However, an exhaustive analysis of S5 variants is clearly unmanageable. By focusing our attention on ideal cases of S5 we can create a reasonable basis for evaluating and comparing team performance towards the shared goal.

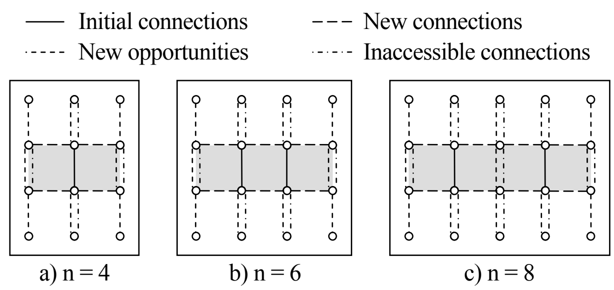

Figure 3. Analysis of three variants of sequence S5

5.4 Comparing designs: the big picture

Our approach for analyzing workspace collaboration now reaches a level that affords comparing the two design alternatives. Figure 4 shows the impact of collaborative overhead in total predicted time versus the proportion of time for doing individual actions. The values are sorted by collaborative overhead to facilitate the detection of the sequences of actions that are more costly to perform in the shared workspace.

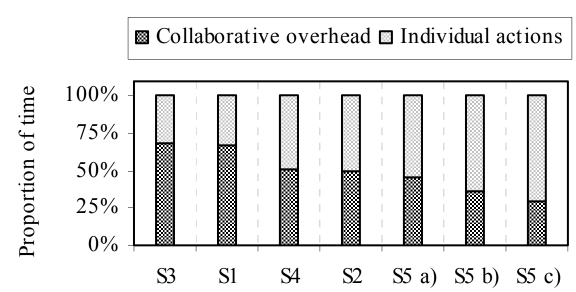

Figure 4. Summary of collaborative overhead

The data in Figure 4 show that the two pairs of sibling sequences, S3/S1 and S4/S2, have very similar proportions of collaborative overhead, and that the variants of S5 have the best proportions of individual actions in total predicted time. These results seem to indicate that the alternative design is preferable to the first design, even more so because, intuitively, collaborative overhead has a negative effect in team performance.

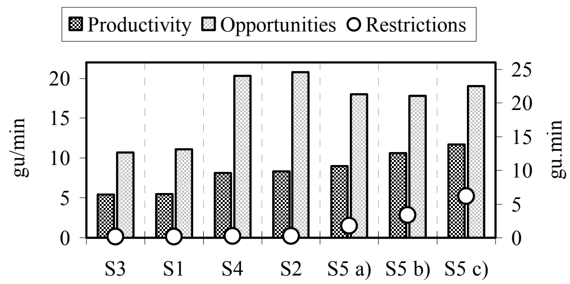

Figure 5. Summary of team performance

To show that the intuition is wrong, at least in this case, we start by stating this proposition: lower proportions of collaborative overhead for achieving individual goals lead to higher team performance towards the shared goal. Now, consider the succession of variants of S5, with equal ordering in Figure 4 and Figure 5. In this succession, reading left to right, the proportion of collaborative overhead steadily decreases while the productivity increases in a symmetrical way, the opportunities remain practically constant and the restrictions raise at a much faster rate. So, contrary to the proposition, the lower the proportion of collaborative overhead in the variants of S5 the *slower* the team progresses towards the shared goal because its team members will probably spend more time waiting to proceed.

Given this somewhat puzzling scenario the designer must find an optimal equilibrium between individual goals and the shared team goal. Were this equilibrium could be is the subject of further work. At the moment the big picture is still getting clearer.

6. Conclusions and future work

In this paper we show how estimates drawn from research in HCI may be used to inform the design of workspace collaboration, in which individual and collaborative tasks are intertwined. In these conditions, groupware usability depends on fine-grained details about how team members interact with the groupware, use workspace awareness, and set their work strategies by balancing the costs associated with the achievement of individual goals and shared team goals.

We propose an analytical approach based on human performance models for examining such tradeoffs in a shared workspace. We define three dimensions, productivity, opportunities, and restrictions, and use them to provide quantitative indications of which design alternatives may be more beneficial to team performance.

Research described in this paper is a preliminary step in the direction of exploring human performance models to evaluate workspace collaboration. We are investigating the development of specific operators related to groupware interaction based on the analysis of typical mechanisms such as workspace awareness or floor control. Then, based on empirical tests, we will attempt to provide estimates for common groupware interactions.

Acknowledgements

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