What's in a Move? Normal Disruption and a Design Challenge

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ABSTRACT
The CHI community has led efforts to support teamwork, but has neglected team disruption, as may occur if team members relocate to another institution. We studied moves in 548 interdisciplinary research projects with 2691 researchers (PIs). Moves, and thus disruptions, were not rare, especially in large distributed projects. Overall, one-third of all projects experienced at least one member relocating but most moves reflected churn across high-ranking institutions. When collaborators moved, the project was disrupted. Our data suggest that moves exemplify normal disruptions. A design challenge is to help projects adapt to disruption.

Author Keywords
Distributed work, turnover, virtual organization, interdisciplinary teams, coordination, R & D, disruption, moving, relocation

ACM Classification Keywords
H.5.3 Group and organizational interfaces. Computer supported cooperative work. Evaluation/methodology J.4 Social and Behavior Sciences, Sociology

INTRODUCTION
Science and technology work is increasingly performed by teams. Evidence of this change can be seen in the growing number of co-authored scientific papers [36]. Teams working on projects exist at universities, industrial laboratories, nonprofit research institutes, scientific alliances, and government agencies such as NASA and NIH. A growing number of projects are large and geographically distributed.

The CHI community has a long-standing interest in computer support for teams and teamwork. Many researchers have studied teamwork in the context of the workplace with its many tasks and distractions [e.g., 24]. Advances have been made in detecting and mitigating daily interruptions [e.g., 19]. Other researchers have examined the distractions inherent in geographically distributed work, with the goal of mitigating the effects of distance [e.g., 15, 5].

CHI researchers have rarely addressed the experience of major disruptive events on teams and teamwork, such as the displacement of key team members. As team leaders and members, we often assume that life will unfold as expected, if hectically. How do we anticipate disruption? Can we design for it?

In this paper we examine one source of disruption in research teams—the move of one or more members to a different university or lab. We show that such events are not rare, and that they have implications for collaborations and projects. We describe the consequences and factors associated with moves, move patterns, and the design challenges involved in these and other disruptions.

Turnover and Disruption
There is a long-standing research literature on turnover (employee losses and gains) in business organizations [e.g., 26]. This literature suggests that personal dissatisfaction with a current situation, that is, a poor match of worker to employer, drives people to move. By contrast, inertia caused by a fairly good (but perhaps not best) job situation keeps people at the same organization [e.g., 20]. The social situation also has an effect. For instance, organizations or teams with more diversity, more conflict, less group cohesion, or less group identity are more likely to lose members [1, 35]. Turnover disrupts routines and creates variability [23].

Little is known about the consequences for research projects when members move. In some respects, more concern could be raised about a stable, closed system in which nobody moved. After some years, research would likely get stale and team members would have redundant expertise. Innovation may require team turnover so that teams are rejuvenated. Preferably, teams bring in newcomers with knowledge and connections [17].

Despite these system advantages of turnover, considerable research suggests that at the project and individual level, moving is a painful experience. Moving entails increasing reliance on online communication, greater geographic distance among members, new institutional allegiances, the pull of local work, and/or less informal communication, all of which increase the costs of coordination [e.g., 7, 8]. There also is some evidence that a person's productivity partly depends on the qualities of his home institution, so that when he leaves, his productivity suffers [16]. In some cases, the project loses the relocated member. This loss can be serious if the person had key expertise or an important leadership role. One analysis of 112 academic "superstars" who unexpectedly and prematurely died shows that their collaborators experienced, on average, a lasting 5% to 8% decline in their quality-adjusted publication rates [2]. Thus, whereas the research system as a whole requires churn to insure cross-fertilization and innovation, the individual project with member relocations is likely to experience disruption of its workflow and relationships, and even face failure if key people disengage.

STUDY OF MOVES

To understand the implications of relocations on research projects, and how support for such disruptions might be improved, we studied collaborative projects with one or more senior members (PIs) who moved to another institution. In today's digitally-connected world, leaving an employer does not necessarily require the mover to leave his or her research projects as well. Furthermore, a mover could join a new team at the new place but maintain old team ties and start an exchange of ideas across teams. Yet getting to this point would still change the dynamics of the originating project. We asked the following research questions: How likely is a research project to have someone who moves? Are there project characteristics that predict who will move? Where do movers go? How disruptive are moves? We were able to use archival data gleaned from NSF and the Web to study patterns of moves, and from a qualitative interview study to examine the experience of project members when members moved.

