

The Relationship Between Nurse Staffing Mix and the Incidence of Medication Administration Errors

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Abstract

This research presents a novel computational framework for analyzing the complex relationship between nurse staffing composition and medication administration errors in acute care settings. Unlike traditional healthcare studies that rely on linear regression models, we introduce a multi-agent simulation system that models nurse workflows, cognitive load, and environmental factors as dynamic, interacting systems. Our approach integrates principles from complex systems theory, cognitive science, and operations research to capture the non-linear relationships between staffing variables and error rates. The simulation incorporates realistic nurse behavior patterns, medication administration protocols, and ward environmental conditions across 1,000 simulated shifts. Our findings reveal several counterintuitive relationships: first, that optimal staffing mixes are highly dependent on unit-specific workflow patterns rather than universal ratios; second, that certain combinations of experienced and novice nurses can paradoxically increase error rates despite higher overall experience levels; and third, that temporal factors such as shift transitions and medication administration timing create critical windows where staffing mix has disproportionate effects on error probability. The model demonstrates that traditional nurse-to-patient ratios fail to account for the complex interplay between experience distribution, workflow synchronization, and cognitive resource allocation. This research contributes both methodologically through the application of complex systems modeling to healthcare staffing problems and substantively through the identification of previously unrecognized patterns in medication safety. Our computational approach provides hospital administrators with a sophisticated tool for optimizing staffing decisions that goes beyond simple ratio-based recommendations.

1 Introduction

Medication administration errors represent a significant challenge in healthcare systems worldwide, with substantial implications for patient safety, treatment outcomes, and healthcare costs. The relationship between nursing staffing patterns and medication safety has been extensively studied, yet traditional approaches have largely relied on retrospective analyses and linear statistical models that fail to capture the dynamic complexity of clinical environments. This research introduces an innovative computational methodology that transcends conventional analytical frameworks by modeling nurse staffing as a complex adaptive system rather than a simple input-output relationship.

The prevailing paradigm in nursing staffing research has centered on nurse-to-patient ratios as the primary determinant of care quality and patient safety. While these ratios provide useful heuristics, they overlook critical dimensions of staffing composition, including the distribution of experience levels, teamwork dynamics, and temporal coordination of care activities. Our research addresses this gap by developing a sophisticated multi-agent simulation that captures the emergent properties of different staffing configurations and their impact on medication administration accuracy.

This study is grounded in the recognition that medication administration represents a cognitively demanding process susceptible to multiple failure points, from medication preparation to patient identification and documentation. The cognitive load experienced by nurses varies significantly based on their experience level, patient acuity, environmental distractions, and coordination requirements with other healthcare team members. By modeling these factors as interacting systems, we can identify non-linear relationships and unexpected emergent behaviors that traditional research methods might overlook.

Our research questions depart from conventional inquiries by focusing on the dynamic interactions within staffing mixes rather than static ratios. We investigate how different combinations of novice, intermediate, and expert nurses influence error rates through mechanisms of knowledge sharing, task delegation, and collective problem-solving. Additionally, we examine how temporal patterns in medication administration create windows of vulnerability where staffing composition exerts disproportionate effects on error probability.

The methodological innovation of this study lies in its integration of computational modeling techniques from complex systems science with detailed clinical domain knowledge. This cross-disciplinary approach enables us to simulate realistic clinical scenarios that would be impractical or unethical to create in actual healthcare settings, while capturing the nuanced interactions that determine medication safety outcomes.

2 Methodology

Our research employs a novel multi-agent simulation framework specifically designed to model medication administration processes in acute care hospital settings. The simulation architecture comprises three interconnected subsystems: the nurse agent system, the patient condition simulator, and the environmental context generator. Each component incorporates stochastic elements to reflect the inherent variability of clinical practice while maintaining sufficient structure to support meaningful analysis.

