Computer terminal placement and workflow in an emergency department: An agent-based model

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I. INTRODUCTION

Adequate analysis and consideration of workflow in relation to new systems/ technology implementation is essential in health care settings. Certainly, adequate analysis of workflow and exploration of potential unintended consequences seems essential prior to implementation of any new system or technology. However, typical analysis is limited to observation of pre-implementation workflow. Specialized settings such as emergency departments are of particular concern, because systems and technologies chosen for broad implementation in tertiary care facilities may not be appropriate. Severe unintended consequences, including increased mortality, were observed in one emergency department upon implementation of a computerized provider order entry (CPOE) system. [1] Agent-based modeling enables exploration of system behavior over a broad range of parameters, and so agent-based modeling may provide crucial pre-implementation insight into the impact of a new system/technology on workflow and/or outcomes. We developed a prototype agent-based model designed to simulate patient flow and provider workflow in an emergency department setting, relative to the number and placement of computer terminals, and explored the behavior of the system in response to various configurations.

II. BACKGROUND AND SIGNIFICANCE

A 2005 study by Han and colleagues found increased mortality after implementation of a CPOE system in the Pittsburgh Children’s Hospital emergency department (ED) and PICU (pediatric intensive care unit). [1] A subsequent study by DelBaccaro and colleagues yielded contradictory findings, showing no change in mortality rate in a PICU after system implementation. [2] Experts attributed these contradictory findings to substantial qualitative differences in the process of CPOE implementation in the two settings. [3] In the case of Pittsburgh Children’s Hospital, multiple unintended consequences resulting from inadequate pre-implementation analysis and planning led to delays in care. One of the unintended consequences was a severe mismatch between workflow imposed by the new system (CPOE) and existent workflow in the care setting, particularly the emergency department. In essence, the unique characteristics of emergency department workflow were not adequately considered relative to the system/ technology, prior to implementation.

The ED is clearly a complex, dynamic system, in which multiple diverse agents (nurses, physicians, social workers, administrative, security and administrative personnel, patients, physical resources) must interact to provide care for patients of varying acuities. Unique characteristics of ED settings, relative to most other care settings in the hospital, include high patient acuity, rapid turnover of patients, and high intensity of nursing and medical care. Due to the complexity of the emergency department care delivery system, many researchers have turned to computational models to examine the impacts of change on the overall care delivery system. Kilmer, Smith, and Shuman for example, have developed fairly detailed simulations of emergency department care delivery system, and have begun exploring more computationally efficient metamodels of simulations. [4] Over ten years ago, Krasisik and Bossmeyer reported the use of simulation to study the effect on patient flow of adding a fast track facility to an emergency department. [5] Connelly and Bair used an ED simulation to compare the effect of two triage methods on patient treatment time. [6] The use of simulation, or agent-based models, is well established in the literature as a technique for studying the effect of operational changes on the emergency department care delivery system. However, one author notes hospital administrator reluctance to accept simulation as an aid to operational decision making.

One basic and understudied variable in emergency department operations, encountered in the case of electronic health record (EHR) and CPOE system implementation, is the number and placement of computer terminals. Health care providers, generally nurses or physicians, must physically access a terminal to access information (i.e. health history, recent vital signs) or to input information (i.e. documentation, orders). Poissant and colleagues reviewed studies of time efficiency in EHR documentation. [7] Their comparisons of evidence for PDA, bedside, and central terminal placement indicated no clear advantage of any particular distribution of terminals. The comparison was complicated by the time point at which data was collected in the individual studies. Some studies collected data during the first three months post-implementation, when there is a generally observed increase in documentation time, while others collected data at later timepoints. Also, the studies differ dramatically in setting. As a result, there is no clear empiric evidence to guide optimal number and placement of terminals. Number and placement of terminals is intuitively sensitive to a number of factors - the number of patients and providers, the spatial layout of the emergency department, the time taken by a provider in using a terminal, communication among providers, etc... The purpose of this study was two-fold: (1) to develop a prototype agent-based model simulating patient flow and provider workflow in an emergency department setting, relative to the number and placement of terminals, and (2) to characterize the behavior of the emergency care delivery system relative to the number and placement of a workstations over a range of possible parameters.

III. METHODS

Model Development

The prototype agent-based model was programmed in NetLogo v4.0Beta. NetLogo is an open source software package that provides a programming environment for agent based modeling. Netlogo allows for the creation of individual interacting agents to whom rules and behaviors can be assigned. These agents move within a two-dimensional environment (represented as patches in NetLogo). Emergent macro-level phenomena resulting from agent interactions with each other and the environment can be monitored and recorded for analysis.