Our dataset consists of 548 projects funded by the Information Technology Research (ITR) of the U.S. National Science Foundation. The project start dates were 2000 to 2004; projects ran five years or more (some are just ending). The ITR program supported interdisciplinary technology research and education. It was a major NSF initiative, growing from U.S. $90M in 2000 to U.S. $295M in 2004. We analyzed data from Medium projects (up to US $1M per year for five years) and Large projects (up to US $3M per year for five years). Seventy percent of these projects were funded through the Computer and Information Science and Engineering (CISE) directorate of NSF, and over 50% of principal investigators' disciplines were computer science or electrical and computer engineering. The other PIs came from all disciplines supported by the National Science Foundation. Most projects involved multiple PIs (mean = 4.9, range = 1 to 26) and most involved more than one institution (mean = 2.3, range = 1 to 13). Most projects also ran for 5 years plus no-cost extensions for 1 or more years.

Quantitative Analyses

Below, we describe quantitative analyses of the entire dataset of projects and researchers to answer our questions about the incidence of moves and factors predictive of moves and movers.

Variables

Movers. Moves were defined as changing employment to a new institution. To identify movers among the 2691 researchers in our dataset, we needed to know the institution of each PI when his or her grant started (2000 to 2004), and through the end or near end of their project. NSF's database of grants provides the location of researchers when they begin a grant. Approximately 40% of the ITR investigators also had a grant from NSF issued in 2008 or later. For these investigators, we obtained their current institution from their latest NSF award.

For the remaining 60%, we used Amazon's Mechanical Turk workers. Three Turkers were asked to find the current institution of an investigator using web search and university directories. A researcher's final institution was determined using a majority vote of the 3 answers. Some researchers are affiliated with more than one institution. To determine such cases, for any researcher whose starting institution at the ITR award date was different than in August 2009, we asked 5 new Turkers to check university directories and determine with which of the institutions the researcher was still affiliated. This step allowed us to properly disambiguate cases where a researcher was simultaneously at two institutions. Note that our data are pertinent only to PIs or senior personnel listed on these projects, not students, post-docs, or technical staff. (For more information on the benefits and risks of using Mechanical Turk, see [10].)

Number of PIs and Institutions. If moves were randomly distributed, the sampling probability of a project having members who move would be a function of the number of people on the project and the number of universities involved in the project. We used each of these counts as variables in our analyses of factors predicting moves.

Institutional Rank (*R & D Funding*). We were interested in determining if institutional prestige or research standing predicted moves or where people moved. The rank of a university could affect moves in several ways. First, movers are likely to want to improve their situation; thus moves are likely to be to an institution with higher or at least equal standing. Second, if a potential mover is already at a top institution, there will be a ceiling effect, in that there will be few places for this top person to go. Third, PIs at top institutions may experience inertia, or reluctance to move, because they risk giving up good resources, work, and local co-authors. The result of these forces would be that most moves would be upward or lateral, but the higher the standing of the person's current institution, the less likely he or she would be to move.

We estimated institutional rank from the data on R&D expenditures (funding levels) reported by research universities to the NSF, which keeps a publicly available record of expenditures of the top 250 U.S. institutions [27]. We divided ordered expenditures to get five ranked groups. In the NSF data, corporation research labs and foreign universities that do not receive U.S. federal funding are unranked so our analyses were unable to include these institutions.

Publications and Other Controls. Projects differ in their members' productivity. We used the average productivity of members before the project as a variable in analyses. To measure productivity, we counted each project member's publications using the Google Scholar search engine [13]. Because Google Scholar indexes the entire web, including self-published and non-peer-reviewed articles, we also used other measures of productivity including Citeseer [29], which covers computer sciences and related fields, and the ISI Web of Science and Social Science and their citation counts [34].

When considering PI publications for a project, we pooled together all publications from the project investigators and removed any duplicated publications where project investigators collaborated on the same paper. We divided the publications into those published prior to the ITR project start date and those published after this date. To check the quality of these automatically extracted publications, we took a 10% sample and checked them manually using Amazon's Mechanical Turk. For each extracted publication, we asked Turkers to find the corresponding author's webpage or résumé with their publications listed, and check that the automatically extracted publication was indeed correct. Overall, 94% of the extracted publications were correct.

In addition to the above publication data, we were also able to derive lists of publications from NSF final (or most recent) annual reports, and to ascertain (from the NSF website), the number of active NSF grants that members of each project had at the time their ITR project was funded, the start date of their ITR project, and the amount of funding their project was awarded [28].

On 548 projects, nearly 9% of members moved, which seems comparatively small. However, because projects had, on average, nearly 5 PIs, the sampling probability of any project having a mover is the number of PIs times the individual probability. In actuality, the percent of projects with at least one mover was 33%.