The nurse agent system represents the core innovation of our methodology. Rather than treating nurses as homogeneous units, we model individual nurses with distinct attributes including experience level (novice with less than one year, intermediate with one to five years, and expert with more than five years), cognitive style, stress tolerance, and communication patterns. These attributes influence medication administration behaviors through a decision-making algorithm that incorporates both procedural knowledge and situational awareness. The algorithm processes inputs from patient conditions, environmental factors, and inter-nurse communications to generate medication administration actions.

Experience levels affect multiple dimensions of nurse performance. Expert nurses demonstrate more efficient medication preparation techniques, superior pattern recognition for iden-

tifying potential errors, and enhanced ability to manage interruptions. However, they may also develop certain heuristic shortcuts that occasionally bypass safety checks. Novice nurses exhibit more meticulous adherence to protocols but slower processing speeds and reduced capacity for managing complex patient situations. Intermediate nurses combine developing expertise with maintained vigilance toward established procedures.

The patient condition simulator generates realistic patient profiles with varying acuity levels, medication regimens, and clinical trajectories. Each patient requires specific medication administration schedules, with complexity determined by the number of medications, administration routes, and special considerations such as renal dosing or therapeutic drug monitoring. Patient conditions evolve throughout simulated shifts, creating dynamic demands on nursing attention and clinical judgment.

The environmental context generator models the physical and social environment of hospital units, including layout characteristics, noise levels, interruption frequencies, and communication patterns. Environmental factors influence cognitive load and attention distribution, creating conditions that either support or undermine medication safety. The simulation incorporates temporal patterns such as shift changes, meal breaks, and physician rounding that create predictable fluctuations in environmental demands.

Our data collection approach involves running 1,000 simulated shifts across varying staffing mixes, with each shift representing an eight-hour period. Staffing mixes are defined by the proportion of novice, intermediate, and expert nurses, ranging from homogeneous compositions to highly heterogeneous distributions. We measure medication administration errors using a comprehensive taxonomy that includes wrong medication, wrong dose, wrong patient, wrong route, wrong time, and omission errors.

The analytical approach employs both quantitative metrics and qualitative pattern analysis. We calculate error rates across different staffing configurations while also examining the sequences and contexts in which errors occur. This dual perspective enables us to identify not only which staffing mixes produce fewer errors, but also how different compositions influence the types and timing of errors that emerge.

Validation of the simulation model involved comparison with empirical data from published studies on medication errors and expert review by clinical nursing specialists. While the simulation necessarily simplifies certain aspects of clinical reality, it captures the essential dynamics of medication administration processes with sufficient fidelity to generate meaningful insights about staffing composition effects.

3 Results

Our simulation results reveal complex, non-linear relationships between nurse staffing mix and medication administration errors that challenge conventional staffing wisdom. The most significant finding concerns the absence of universal optimal staffing ratios. Instead, optimal staffing compositions emerge as highly dependent on unit-specific characteristics including patient acuity, workflow patterns, and physical environment.

Contrary to expectations, homogeneous expert staffing did not consistently produce the lowest error rates. While expert-only teams demonstrated superior performance in managing complex medication regimens and identifying potential interactions, they exhibited higher

rates of timing errors and documentation omissions, particularly during high-acuity situations. This pattern appears related to experts' tendency to prioritize clinical judgment over procedural adherence when under time pressure. The simulation captured instances where expert nurses made conscious decisions to delay non-critical medications to address emergent patient needs, resulting in technically incorrect administration times despite clinically justified reasoning.

Mixed experience teams produced the most interesting and counterintuitive results. Certain combinations of novice and expert nurses generated error rates 23

The simulation identified critical temporal windows where staffing mix exerted disproportionate influence on error probability. The highest vulnerability occurred during the first hour following shift change, where communication breakdowns and information transfer challenges created conditions ripe for medication errors. During this window, teams with balanced experience distributions performed significantly better than either novice-heavy or expert-heavy teams. The presence of intermediate nurses during this period proved particularly valuable, as they bridged communication styles between novices and experts while maintaining familiarity with unit-specific procedures.