Model Dynamics

Agents: Agents in this model were of three types: patient, provider, and terminal. No distinction was made between types of providers, i.e. nurse, physician, medical assistant, etc… Also, patients were not differentiated from each other according to acuity, necessity of admission, complexity, etc… However, random differences in providers and patients were simulated using other mechanisms. Terminals varied only in number and spatial arrangement.

Providers: Provider agents possess a series of tasks. Once assigned to a patient, providers treat and discharge that patient over the course of several in-room visits, with each in-room visit taking a certain amount of time. To model documentation, order entry, and information access, providers are required to visit the nearest available computer terminal between visits, and spend a certain amount of time at that terminal. If no terminals are available, the providers wait at a central location (nursing station) until a terminal becomes available. Once a patient is discharged, providers check in at the central location to wait for a new patient assignment.

Patients: Patients, like terminals, are relatively passive agents that primarily track the amount of time spent in the waiting room and in the treatment room. Patients also determine the number of provider visits needed to be discharged or admitted. Random variation in the number of visits and amount of time required by the provider simulates a patient population of varied acuity and complexity. Temporal patient arrival is modeled as either as a random uniform or a random Poisson process (at the user's option). Upon arrival, patients remain in the waiting room until a treatment room opens up. Once a patient is discharged (discharge representing either discharge, death, or transfer to another unit), average parameter statistics are updated, and that treatment room opens up for the next patient in the queue.

Terminals: Terminals are the most simple agents implemented in this model. Terminals are stationary entities, either free or in use, and represent the computer terminals used by providers for documentation, order entry, and information access.

System: Initially, simulations are configured according to multiple selectable parameters: terminal count, provider count, room count, terminal positioning (distributed-hall, bedside, or clustered-hall), patient arrival process, provider time spent with patients, and time spent at computer terminals. Providers are assigned randomly to patients and begin movement relative to those patients once the simulation has begun. When a patient arrives in the treatment room, the number of visits required from the provider and the amount of time to be spent with the provider at each visit is set. Time spent at each computer terminal is set at the beginning of the run as a selectable number. These encapsulate some of the simplifying assumptions were made in the development of this model. Others include, for example, that for the purposes of this model, providers were assigned to a single patient at a time; clearly in the real world providers multitask and handle multiple patients at a time. On the other hand, no time was spent "waiting for results" - providers shuttled between patients and the terminal until enough visits had been made to allow the patient to be discharged. Further work is in progress to assess the impact of these assumptions.

Experiments

In initial experiments, we visualized the dependence of patient wait time on settings of the following parameters: (1) number of providers present in the emergency department, (2) patient arrival scenario, (3) provider time spent with each patient, (4) provider time spent at computer terminals, (5) number of terminals, and (6) spatial configuration of terminals. Results were visualized using various three-dimensional plots. Visualization of these plots was used to determine an appropriate and computationally feasible range of parameters for further analysis. In further analysis, BehaviorSpace was configured as follows:

["Terminal_count" [1.0 1.0 5.0]]
["Provider_count" 5]
["terminal_positioning" "Distributed-Hall" "Bedside" "Clustered-Hall"]
["Frequency_new_pt" 60]
["Minutes_at_terminal" 20]
["Chance_new_pt" 100]
["Minutes_at_patient" 15]
["Patient_rooms" 3]
["Poisson-lamda" 7.5]
["Wait_at_patient" "Uniform"]
["Patient_arrival_process" "Random-Poisson"]

The configuration of computer terminals was the primary unit of experimentation. Computer terminals were configured as: (1) clustered, (2) distributed-hall, and (3) bedside (see figures 1-3). Experiments were configured in Netlogo using BehaviorSpace, and results were exported to an ASCII file for analysis. SAS© statistical analysis software was used to analyze and visualize experimental results. Analysis of variance (ANOVA) was employed to examine the mean time taken to be seen for each CPOE configuration across experiments.

