# Close, But Not Close Enough:

# A Spatial Agent-Based Model of Manager-Subordinate Proximity

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Abstract

Employees may be co-located with their manager or they may be separated by distances ranging from a short walk to across oceans, with many gradations in between. Some distances, such as those between floors of an office building, are physically short but may be psychologically quite far. The current project developed a spatial ABM to examine the likelihood of unplanned manager-subordinate encounters in an office setting with two floors. Early results suggest that subordinates located on a different floor than their manager are substantially less likely to have even a single spontaneous encounter with their manager in a work day, despite a relatively short physical separation. If leader-follower (i.e., manager-subordinate) relationships are influenced by spontaneous face-to-face encounters, this finding represents a challenge for organizations with managers having subordinates who are close, but not close enough. Additionally, attempting to impose top-down requirements to travel between floors (e.g., when scheduling meetings) may do surprisingly little to abate this problem. Implications of these findings for organizations are discussed, as are limitations and future research, including possibilities for future model verification and validation.

*Keywords:* workplace design, supervision, leadership, management, employee performance, virtual teams, leader distance, collaboration, agent-based modeling, ABM

# Close, But Not Close Enough: A Spatial Agent-Based Model of Manager-Subordinate Proximity

Organization science research has examined how distance impacts leader-follower relationships and outcomes (e.g., Brunelle, 2013). Most studies are concerned with so-called virtual work, in which collaborating employees are not physically co-located. "Virtual" and "co-located" are potentially fuzzy terms when considering spatial proximity of managers and subordinates, however. A subordinate who sits outside his manager's office would seem to meet the definition of co-located, but what if the subordinate sat in a different building on the same campus? Would it make a difference if that campus is a sprawling university or small urban research hospital? Many possible spatial configurations of managers and subordinates exist, ranging from adjoining desks to different continents. In fact, astronauts stationed on the International Space Station are arguably not on the same planet as the person who likely provides their performance appraisals!

When Steve Jobs was CEO of Pixar, he reportedly obsessed over the design of the company's new headquarters, requiring the bathrooms be located in the central atrium, ostensibly because he appreciated the value of networks and wanted to facilitate serendipitous personal encounters between Pixar employees (Isaacson, 2014). Very few studies have examined quantified spatial distance as a variable affecting either individual psychological outcomes or performance. In a self-described first of its kind study, Lee, Brownstein, Mills, and Kohane (2010), examined whether the actual physical proximity of collaborators affected the scientific impact of their research, as measured by citation counts. Coding each collaboration to precise geolocation in three-dimensional space, the microscale (same building) proximity of first and last authors on publications was a significant predictor of impact. The mean citation for this relationship decreased as distance increased up to 1 kilometer as well as in the three categorical ranges of same building, same city, or different city.

Organizations typically grow organically and employees are usually assigned to supervisors based on the organization chart, not precise seating location. Physical location may be a consideration in supervisor assignment, but the widely-held belief that technology enables effective virtual work likely decreases the weight given to assigning an employee to a co-located supervisor rather than a supervisor who is closer to the employee in the organizational hierarchy. The unpredictable growth of organizations coupled with high costs of real estate in many areas inevitably results in odd seating arrangements: if all seats in an office suite are occupied, a new employee may be assigned a space in a different suite or different floor. Various overlapping "teams" also exist in organizations: a common dilemma is whether to co-locate the executive team horizontally or co-locate each executive with the vertical team that he or she manages (Frisch, 2012). Legacy factors may weigh heavily in such decisions: if an employee has worked from a particular location for a length of time, s/he may simply stay put regardless of changes in role, responsibilities, or reporting relationships. Altering lines on an organization chart is easier than physically relocating employees, which may be one reason why organizational changes happen more frequently than employee relocations. Work groups may also be assembled on a short-term or ad hoc basis, and the costs of physical relocation may be unjustified for such temporary relationships.

How should organizations address the physical proximity of employees and the location of managers and their subordinates, in particular? If impact is greatest for collaborators with the shortest physical distance between members (Lee et al., 2010), this suggests that organizational decision makers might give additional weight to co-location of collaborating employees, perhaps even prioritizing geographic location over organizational structure or other factors in making either space-assignment or reporting relationship decisions. While Lee et al. (2010) conducted their analysis using entirely secondary data, other studies have used self-report questionnaires to examine the relationship between supervisor-subordinate proximity and psychological variables and performance outcomes (Connaughton & Daly, 2004; Kieffer, 2015). Self-report questionnaires explore some of the potential mechanisms that might result in performance differences but typically lack the fine-grained spatial information used by Lee et al. (2010). The complex nature of organizations and individual psychology also make conducting true experiments of space assignment and reporting relationship decisions impractical. As a result, most data comparing co-located and virtual workers is self-reported, subject to bias, and at best yields correlations and speculation on causes and processes. An ABM allowing individual agents to interact in precisely defined and quantified space can serve as a virtual laboratory for exploring the effects of manager-subordinate proximity on both proximal outcomes like frequency of contact and perhaps ultimately such distal outcomes as employee and organizational performance. This preliminary effort developed a spatial ABM simulating a work organization in which subordinates interact with managers through spontaneous encounters. Of particular interest is whether the physical seating locations of individuals with reporting relationships might enhance or detract from an effective manager-subordinate relationship.