Interviews

In 2009 and 2010, we interviewed 55 of all the ITR researchers from 23 universities and 52 of the ITR research projects. We sampled from a geographic spectrum reflecting the spread of ITR projects overall—15 researchers from the Northeast, 13 from the South, 7 from the Midwest, and 20 from the West. We aimed for multiple individuals per institution to help understand differences within and between them.

We conducted half- to one-hour interviews that took interviewees through their projects. Participants were encouraged to discuss their local environment for research and their project experiences. We asked them about how they found their collaborators, planned their budgets and projects, and how they organized the work and publications. For this study of moves, we are interested in discovering (a) if PIs mentioned moves spontaneously when asked to describe their projects, and (b) to determine whether they experienced moves as major events in the life of their projects.

Coding

An external service transcribed the interviews, and the authors coded them, aided by QSR International's NVivo 8 software. Our coding method was based on Strauss and Corbin's [32] grounded theory method, in which existing theory is a partial but not limiting lens for interrogating the data. We started by open coding a small sample of interviews independently, compared our results, adjusted and added categories, and then proceeded to open coding of all the data. We repeatedly discussed our findings to cover the experiences interviewees described.

At the second level of coding, called axial coding, we grouped the lower-level codes into thematic clusters and drew connections among them to tell a story about how the projects evolved. As we continued to develop categories, we also compared what we were learning with existing theories of coordination and collaboration processes. By the final stage, we had identified disruption as a theme running through many interviews. Moves were by far the most frequent source of disruption followed by serious illness or death of a PI.

RESULTS

From regression analyses, we predicted the likelihood of a project having at least one mover and the number of movers on each project. These analyses were run as mixed models with publication data as a within-project variable nested within each project (that is, each project's members have unique publications found using three indexes: Google Scholar, Citeseer, and Web of Science/Social Science). Average correlations among these indexes range from .54 to .90. We also ran logistic regressions on whether anyone moved, and least squares regressions on how many people in a project moved. Since these analyses gave similar results, we only describe one of the analyses below.

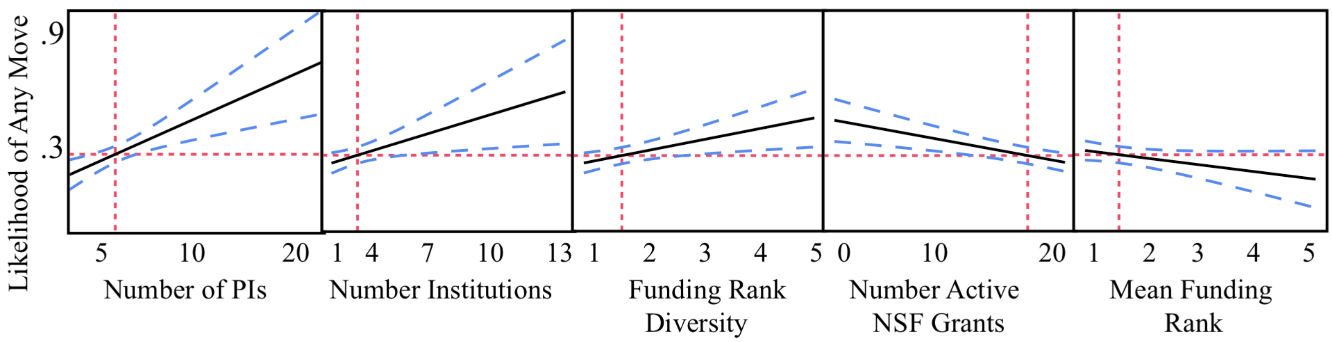

Figure 1. Predicted likelihood of a project having at least one member who moves. (Dashed lines show confidence intervals.) The likelihood averages one-third, and increases with the number of PIs, number of institutions involved in the project, and peer group diversity, but decreases when project members have more active NSF grants, and the average research funding of the institutions involved is higher (peer group rank is higher).

Probability of a project experiencing moves

From a standard least square regression, we found that having a member of a project move was unrelated to the average member productivity prior to the project, to the project's funding, to its number of disciplines, or to when the project started. However, as predicted from sampling probabilities, the likelihood of a project having at least one member who moved was significantly increased by having more PIs on the project ($F [1, 2179] = 12.1, p < .001$). The probability of having a mover was also significantly increased by having more institutions involved in the project ($F [1, 2179] = 5.9, p = .01$). Inertia (and/or ceiling effects) also made a difference. Projects whose members were located at higher ranked institutions were significantly less likely to lose a member ($F [1, 2179] = 12.4, p < .001$). Further, the more active NSF grants held by members of a project, the marginally less likely the project was to lose a member ($F 1, 2178] = 3.1, p = .08$). Finally, more diversity of members' institutions' funding ranks predicted a greater likelihood of at least one member moving ($F [1, 2179] = 6.9, p < .01$). We show these results in Figure 1.