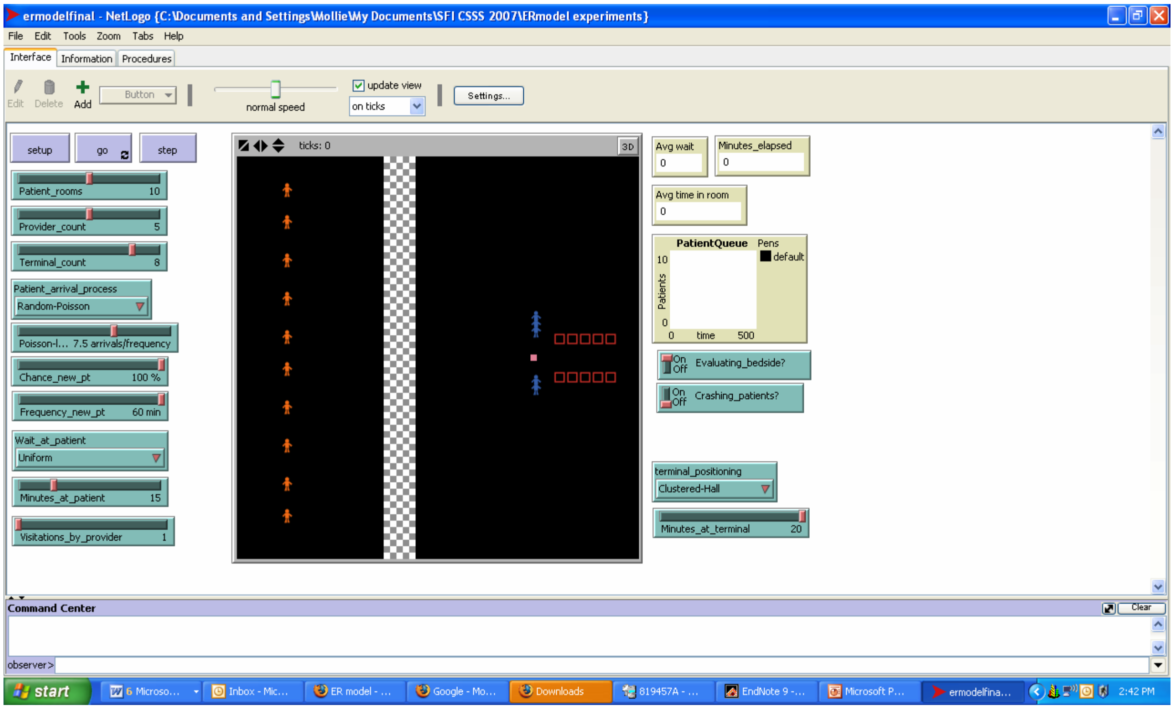

Figure 1: Clustered Computer Terminal Configuration

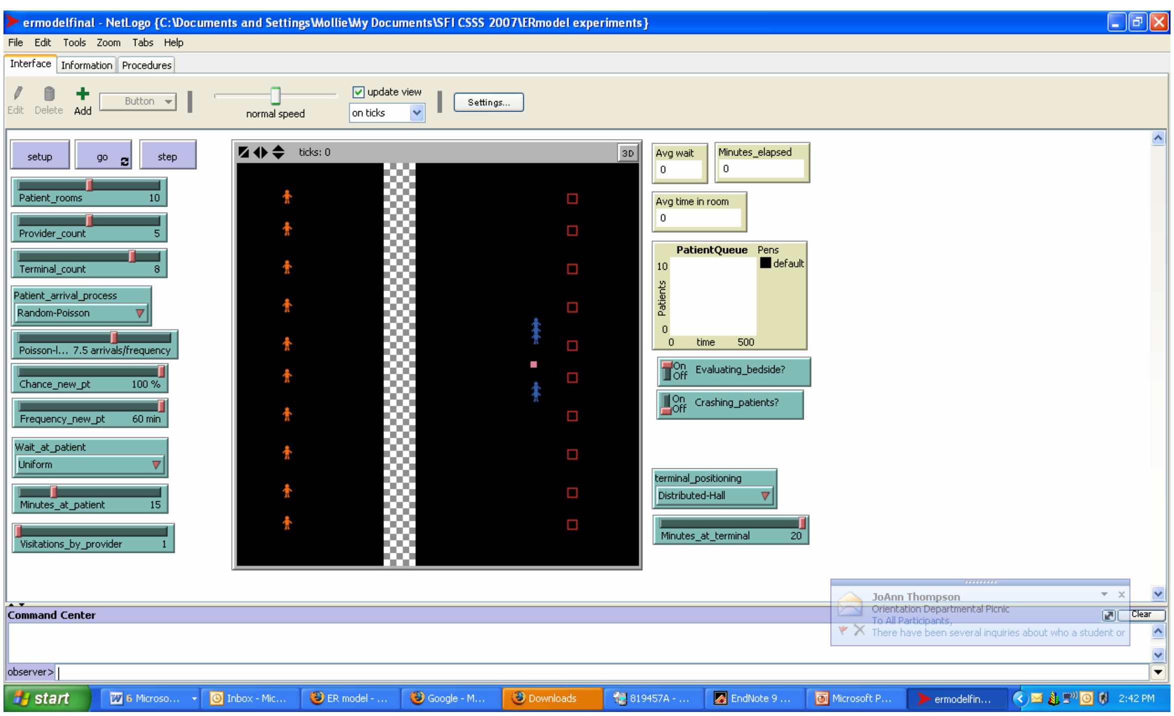

Figure 2: Distributed Computer Terminal Configuration

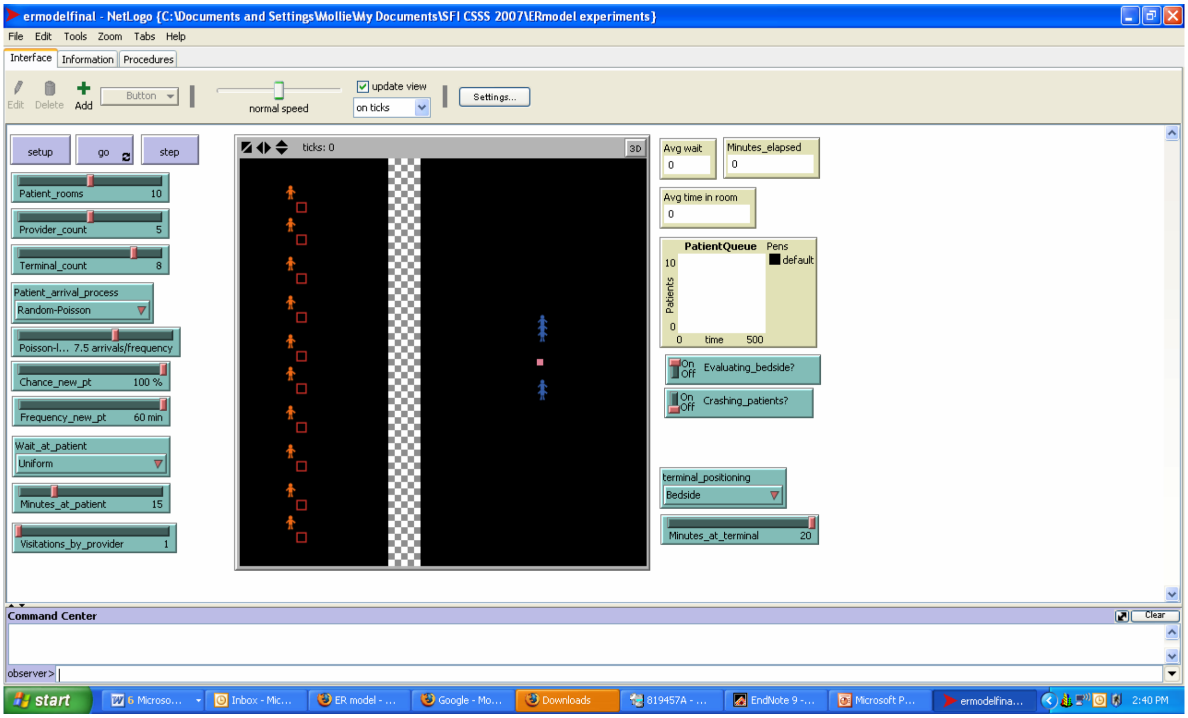

Figure 3: Bedside Computer Terminal Configuration

III. RESULTS

ANOVA showed statistically significant differences in time taken to be seen ($p<.0001$), the amount of time from patient arrival in a treatment room to discharge. As expected, the bedside configuration produces the shortest time taken to be seen (15.2 minutes). The central cluster configuration proved to be the next best option (35.1 minutes) as compared to the distributed hallway configuration (58.3 min).

IV. DISCUSSION

Our outcome of interest was the time taken for a patient to be seen and discharged. We found that this outcome varied among spatial computer terminal configurations. Bedside terminals produced the shortest time to discharge. Our simulations showed that a clustered configuration may be the next best option with respect to optimizing workstation flow, but that result may be an artifact of the specific spatial layout chosen in our model. Further refinement of the model would be necessary to adequately characterize workflow differences related to spatial placement of terminals outside patient rooms. Bedside terminals are increasingly common, but they are also more expensive, and may be more prone to theft and damage than terminals placed in distributed or clustered configurations, and may not be an option for some emergency departments.

The simulations presented in this study were based on a hypothetical emergency department setting. Optimal computer terminal configuration may vary depending on the spatial and workflow characteristics of a particular ED. Additionally, this low fidelity model does not accurately represent provider behavior. In real emergency departments, providers often multi-task and work in teams. Also, patients vary in acuity and in amount of time required for patient care, communication, documentation, and other tasks. Finally, a more realistic queuing scenario, such as those currently under study at LDS Hospital in Salt Lake City, UT, would be necessary to increase model fidelity. [8]

Initial exploratory experimentation and visualization evidenced the extreme sensitivity of this model to changes in the various parameter settings. Consequently, the results presented in this study are clearly preliminary and should be interpreted with caution. However, this prototype model demonstrates clear potential as a tool for pre-implementation workflow analysis. Using customized, higher fidelity versions of this model, optimal computer terminal placement and other potentially disruptive changes could be explored in relation to the spatial layout and workflow of specialized patient care settings.

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