**Leader Distance, Workplace Design, and Collaboration**

Wilson , O'Leary, Metiu, and Jett (2008) lament that organizational scholars have not sought to understand distance as a dynamic phenomenon like time and instead have mostly viewed distance objectively, in physical terms only. They describe a theoretical model that attempts to explain the "far-but-close" and "close-but-far" paradox in which objective physical distance likely only accounts for a fraction of perceived proximity, owing to a number of individual and socio-organizational factors and mediated by communication frequency and depth and identification with the other (Wilson et al., 2008). Antonakis and Atwater (2002) in a highly-cited review of leader distance, suggest that leader distance is comprised of physical, perceived social distance, and perceived task interaction frequency, and the interaction between these factors, suggesting that physical distance is not specifically required for positive leader-follower relations so long as distant followers are exposed by other means to the leader. A particular challenge with this literature is the ambiguity of operational definitions and various types of distance; for example, Avolio, Zhu, Koh, and Bhatia (2004) note that "structural distance" has been defined as physical distance between leader and follower, organizational structure, and supervision structure. While physical distance is frequently found to moderate leader-follower and performance relationships (e.g., Howell & Hall-Merenda, 1999), the operationalization of the physical distance variable varies substantially across studies.

A separate literature exists on the effects of workplace design on collaboration. Allen's classic work examined the design and layout of R&D organizations and impact of design on collaboration (Allen, 1997, 2007). Allen (1997, 2007) noted that individuals are generally averse to using elevators, suggesting that individuals' mental representations of a building are, for the most part, constrained to the single floor on which they are located. He lauded Bell Labs for creating lengthy hallways with cellular offices, requiring that scientists pass by the offices of many others while traveling to other in-office destinations. Augustin (2014) opens a recent issue of the Journal of Interior Design with a review of designing workplaces for collaboration, noting a recent resurgence in face-to-face communication, the only current means of communication capable of transmitting *all* of the complex information—including body language and chemical signals—that humans have been using for thousands of years. Allen (2007) similarly suggested that "Type I" communication – basic information required to get the job done – is easily transmitted using either face-to-face or technologically-mediated communication and does not decay with physical distance, but more complex "Type III" communication providing inspiration and promoting creativity and innovation nearly disappears with physical distances greater than 30 to 50 meters. Proximity of team members on 145 different software teams predicted innovation and quality (Hoegl & Proserpio, 2004), and co-location substantially affects performance of biomedical researchers, (Lee et al., 2010), mentioned previously. Space syntax (Bafna, 2003) has been used to investigate how office configurations and social networks interact and is a superior measure to Euclidean distance in predicting tie formation (Sailer & McCulloh, 2012). Finally, visible co-presence (i.e., seeing another employee from your desk) is highly predictive of face-to-face interaction, though movement patterns may not be particularly consequential in some organizations (Rashid, Kampschroer, Wineman, & Zimring, 2006).

A distinct, qualitative difference may then exist for employees who are separated by floors in a building, which is not currently captured in the literature on co-located and virtual teams. The studies that view distance in only coarsely dichotomized physical terms (i.e., co-located or virtual) do not make this fine-grained and potentially important distinction between employees they lump together as co-located.

**Prior Agent-Based Models**

ABM is not typically used by organization science researchers. However, Powell (2013), an undergraduate student of Uri Wilensky, in an unpublished model and paper titled "Workplace Layouts and Collaborations," used NetLogo to explore how various office layouts affect the possibility of research collaborations following physical encounters. The current model was influenced methodologically by Powell's (2013) model, but tests a different research question: Can a spatial ABM of a multi-floor office help to quantify the amount of "unearned" manager encounters that subordinates receive as a result of their seat location?

## Method

Appendix 1 provides the detailed ODD for the agent-based model (Grimm et al., 2010). Figure 1 displays the model GUI. The current model uses an open-office layout[1], in which employee agents sit at long tables in the open room and manager agents sit in offices on each floor. A cell grid (not visible) is overlaid on the office; cells represent spatial locations in the office as network nodes connected to neighboring locations with an elevator as the only possible path between the first and second floors.