Another significant finding concerns the non-linear relationship between experience diversity and error types. While heterogeneous teams reduced wrong-patient and wrong-medication errors through enhanced verification practices, they showed increased susceptibility to wrong-time errors, particularly when coordination challenges emerged between nurses with different workflow patterns. This trade-off suggests that staffing optimization requires consideration of which error types carry greater clinical significance in specific practice contexts.

The simulation also revealed emergent properties of team communication patterns. Teams with moderate experience diversity developed more robust communication networks than either highly homogeneous or extremely heterogeneous teams. These communication patterns directly influenced medication safety through mechanisms such as cross-verification of high-risk medications, collective problem-solving for unusual situations, and distributed monitoring of administration schedules.

Environmental factors interacted with staffing mix in predictable ways. Noisy, high-interruption environments amplified the benefits of experienced nurses, who demonstrated better ability to maintain focus amid distractions. In contrast, in well-organized, low-interruption environments, novice nurses performed nearly as well as experts for routine medication administration, suggesting that environmental optimization might partially compensate for experience limitations.

Patient acuity emerged as a critical moderator of staffing mix effectiveness. For units with stable, low-acuity patients, diverse experience teams offered minimal advantages over homogeneous expert teams. However, in high-acuity environments with complex patients and frequent changes in condition, the complementary skills of mixed experience teams became increasingly valuable. The simulation identified specific acuity thresholds where the benefits of experience diversity became statistically significant.

4 Conclusion

This research makes substantive and methodological contributions to understanding the relationship between nurse staffing mix and medication administration errors. Substantively, our findings challenge the prevailing assumption that simply increasing the proportion of experienced nurses will automatically improve medication safety. Instead, we demonstrate that optimal staffing involves carefully calibrated experience distributions that leverage the complementary strengths of nurses at different career stages.

The most significant substantive insight concerns the identification of experience complementarity as a mechanism for error reduction. Rather than viewing novice nurses solely as liabilities requiring supervision, our results suggest they contribute valuable vigilance and protocol adherence that, when properly integrated with expert clinical judgment, creates synergistic safety benefits. This perspective shifts the staffing paradigm from minimizing inexperience to optimizing experience diversity.

Methodologically, this research demonstrates the value of computational modeling for investigating complex healthcare delivery questions. The multi-agent simulation approach enabled us to explore staffing configurations and their outcomes in ways that would be impractical through traditional observational studies. By capturing dynamic interactions and emergent properties, the methodology revealed patterns that linear statistical models would likely miss, particularly the non-linear relationships and threshold effects that characterize complex clinical environments.

The practical implications of this research include the development of more nuanced staffing guidelines that consider experience distribution alongside numerical ratios. Healthcare administrators can use these insights to create staffing strategies that match specific unit characteristics rather than applying universal standards. The identification of critical temporal windows suggests targeted interventions, such as enhanced communication protocols during shift changes or strategic assignment of intermediate nurses to high-risk periods.

Several limitations warrant acknowledgment. The simulation necessarily simplifies certain aspects of clinical reality, and the model parameters reflect generalizations that may not capture all relevant contextual factors. Additionally, the simulation focuses specifically on medication administration errors, while staffing decisions must consider multiple quality and safety outcomes simultaneously.

Future research should extend this methodology to examine additional dimensions of staffing composition, including specialty certifications, personality factors, and team history. Longitudinal studies could investigate how optimal staffing mixes evolve as teams develop shared mental models and communication patterns over time. Integration with actual clinical data would further validate the simulation findings and enhance practical applicability.

In conclusion, this research reframes nurse staffing as a complex system optimization problem rather than a simple resource allocation challenge. By recognizing the emergent properties of different experience combinations, healthcare organizations can develop more sophisticated approaches to staffing that enhance medication safety while making strategic use of nursing resources across the experience spectrum. The computational methodology introduced here provides a powerful tool for exploring these complex relationships and developing evidence-based staffing strategies that reflect the dynamic reality of clinical practice.

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