In sum, a project is more likely to have movers if it has more members, more universities involved, and more diversity of rank, and it is less likely to have movers the more grants the PIs have and the more highly ranked its institutions (using the R & D funding measure).

Who moves?

Because moving is something individuals do, we employed hierarchical linear modeling to estimate the impact of various factors on the probability of moving among all 2,691 PIs in the dataset. In doing so, we could estimate how a factor such as a person's own productivity prior to the project, and how his co-authorship with other project members prior to the project, increased or decreased his likelihood of moving. The individual factors we were able to use from the dataset were the rank of the individuals' (initial) institution, whether they were the lead PI or not, their academic rank (professor or more junior), their discipline as CS/EE or other, how many ITR projects and other NSF projects they had, their publications prior to their ITR project, and their prior co-authorship with other members of the project. We repeated these analyses for the three publication indexes we had: Google Scholar, Web of Science, and Citeseer.

In the analyses using Google Scholar publications and co-authorship, we found that higher productivity prior to their ITR project(s) significantly increased a PI's likelihood of moving ($p < .01$), suggesting that those with a better record have more opportunities to move. However, holding prior productivity constant, PIs were less likely to move the higher their institution's rank ($p < .001$), if they were the lead PI on their project ($p < .05$), the more NSF grants they had ($p < .01$), and if they were a full professor ($p < .001$). These results suggest that inertia from a good situation [20] and a ceiling effect due to fewer options that are significantly better discourage moves. Also, with all the above variables in the model, more co-authored publications negatively predicted moving ($p < .01$), suggesting that collaborations at the current institution also hold people to a place.

The Citeseer and Web of Science analyses, with more restrictive definitions of "publication," were similar, but the co-publication findings were not significant. Citeseer is heavily computer science, so undercounts collaborations with other disciplines in non-ACM outlets; Web of Science undercounts conference publications.

Where did movers leave and go?

We next turn to the question of where people moved, omitting unranked institutions that do not receive federal funding. The statistical patterns described above suggest that voluntary moves will be more likely into, rather than out of, highly ranked institutions. Those at a more highly ranked institution are less likely to move, due to inertia and ceiling effects. However, when they do move, the literature on turnover suggests that (voluntary) movers will be focused upward towards more highly ranked institutions.