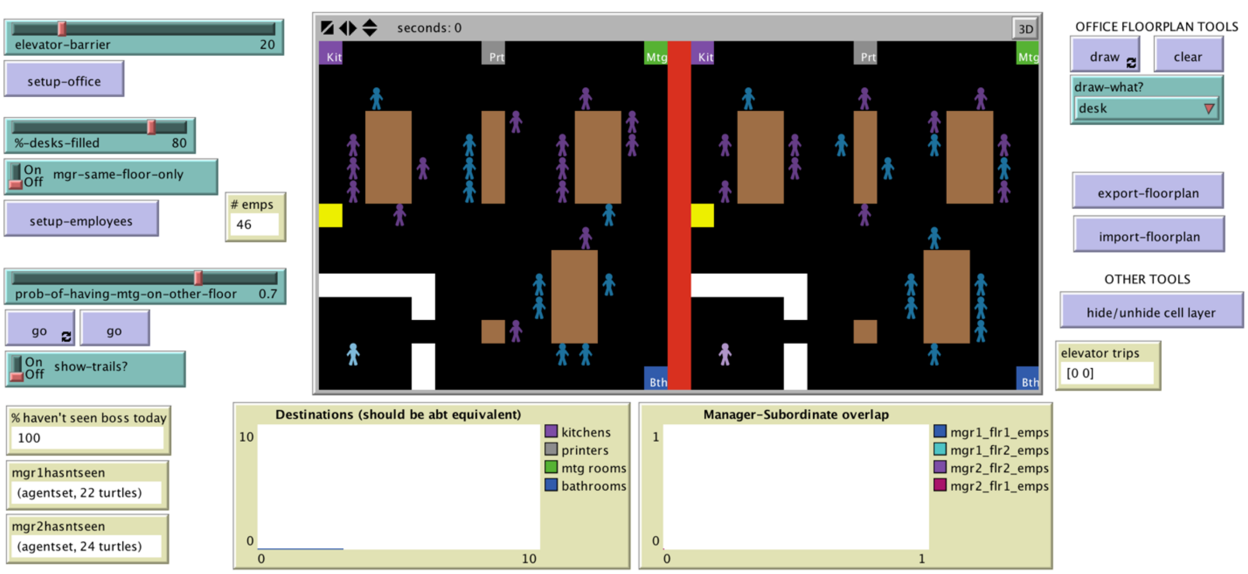


**Figure 1.** Model GUI, displaying spatial layout of two office floors connected by a single elevator (yellow). Managers sit inside offices in the corner of each floor, and employees sit on a randomly-chosen side of a desk, with no more than one employee per (square) desk space. Destinations are distributed along the perimeter of each floor, including the kitchen (Kit), printer (Prt), meeting room (Mtg), and bathroom (Bth). Agents *only* utilize the elevator to go to the meeting room on the other floor; it is assumed that all employees would choose to remain on the same floor for kitchen, printer, and bathroom use.

During the workday, agents leave their desks at various times and travel to the printer, bathroom,

[1] Other spatial configurations or layouts are possible.

kitchen, or meeting room; spend time at their destination; and finally return to their desks. The frequency and duration of trips result from time lengths assigned by random draws from distributions (see Appendix 1, ODD protocol). Agents use the elevator only to travel to meetings on the opposite floor. Agents record the duration of encounters with each other.

The current model focuses on the probability of encounters between managers and subordinates and how probability varies when managers and subordinates are separated by floors. The primary research question is whether placing subordinates on a different floor than their managers will drastically reduce manager-subordinate encounters. Using the stable model, output from multiple runs[2] of the control condition (employees assigned only to the manager on the same floor) was compared with output from multiple runs of the experimental condition (employees assigned to a manager on either floor). The primary independent variable in the experimental simulations is manager assignment and the dependent variables are manager-subordinate face-to-face interactions and the length of time manager-subordinate pairs "overlap" spatially. A secondary IV was also varied – the probability that an employee would go to the meeting room on the other floor via the elevator. The intent of manipulating this second variable was to examine to what degree imposing top-down control on agents' behavior might affect the dependent variables.

While desiring that managers see every subordinate every day may seem like an arbitrarily high bar for busy managers in modern organizations, the possibility that a particular spatial arrangement might lead to persistent, ongoing patterns of contact in which certain employees rarely see their manager while other employees frequently see their manager can affect constructs related not only to leadership and supervision, but also employee satisfaction and performance. The current model does not adhere to any specific theory of how manager-subordinate contact affects such outcomes, but assumes that little to no in-person contact with a manager, despite being physically located in the same building, negatively affects the development of a positive leader-follower relationship.

**Calibration, Sensitivity Analysis, and Verification and Validation**

The current model is abstract and was not calibrated to empirical data. An attempt was made to source calibration data, but surprisingly little empirical data could be located on, for example, how frequently office workers actually use the restroom each day. Sensitivity analysis was conducted through parameter sweeps to ensure that no aberrant agent or model behavior occurred as a result of parameter manipulation.

Model verification occurred during development using unit tests written into model code (Wilensky & Rand, 2015). Validation requires at least some concordance between the model's behavior and the behavior of the target system (Gilbert & Troitzsch, 2005). One validation strategy is to invite subject-matter experts to review the model process and either criticize assumptions and behavior or confirm that agent and model behavior are plausible. The current model is intended to be a parsimonious, straightforward, and abstract representation of a modern office such that almost any knowledge worker should be in a position to validate at least the general plausibility of agents' behavior.

Obtaining data for quantitative validation was not feasible for the current modeling effort. Crooks, Croitoru, Lu, Wise, Irvine, and Stefanidis (2015) recently suggested "scene activity analysis" as a methodology for improving pedestrian agent-based models, relying on the increasing availability of video surveillance in urban spaces and mobile device geolocation data. The current model is essentially a pedestrian ABM, so such data would be extremely beneficial in calibrating and validating employee movements, but is unfortunately difficult to obtain for workplaces.

[2] Multiple runs necessary since each model run unfolds differently due to stochasticity.

## Results

Initial results suggest subordinates with a different-floor manager are far less likely to spontaneously encounter their manager than those assigned a same-floor manager. While not terribly surprising, the magnitude of the result is noteworthy. When all of a manager's subordinates are on the same floor as the manager, even managers of as many as 20 to 26 subordinates will encounter almost every employee at least once during an 8-hour workday as employees and managers simply travel around the office to get food or drink, obtain printouts, or use the restroom. These encounters occur in the absence of any top-down scheduling of meetings, interactions, or any formal work processes whatsoever, suggesting that even without work-related encounters with employees, same-floor managers should have an opportunity for at least one face-to-face interaction with nearly every subordinate, every day, with only 2.2 to 3 percent of employees not seeing their same-floor manager on a given day. When assignments to a manager on a different floor are permitted, however, the percentage of subordinates never seeing their manager increases sharply, with an average of between 24 and 38 percent of each manager's team never encountering the manager that day. This result occurs even though every employee—including managers—has a 50 percent probability of visiting the meeting room on the other floor each time their destination is a meeting room.

**Manager-Subordinate Encounters.** As described above, assigning employees to managers on different floors dramatically reduced the likelihood of manager-subordinate encounters over the course of the day as simulated over 100 runs. Table 2 provides descriptive statistics from the experimental runs.

**Table 2.** Results from 100 experimental model runs.

| | Subordinates (constant) | Average number not seen in a single day | Min number not seen | Max number not seen |
|---|---|---|---|---|
| Manager 1 (floor 1) | 28 | 6.7 | 3 | 13 |
| Manager 2 (floor 2) | 18 | 6.8 | 3 | 10 |

**Random Encounters – Employees.** The model was also used to examine how employees' assignment to an open-office environment might affect random encounters. With an employee population of 48 (i.e., 2 managers, 46 subordinates), the average number of unique other employees a single employee will encounter in the course of a day is 33.8 individuals, or nearly 70 percent of the total organization population.

**Effect of varying probability of meeting on other floor.** The effect of manipulating a second independent variable – the probability of an employee going to the meeting room on the other floor – was investigated. The default probability was arbitrarily selected as 0.5. In reality, the probability of staying on the same floor for a meeting is probably quite high, but this represents a potential behavioral lever for organizational use in an attempt to increase random encounters. Whether by edict, norm, or conference room booking software, employees could be somehow required to schedule their meetings on floors other than their own. A set of model runs examined the outcome of setting this parameter to either 0.3 or 0.7, with 20 runs conducted for each of the two conditions. Manipulating this variable did have an effect: overall, unique individuals encountered, on average, increased from 32.1 with probability at 0.3 to 35.9 with probability at 0.7. For manager-subordinate encounters, percentage of subordinates who did not see Manager 1 decreased from 36.8 to 30, and percentage of subordinates who did not see Manager 2 decreased slightly from 48 to 47 percent. This slight gain, however, would likely not justify a seemingly onerous requirement to attend 70 percent of one's meetings on a different floor!

## Discussion

The disparity in random encounters between same-floor and different-floor manager-subordinate assignment conditions raises questions about the effectiveness of locating managers and subordinates on different floors if random encounters between managers and subordinates do in fact play a substantial role in the leader-follower relationship. If people or places on a different floor of a building are cognitively "invisible" as Allen (1997, 2007) suggests this creates an obvious problem: by being out of sight, both managers and subordinates are consequently out of each other's minds. This effect may have additional implications for the distribution of prime work assignments, opportunities for performance observation, and giving/receiving timely performance feedback. Moreover, despite the knowledge work taking place in many modern organizations, some managers nevertheless subscribe to an industrial-era mentality regarding performance: an employee's time at her desk is believed to equate to performance. Managers will frequently have the opportunity to observe same-floor subordinates at their desks, but will have far fewer opportunities to observe different-floor subordinates at their desks. Bias in performance ratings is one possible consequence. Second, as mentioned in the introduction, organizations often grow organically in both workforce and office space and rarely are the two in sync. Nor are organizations in the habit of keeping prime central office space free for newly-hired personnel. Far more often, the newest hire can find himself at the greatest distance from his manager and team, sometimes in a temporary or makeshift workspace, possibly on a different floor. These results suggest a new employee might therefore see far less of his manager than other, more tenured employees do, with obvious implications for the new employee's onboarding and developing a relationship with his new manager, disadvantaging the new employee from the outset with regard to work opportunities and early performance feedback.

The present model represents an initial effort at modeling the impact of the spatial arrangement of employees and how spatial factors might affect contact with managers. While an extensive literature exists measuring psychological distance between leaders and followers, physical distance has not received the same scholarly attention. When physical distance has been considered, distance measures are often coarse and researchers typically have limited understanding of human spatial attributes, movement, and patterns. While rich data on who talks to whom exist from technologically-mediated communication such as voice-over-IP (VoIP), email, and instant messaging, face-to-face interactions remain far more elusive to measurement. Spatial ABM is the logical choice for investigating these research questions of face-to-face interactions. Ideally, empirical data on employee movements and face-to-face interactions would be used to calibrate and/or validate a spatial ABM in order to move models like the current effort from abstract to empirically analyzable models more suited to either historical explanation of observed outcomes or possibly projection of future outcomes (Parker, Manson, Janssen, Hoffmann, & Deadman, 2001). This type of progress could free organization scientists from being shackled to only what exists in the "big data" datasets and instead allow the possibility of asking "what-if?" questions about outcomes that either haven't yet or may have happened but haven't yet been recorded, even in the "big" data.