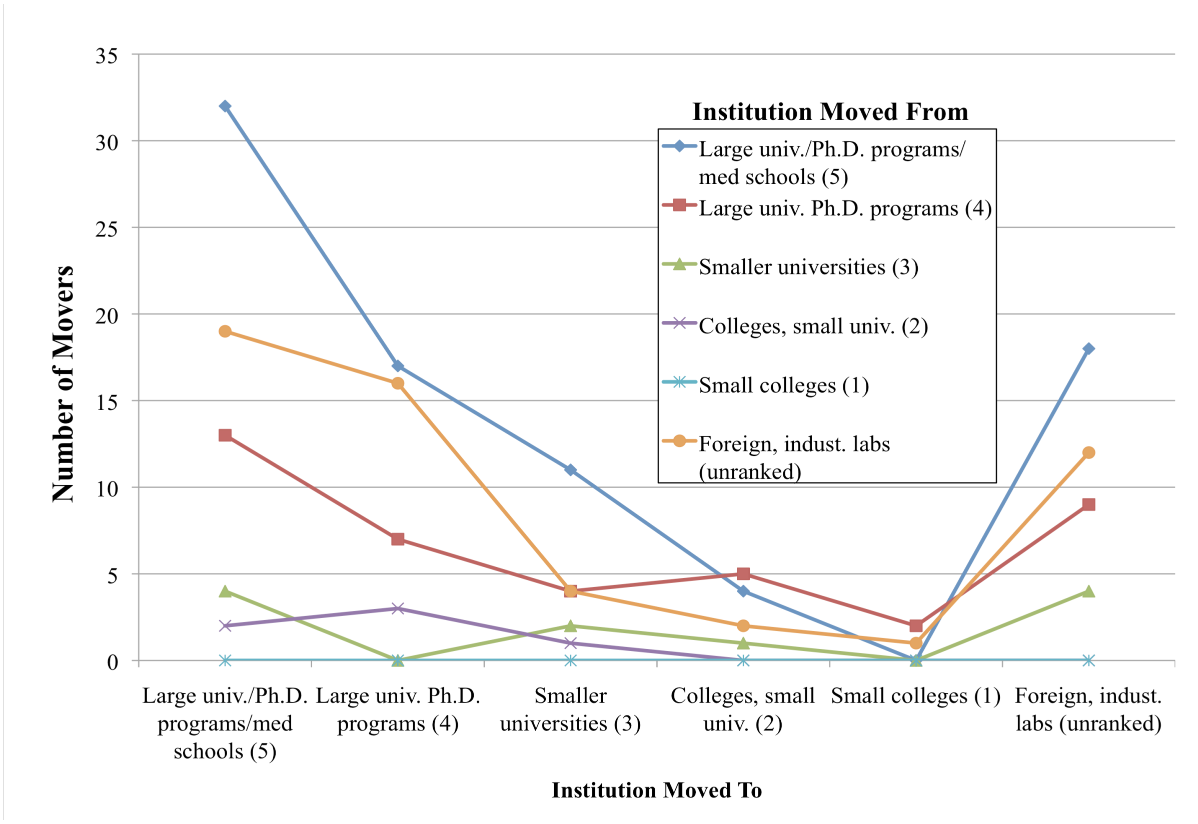

Figure 2. Institutions that movers left and went to, categorized by rank of institution (in parentheses after label). Ranks are derived from R & D funding statistics. The highest rank reflects the top 20% of universities in total R & D funding. Unranked institutions (red) include foreign universities and industrial labs.

Graphically, this pattern shows no cycles, where a cycle is defined in the traditional graph theory sense. Specifically, a cycle is 3 or more institutions in a particular sequence (e.g. A ➜ B ➜ C ➜ A) that have investigators moving from one institution to the next and back again. The fact that our graph has no cycles is not due to chance. In a randomly generated graph, the probability of there being no cycles decays exponentially with the number of nodes, and in case of our graph with n = 91 nodes, a cycle is likely [11,22]. This means that there is a natural ranking of the institutions produced by observing institutions that have the most PIs moving towards or away from them. Nodes that have the highest in-degree and lowest out-degree (the largest number of PIs moving to them, and the lowest number of PIs moving away) are the most desirable in an implicit desirability ranking. By contrast, nodes that have low in-degree and high out-degree are least desirable.

Our data suggest the desirability of an institution is partly but not fully tied to its rank score as measured by R & D funding. There are other rankings we could have used such as the U.S. News rankings, but that would have required us to match movers with department and school rankings. Moreover, some movers changed fields when they moved, requiring a much more fine-grained analysis.

Figure 2 shows the number of individuals who moved to and from institutions in the five R & D funding ranked groups (top 20% to lowest 20%). This chart includes those from unranked institutions such as corporate research labs and Canadian universities that do not receive U.S. federal funding. The chart shows that if people do move, they are unlikely to move from small institutions, and further, that movers tend to move laterally or to larger institutions. Unranked institutions, such as research labs, contribute a set of movers to high-ranking institutions.

Together with the regression analyses described earlier, these analyses provide a partial picture of the moving phenomenon across institutions. At larger, high-ranking institutions, inertia and ceiling effects discourage people at these institutions from moving (a result consistent with economic analyses of turnover). At smaller institutions, few PIs move, perhaps out of choice or because, with teaching loads very high, it is extremely hard to sustain research that will enable moving to a highly ranked institution. The result is quite a few lateral moves, especially to and from highly ranked institutions.

Effects of Moves

To assess the impact of moves on projects, we examined the publications of project members after their ITR grant started, controlling statistically for members' pre-grant publications, start date of project, the number of PIs on the project, R & D funding rank, number of institutions involved, number of disciplines involved, logged proposal funding, and type of publication (Scholar, Web of Science, Citeseer). Here, we are interested in disruption from moves, so we examined the impact on publishing by project members of anyone leaving after the project started. (Results reported here are the same if we count the number of moves.)

The results of these regressions show a surprising trend overall, such that having members move tended to increase total publications of members of the project ($F [1, 535] = 5.1$, $p = .02$), but this trend was true mainly of ITR projects that were an average size of five PIs or smaller. Modeling the interaction of anyone moving and the number of PIs gives a large interaction effect ($F [1, 535] = 6.9$, $p < .01$). The effect, shown in Figure 3, shows that large projects experienced lower publication rates when people moved.