Organizations and employees continue to perpetuate worksite co-location and many employees commute to an office each day for this reason. Simply contrasting virtual teams with co-located teams may be missing the point: though physical distance can be measured or calculated with relative ease, the psychological and cognitive components of distance (e.g., "near but far") will also affect behavior and outcomes. The current model suggests one process by which these components might interact. Extrapolating from Allen's (1997, 2007) work and current findings, subordinate employees located on different floors from their managers might just as well be in different buildings or possibly even different cities. Indeed, one could imagine that *greater* physical separation might prompt more intensive efforts at communication and relationship-building between manager-subordinate pairs since both individuals are cognizant that there is almost no possibility of a random encounter. A subordinate on an adjacent floor may be physically quite close to a manager, but close may not be close *enough* for the development of a manager-subordinate relationship conducive to individual and organizational performance.

**Limitations and Future Research**

Several limitations of the current effort exist. There is no provision for the work networks or social networks of employees; employees do their work in isolation, choose destinations, and travel around the office and are not affected by the behavior of other agents. In a real organization, agent behavior would not be quite so random: employees would likely be meeting with others working on common projects. Prior to and after such meetings, a greater degree of encounters and path overlap would likely occur as employees travel together en route to meetings or back to workspaces and as employees combine trips, such as stopping for coffee before heading to a meeting and visiting the restroom after the meeting (depending on the amount of coffee consumed, of course).

There is also no provision for managers to either purposefully seek contact with subordinates or to intentionally act to increase random encounters.

The current model is very limited in its implementation of agent psychology. Typically, extensive question batteries are developed and validated to measure psychological constructs in the workplace. Such constructs are generally accepted to be complex in their own right and substantial variance in measured constructs remains unexplained and/or attributed to unidentified latent constructs. Ideally, a workplace model examining employee outcomes would, at least to a degree acceptable by subject-matter experts, more precisely implement the processes understood to affect employees[3]. An important agent psychology limitation is the inability to precisely represent, in code, the psychological interpretation of physical distances and especially the elevator.

As an organizational simulation, the current model lacks the information-processing and information-centric paradigm advanced by Simon (1976) and March and Simon (1993). If organizations are indeed in the business of processing information, adding a work simulation module might affect model outcomes substantially since work would offer different opportunities for contact. A module could be implemented such that various pieces of information must be communicated between networked agents to complete a task or project, and agents are permitted to use a variety of communication methods (e.g., face-to-face, telephone, email) whose use will depend on physical proximity, availability (synchronous versus asynchronous communication), and psychological distance. Ideally, this extension would also examine the effects of spatial and network structure on organizational performance (e.g., Guetzkow & Simon, 1955).

Finally, the spatial aspects of the current model were highly abstracted and only a single office layout was simulated. Finer spatial resolution and the utilization of space syntax to inform and measure agent behavior and as independent variables affecting outcomes should be incorporated to more precisely quantify how, where, and why manager-subordinate encounters occur.

Substantial opportunities exist for future research both with the current model and in this area, more broadly. Using the current model, a factorial experiment will be carried out to examine the sensitivity of varying parameters on manager-subordinate encounters. As noted above, developing a higher-fidelity model calibrated and validated with empirical data is an important long-term goal of work in this area. At a late stage of the current effort, a “sociometric badge” dataset available for research use was identified (Olguin et al., 2009), purportedly containing behavior, performance, and interpersonal interaction data recorded at a “temporal resolution of a few seconds” at a Chicago data server configuration firm over the course of one month. Likewise, ethnographic or observational data might be used for similar purposes if sufficiently detailed and spatially explicit. Ideally, spatial configuration and interaction information would be examined in relation to real-world organizational performance outcomes.

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[3] This might be accomplished through companion modeling or participatory modeling.

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Appendix 1

**Overview, Design Concepts, and Details (ODD) Protocol**

This appendix describes the Manager-Subordinate Proximity Model using the Overview, Design Concepts, and Details (ODD) Protocol as prescribed by Grimm et al (2010).

## 1. Purpose

The purpose of the Manager-Subordinate Proximity model is to investigate the effect of employees' assigned seating locations in a typical multi-floor office layout on frequency of interaction with their assigned managers.

## 2. Entities, State Variables, and Scales

*Agents.* The model is populated by agents representing employees of two types: managers (one per floor) and subordinates. State variables include: identifier (ID number), employee type (manager or subordinate), assigned desk location, and internal "countdown" timers that regulate whether employees stay at the current location or move to/from office locations and their desks. Agents also possess a memory of the identifier of every other agent encountered as the simulation runs.

*Spatial Units.* The model also includes a cell grid on which the office layout appears, with each cell representing a spatial location in the office. Spatial units are used to represent floors in an office building, assigned desks in an open-office layout, bathrooms, printers, meeting rooms, kitchens, and an elevator with access on each floor. Each spatial unit possesses its own state variables: name/identification and whether it is traversable by employees (i.e., walls and furniture are not traversable by employees and the elevator is the only possible path between the first and second floors). The use of a cell grid permits each spatial location to be represented as a network node that is connected to its Von Neumann neighbors.

*Scales*. The temporal scale of the model is in seconds, since the purpose is to examine employee behavior over time. One time step is equivalent to one second. A single run of the model proceeds for 30,000 seconds, approximately one eight-hour work day.

## 3. Process Overview and Scheduling

Agents (employees and managers) work at their assigned desks while their internal timer counts down to zero, at which time the agent gets up and heads for one of the following destinations: the bathroom, printer, meeting room, or kitchen, with the kitchen representing the source of water, food, and coffee. Destination is randomly chosen, giving agents an equal probability of visiting any one of the four destinations each time they leave their assigned desk. Agents always travel from their desks to their destinations along the shortest network paths on the cell grid, in which each cell is connected to its Von Neumann neighbors.

Once agents reach their destinations, a second internal timer begins counting down to represent the length of time they will remain at the destination. The second timer is randomly drawn from a Poisson distribution with a mean of 300 seconds (five minutes). For some destinations—the printer, for example—this may be longer than reasonable, while for destinations like the meeting room or the kitchen, it may be too short. The model strives for parsimony, as introducing greater realism could lead to the need to model greater complexity such as scheduled meetings between employees. Employees simply remaining at their destinations for some period of time allows for the possibility of some spatial overlap in addition to encounters, enabling quantification of the amount of time subordinates actually spend in the presence of their manager. After the second internal timer reaches zero, employees always return to their assigned desks. There is no chaining of destinations in the current model (i.e., visiting multiple office locations in a single travel episode). The following pseudocode illustrates each agent's behavior in the current model:

```
Set countdown timer

When countdown timer 0

    Select destination (kitchen, printer, meeting room, or bathroom)

            If destination meeting room

                Then choose floor using probability parameter

    Travel shortest path to destination

    Set destination timer

        When destination timer 0

            Travel shortest path back to desk

    Reset countdown timer
```

During every step of the model run, each agent records the identity of any other agents at the same physical location, regardless of whether the encounter occurs while walking between destinations or at destinations, which include employees' own desks. These lists constitute a measure of social contact or encounters over the course of the workday and can be examined to understand which variables and behaviors affect contacts between employees and, importantly, between managers and subordinates. Employees also track the amount of time they spend with their manager. Globally, the model tracks which employees have not seen their manager at all.

## 4. Design Concepts

### 4.1 Basic Principles

A basic principle of the manager-subordinate proximity model is that spatial location is a critical variable when studying individuals in the workplace, and is a variable too often neglected by organizational scholars or else reduced to a binary classification of either "co-located" or "virtual." While this dichotomous distinction is certainly important, it lacks the ability to discriminate finer-grained spatial gradations within co-located or virtual teams.

A related basic principle, derived from the building design literature, is the psychological barrier to elevator usage and hypothesized single-floor mental representation of a building in individuals' minds, evidence for which is suggested by the commercial and retail adoption of spaces using escalators and building features (e.g., transparent glass partitions) permitting visibility of locations on other floors (Allen, 1997).

Additionally, space syntax (Bafna, 2003) has been used to investigate how office configurations and social networks interact and has suggested that considering paths and routes is superior to Euclidean distance in predicting tie formation (Sailer & McCulloh, 2012).

The Manager-Subordinate Proximity Model seeks to demonstrate *in silico* that these principles lead to quantifiable differences in manager-subordinate encounters and exposures and to further illustrate that seemingly minor differences in spatial location (e.g., sitting at one desk rather than an adjacent desk) have the possibility of explaining substantial variance *between* employees.

### 4.2 Emergence

Emergence is not a key design concept in the current iteration of the Manager-Subordinate Proximity Model. Currently, agents do not react or change their behavior in response to other model entities. At this stage of development, the model intends simply to illustrate the potential gaps in studies of employees that do not include fine-grained spatial location as a variable. In this sense, the model is a baseline that can be extended by the addition of agent-agent interactions or agent learning (e.g., agents' learning to time their breaks to coincide with coworkers or their manager). A longer-term goal of this research is to model a large corporate workforce spatially distributed over distances at both micro- (e.g., same building) and macro-scales (e.g., same city, different city) with agent behavior rules that could potentially lead to emergent outcomes.

### 4.3 Adaptation

In the current stage of modeling, agents do not seek to adapt or improve.

### 4.4 Objectives

Individual agents have no utility maximization objectives in the current model, though they satisfy their individual biological or workplace needs on a stochastic schedule. At the level of the organization (i.e., the overall model), however, the organizational objective is to increase manager-subordinate exposure through either workplace design or assignment of subordinates to managers based on spatial proximity. At the current stage of modeling, these objectives are pursued through manipulation of model parameters and comparing model run results and not by learning within the model, itself.

Additionally, the model tests whether the imposition of top-down control (a technique commonly employed by organizations) might permit the organization to meet its objective of manager-subordinate interaction. Whether by edict, norm, or conference room booking software, employees could be required to schedule their meetings on floors other than their own. This feature is implemented in the current model as a parameter comprising the probability that an employee agent heading to a meeting has that meeting a different floor.

### 4.5 Learning

Neither agents or the organization learn or change behavior during model execution.

### 4.6 Prediction

Agents do not make predictions in the current stage of model development.

### 4.7 Sensing

Agents sense (i.e., know) the spatial location (state variables) of their desired destinations. Agents sense (i.e., know) the shortest path along the spatial network to reach their destinations. Agents sense the presence of other agents, though they do not react to them other than storing them in memory.

### 4.8 Interaction

Agents do not interact with each other (aside from committing encounters to memory) and agents interact with environmental entities (i.e., office features) only insofar as remaining in place for as long as agents' stochastically-drawn timers specify.

### 4.9 Stochasticity

The current model includes a number of stochastic processes/elements. As detailed above, agents' decision to leave their desks and head for one of four in-office destinations is the result of a countdown variable that is randomly selected from a normal distribution with a mean of 60 minutes and a standard deviation of 30 minutes. The length of time that an agent stays at a particular destination is the result of second countdown timer that is randomly selected from a Poisson distribution with a mean of 5 minutes. Agents' decision of which of the four in-office destinations is also stochastic; selection is random among the four possible destinations.