The negative effects of moves on large projects might be explained in at least two ways. First, perhaps large teams fail to take the departure of a PI as a serious event and they underestimate the need to address the impact of this departure on the research by, for example, redistributing tasks. Such a result accords with research on injuries in professional hockey. Stuart [33] found that when stars left professional hockey teams, these teams restructured themselves and maintained their performance, but when average players left, the teams mostly ignored these departures and failed to maintain their performance. Another possible reason why large research teams might publish less after members leave is that they try to restructure themselves after a departure, but are not able to adequately do so. We also saw that more people moved in distributed projects, and distributed projects were more seriously impacted. This phenomenon suggests that distance could have impaired large teams' ability to adjust

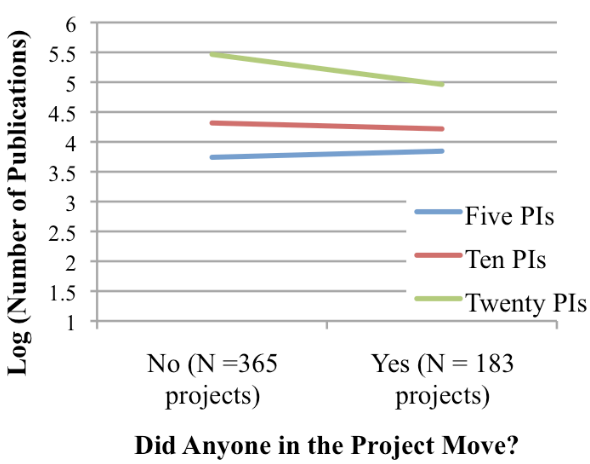

Figure 3. Effect of one or more movers on publications by project members, as a function of the number of PIs, controlling for pre-grant publications, the number of institutions involved and other variables—see text). A median project, with five PIs, slightly increases its rate of publication with anyone moving, but members on projects with many PIs published significantly less when members moved.

to members' moving.

Before we leave these quantitative analyses, we need to remind readers of a major limitation of these analyses. That is, we do not know which of the movers in our sample abandoned their old ITR project and which of them continued to work it with despite moving. For that reason, we do not know whether movers' publications were from their ITR project or a new project. One hint that movers tended to leave their ITR projects is found in an analyses of the number of co-publications with other members of the ITR project. We observed the same pattern as shown in Figure 3. That is, when members moved, co-publications among project members did not change overall, but co-publications were reduced significantly when the project was large ($F [1, 513] = 1.9$, $p = .05$). These data suggest that movers were more likely to abandon large ITR projects than smaller ones.

Interview Results

Eighteen of 55 interviewees spontaneously mentioned that one or more people on their project (or they, themselves) had moved. (This ratio is representative of the dataset as a whole, i.e., one-third of all projects contained at least one person who moved.) We examined interviewees' narratives to discern how moves were linked to other experiences of the research project and team.

Moves were surprising and disruptive

Job searches by researchers are usually clandestine because job seekers do not wish to jeopardize relationships and standing in their current position if a job offer does not come through. Thus when project members moved, it was usually a surprise to all but their closest colleagues.

> *He went off and became, you know, he's a tenured full professor in the [science] department. So you know, these are sort of unexpected, but they're sort of good things.* (Researcher #24)

Moves created unanticipated work for movers and the rest of the project team. Movers had to attend to the task of restructuring their lives. Those who remained had to find replacements, re-budget the project, or accomplish tasks left behind. Sometimes the distance between collaborators increased significantly (Figure 4), so the effort required to maintain the collaboration and supervise students also increased.

> *Two people of the project, two of the initial people, left because one of them didn't get tenured. The other one left for personal reasons. So that also created some turmoil in terms of who's going to do that part of the work. And so I as the PI got a little overwhelmed with doing the individual people's work as opposed to coordinating it.* (Researcher #36)

> *So there were some issues, you know, with budgets and shifting and creating new subcontracts.* (Researcher #51)

Not the only sort of bureaucratic issue we had initially when ____ left was since he still wanted to support [his graduate students at his former university]. Then in the process, maybe at the time he was already negotiating this, but he went to [new university] and his students stayed in [former university]. And so he was still supervising the students sort of but he wasn't part of the phone calls and things like that and sometimes-- and it was awkward for his colleagues I think at [former university] to tell the students what to do… So that was a slight-- it was actually something of a problem. (Researcher #12)

Moves created actual and psychological distance

In addition to the concrete tasks created when people moved, physical and psychological distance increased between those who moved and those who did not (see Figure 4). Physical changes increased the amount of planning and effort to communicate, and that, plus psychological distance, sometimes caused a reduced willingness to share funding and students with those who moved. Some movers subsequently became inactive in their project.

[This] guy moved to [new university], and I really don't know if he was involved with the grant after that. Like, I did not have any interaction with him. That's why I'm blanking on his name. (Researcher #52)

She later left for the [new college], so we ended up not using her very much. (Researcher #35)

He moved to ____ but I think when he moved over there, he did not really carry his funding with him. ... He's sort of a collaborator. (Researcher #54)

Moves could invigorate projects

As our quantitative results suggest, movers or their teams sometimes benefited from moves. (Quantitative results suggest these effects occurred on teams with five PIs or fewer.) For instance, at the new university or lab, the project could receive valuable new exposure and new colleagues or students.