Of the four in-office destinations, the choice of same-floor or different-floor meeting room is stochastic but affected through the use of a probability parameter, described in section 4.4.

In reality, the decision to get up from one's desk and travel elsewhere in an office, as well as the likelihood of staying in a particular destination for a particular length of time are complex and likely depend on a number of biological, social, psychological, and work factors. The current model is explicit in simplifying this behavior by making assumptions about the frequency and duration of these behaviors and by using stochastically-drawn lengths of time to attempt to capture some of this variability and complexity without overcomplicating the model.

### 4.10 Collectives

Collectives in the current model derive from the assignment of state variables, including employee type (manager or subordinate), manager assignment (e.g., 1st floor manager or 2nd floor manager), and assigned floor (i.e., 1st floor or 2nd floor). Collectives do not affect agent behavior in the model, though they affect model results; at the end of each simulation run, the model calculates the number of members of a manager's team the manager has not seen that day.

### 4.11 Observation

Observation of the current model occurs at several levels. A model view, shown in Figure 2, allows user observation of the model as it executes in real time. Additionally, each agent records in memory every other agent it has encountered during the course of the simulation. The spatial grid over which agents travel records the frequency with which it has been traversed, allowing an analysis and visualization of the most-frequently used routes in the simulated office.

Data are generated and recorded by the model during each step at runtime. Not all data are used; specific data is examined (sampled) depending on the research question of interest. The current model was developed with extension in mind, with a longer-term goal of simulating activity in a workplace and permitting the ability to test a range of empirical questions potentially affected by spatial variables.
As an example, an organization might ask, "How can we assign subordinates to managers so managers and subordinates are more likely to randomly encounter each other in the office?" However, a fundamentally different—although related question—is asking whether a specific seating assignment might disadvantage a particular employee over another with regard to *individual* likelihood of encountering one's manager. These questions are at two different levels; the former is at the macro level of the organization, the latter at the micro level of the individual.

## 5. Initialization

At $t$=0, the model is initialized as an office with a set of features typically found in an office: seating locations (i.e., desks), printers, bathrooms, meeting rooms, kitchens, as well as structural features including walls, managers' offices, an elevator, and a separation between floors.

At initialization, employee agents are given a single spatial seating assignment, representing an employee's assigned desk location. As detailed in section 2, an agent's assigned desk location is a state variable and remains constant, both during the course of a model run and over multiple runs.

Employee agents are also assigned to a manager, either on the same floor or different floor and agents' internal countdown timers are drawn as follows:

```
Set countdown timer
      Draw random-normal
            mean 60 min
            stdev 30 min
Set destination timer
      Draw random-poisson
            mean 5 min
```

In the current model, agent activity was accelerated by reducing the values drawn for both counters by 80 percent (i.e., speeding up the model by a factor of 5).

Figure 2 displays the manager-subordinate proximity model in its initial state.

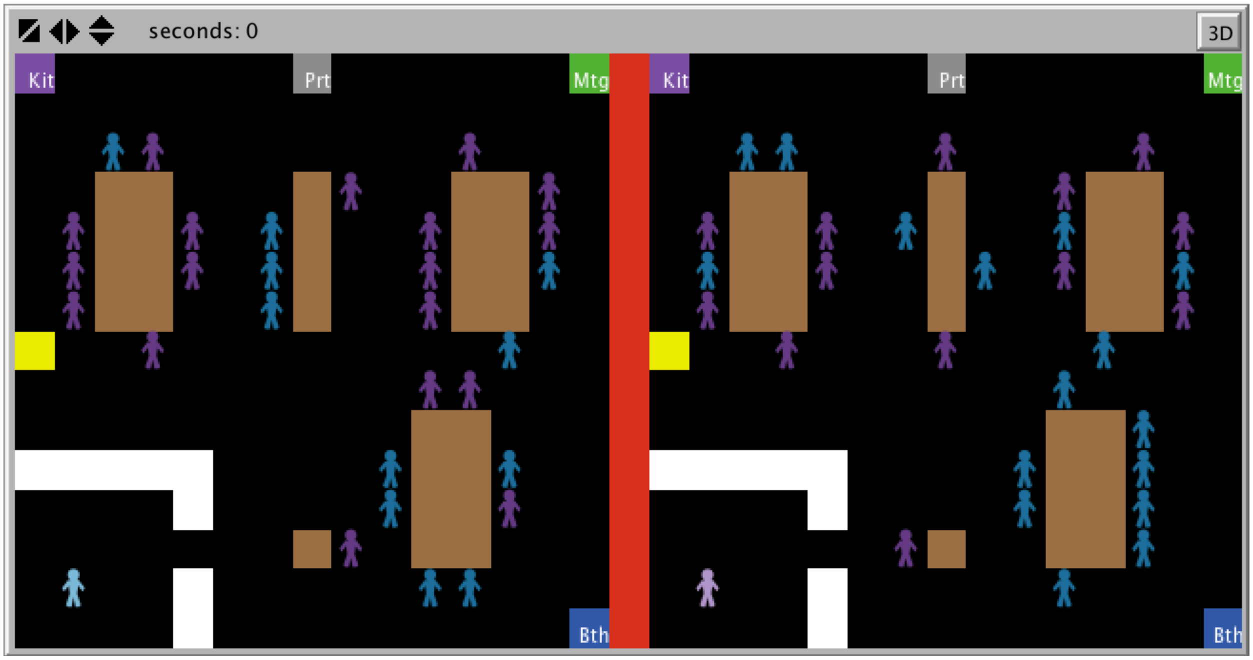


**Figure 2.** Model Initialization. Spatial layout of two office floors as modeled, connected by a single elevator (yellow). Managers sit inside offices in the corner of each floor, and employees sit on a randomly-chosen side of a desk, with no more than one employee per (square) desk space. Destinations are distributed along the perimeter of each floor, including the kitchen (Kit), printer (Prt), meeting room (Mtg), and bathroom (Bth). Agents *only* utilize the elevator to go to the meeting room on the other floor; it is assumed that all employees would choose to remain on the same floor for kitchen, printer, and bathroom use.

## 6. Input data

The model does not use input data to represent time-varying processes.

## 7. Submodels

### 7.1 Agent Behavior

The current model contains a number of parameters that affect agent behavior and model results. Table 1 details model parameters. Some parameters like agents' countdown timers are implemented only in the model code and cannot be altered in the GUI. Other parameters are user-adjustable prior to running the model. The primary experimental parameters include manager assignment (`mgr-same-floor-only`) and the probability that an agent will travel to the other floor for a meeting (`prob-of-having-mtg-on-other-floor`). Other parameters that affect the characteristics of the simulation include `%-desks-filled`, allowing for less than full employment and consequentially smaller teams and `elevator-barrier` which can approximate the psychological and/or physical barrier represented by an elevator in an employee's decision to travel to another floor compared to walking a meter on the current floor. In the current implementation, changing `elevator-barrier` results in different path lengths as employees travel between floors, but because the elevator is the only means of traveling between floors it does not change actual agent behavior. The `elevator-barrier` could, however, be used to explore the likelihood that an employee would opt to travel a shorter vertical distance to reach a destination like a printer than a greater horizontal distance to reach the printer on the same floor.

Empirical data on real-world elevator use compared with walking on a current floor could not be located[4], though Allen (1997, 2007) emphatically maintains that pedestrians resist elevators, particularly if escalators are available.

**Table 1.** Model parameters. **Bold** values indicate stable model defaults.

| **Parameter** | **Sample Values** | **User-adjustable?** | **Notes** |
|---|---|---|---|
| elevator-barrier | 1 to 100; **20** | Yes | Barrier to using elevator; value 1 is the same as walking 1 m horizontally, 20 is the same as walking 20 m horizontally |
| %-desks-filled | 1 to 100; **80** | Yes | A maximum of one employee per desk may be assigned in the model (58 desks in current model); this parameter creates fewer employees to simulate smaller teams |
| mgr-same-floor-only | On (true) / **off** (false) (Boolean) | Yes | If yes, employees only assigned to manager located on same floor; if no, employees assigned to manager on either floor |
| prob-of-having-mtg-on-other-floor | 0.0 – 1.0; **0.5** | Yes | Probability of employee whose destination is meeting room will go to the room on the other floor; the only way that agents will traverse floors via the elevator. Set to 0.0, no travel between floors occurs and set to 1.0, employees will always travel to other floor for meetings |
| show-trails? | on/**off** (Boolean) | Yes | Simple visualization that leaves a color trail along the path that agent has traveled |
| countdown-timer | Randomly drawn from normal distribution, mean 60 min, SD 30 min | No | Length of time before employee gets up from desk and travels elsewhere in office; initialized at beginning of model and reset each time employee returns to desk |
| wait-countdown | Randomly drawn from | No | Length of time before employee leaves |

4 There is a substantial literature on the topic of elevator versus stair usage, but focused on efforts to promote the use of stairs for health reasons. One possible calibration method would be to calculate the physical effort required to change floors using the elevation change (i.e., the exertion required to climb stairs) and perhaps use some fraction of this value as the `elevator-barrier`. However, this would only account for the physical aspects of changing floors and neglect the psychological barriers, which Allen's (Allen, 1997, 2007) work suggests plays a significant role in pedestrian movement in office and retail buildings. At present, this remains a limitation for future research.

| | | | |
|---|---|---|---|
| | Poisson distribution, mean 5 min | | after reaching destination |

### 7.2 Elevator Psychology

As Allen (2007) suggested, humans appear to have a psychological aversion to using elevators, preferring to remain on a single floor and potentially lack an accurate mental model of a multi-story space unless design features permit visual inspection of other floors as in some multi-story shopping malls. To this end, the user can model this psychological process using the elevator-barrier submodel. By altering the psychological *weight* of elevator use, users can explore agents' *perceived* distance of traveling between floors rather than traveling on the same floor. To concretely illustrate how this submodel is applied, consider the following example: An employee is seated on the first floor. The sole printer on the first floor is at the greatest possible distance from the employee, requiring the employee to traverse the entire length of the office to reach the printer. However, a printer on the second floor is located immediately above the employee's desk location and the elevator between floors is also near the employee's desk. At what elevator "psychological weight" would the employee utilize the second floor printer – requiring a round-trip on the elevator – rather than walking the greater Euclidian distance to and from the first floor printer?

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