I think it [the move] helped in the sense the area that he was working in for this project, I think it raised his visibility with some of the people at [his new university]. (Researcher #51)

[He] relocated… so that sort of extended what would have been a four institution project to a five institution project, and we ended up incorporating his new junior colleague ____. (Researcher #49)

This finding is reminiscent of James March's [23] theory of exploitation and exploration in which modest personnel turnover reduces the average knowledge of individuals in a team (because experienced people depart and new people are still learning). However, turnover increases aggregate knowledge. The increase comes not because individuals know more, but because old-timers tend to know the same things. Newcomers, like the junior colleague and post-doc added to the project, are less experienced but what they know is less redundant with the knowledge of the team, thus likely to improve innovation.

DISCUSSION

The quantitative data are consistent with the argument that moving is "normal." It is normal because it occurs statistically quite often, and it is normal because it arises

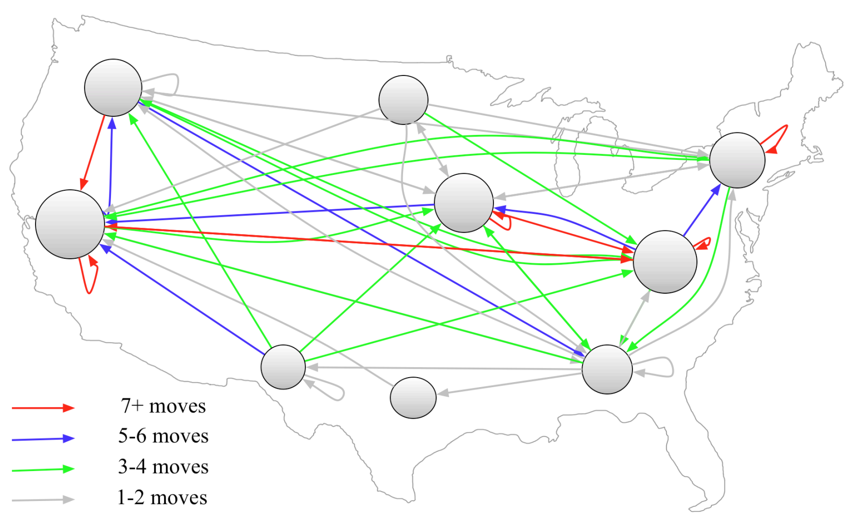

Figure 4. Moves of project members within and across regions of the United States.

from the expected career and personal interests of individual investigators (e.g., to move from an undesirable employer to a better one). Thus, projects are likely to experience movers whether they are good or poor projects, although larger projects, and distributed projects, have a higher probability that someone will move.

The interviews suggest that when project members move, it is a disruptive event in the life of a project. Moving is disruptive in a different way than daily interruptions and distractions [19] on the one hand, or extreme crises or disasters, such as Hurricane Katrina or war, on the other [14, 25, 30]. Moving rarely threatens the entire project but it can change the structure of the project, relationships among collaborators, the workflow, and nature or distribution of research tasks. If the project team does not address these difficulties, its performance will fall. We see in our quantitative analyses that larger and more distributed projects are more likely to experience negative outcomes. We think that happened either because the team did not think to adjust to the moves or that it could not, due to the large coordination costs that would be involved.

Although moving was the most frequent source of disruption mentioned in the interviews, it was not the only one. Projects experienced PI death or serious illness (4 projects), key students failing or abandoning important tasks (5 projects), major legislative or organizational changes (3 projects), and long PI absence (1 project). All of the latter were described as surprises, out of the control of the project itself, and negative, with serious impact on the work or group dynamics.

> *And I can't continue to work with ___ because he's dead now, which has been a terrible thing for me, because a lot of the projects I was working on actually, when he died, were with him*. (Researcher #19)

> *And when the student kind of failed at the task, she was not replaced with another student…we did a lot of work that had to be thrown away.* (Researcher #42)

> *Congress cancelled the project, so we couldn't do our piece of the work.* (Researcher #13)

> *The manager we had been working with retired ... and was replaced by someone who was incredibly hierarchical… [and we had to abandon that part of the project]* (Researcher #33)

> *Well, I was actually gone for three years*. (Researcher #53)

If we add these projects to those that experienced movers, we find that over half of the projects whose PIs we interviewed experienced at least one disruptive event in the course of their project. We are not able to generalize to other kinds of teamwork or research projects, but it would probably not be too far off to guess that many teams and projects are likely to experience disruption as well.

DESIGN CHALLENGE

If we can speculate, based on our data, that more than half of all research projects will experience an unpredictable disruption, teams should proceed with this possibility in mind. How might we think about designing for collaborative support in the face of disruption?

One approach would be to structure the team to reduce the risk or effects of disruption. There is a large literature on planning for disruption in service and manufacturing industries [e.g., 21], from which we might take some general ideas and quandaries. One common theme in the disruption literature is that using highly optimized, lean teams and practices increases vulnerability to disruption [31]. This is especially true when tasks are interdependent, as is typically the case in research. Redundancy will increase reliability. For instance, ideally, a project engages PIs and students with overlapping expertise, such that if one person or piece of work is lost, the knowledge of that person or work is not lost as well. A few of the PIs we interviewed were able to use redundancies to reduce project risk:

> *Then after I moved to [new university] I took some chunk of the ITR and I was doing a project that was again related to [field of ITR project] but was more the kind of stuff that I wanted to do and I was less involved with the [project] ... but I had a post-doc on that part and I think it was very sort of formative for him.* (Researcher #3)

Nonetheless, redundancy is often infeasible in today's lean project teams. Redundant experts can increase costs, coordination overhead, and conflict; moreover, redundancy increases the size of the project, which may itself have negative impact.

As an alternative to redundancy, project members can reduce their interdependence by decoupling tasks and running a more loosely-coupled project. Many projects did decouple tasks, especially across sites and disciplines, with the aim of reducing coordination costs and increasing efficiency [4]. All had the ideal goal of coming together later, but by splitting up the work early, teams reduced the likelihood that the research would be integrated.

A problem with advance planning is that few disruptions are the same. For example, an "output disruption" (e.g., a member stops working on the project) suggests that the work should be spread across sites or people, but an "input disruption" (e.g., funding cuts) suggests that the work should be centralized in one site so that the effects can be rationalized. Moreover, there is some evidence (albeit from laboratory studies) that deliberate planning does not help groups adapt to disruption, and is unrelated to whether they are, in fact, able to adapt [9].

Collaborative systems, however, could be designed with team resilience as a goal. For example, research projects should be able to re-organize project budgets within and across affected organizations when someone moves. A shared system for administrators across institutions could allow all parties to view constraints and requirements, and to negotiate adjustments. Yet currently, budgeting is neither malleable nor collaborative.

> *I was just going to suggest that if there was one thing I could point to that would make things easier, it's that the people who provide support [for research] in the university… budget and so on, it's kind of unfortunate that they don't get to collaborate. You know, they are isolated in their cubicles*. (Researcher #11)

Requirements for collaborative resilience

We argue that an important challenge for designers of collaborative systems is to help teams develop and sustain collaborative resilience in the face of disruption. We define collaborative resilience as the ability of a collaboration to recover successfully from disruption, and to adapt (or reinvent) the project as its circumstances change.

Research in resilient social systems suggests that resilience increases when people communicate across multiple networks, and experiment with new arrangements and ways of thinking [12, 18]. The same environments, networks, and team climate that encourage innovation also could support resilience [3]. Thus, as noted above, collaborative systems for research administrators would open up bureaucrats' horizons on budgeting as well as help them cope with the moves of PIs. Collaborative systems to support joint Ph.D. degrees across institutions would encourage creative thinking about curricula as well as help support interdisciplinary students. Collaborative systems for cross-disciplinary advising of students would encourage multiple perspectives on research methods as well as increase shared knowledge and situation awareness in a project. And easy-to-use applications for project managers to create network diagrams of project member advice and work networks would not only help them leverage the teams collective knowledge, but would aid them in assessing cross-boundary collaboration strengths and ensure integration of work following a restructuring of the team [6].

CONCLUSION

Relocations of team members during a research project are an example of events that frequently disrupt teams and their work. Our work contributes to the field of HCI by highlighting the experience of disruption of collaborations because of people moving. Collaboration is a long-standing topic in HCI but sources of instability have not been studied. We show in a dataset of 549 teams that losing members due to moves was surprisingly likely and, from our quantitative data that moves are associated with a loss of productivity in large teams. Qualitatively, teams experienced moves as disruptive and had to adapt to this disruption. These findings are important for design of technologies for collaboration, which typically assume stability of membership. Teams experiencing disruption are not well supported by today's collaborative systems. Systems that better link and make visible horizontal (e.g., administrators and students across institutions), diagonal (e.g., administrative persons at other institutions, and vertical (e.g., administrative and operational personnel) tiers of research projects might improve both innovation and resilience to disruption in research teams.

ACKNOWLEDGMENTS

We thank the National Science Foundation for support of this work through grants OCI-0838385 and SBE-0830306.

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