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PROACTIVE PATIENT FLOW REDESIGN FOR INTEGRATION OF MULTIPLE OUTPATIENT CLINICS

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ABSTRACT

Successful merging or consolidation of interdependent healthcare clinics have been shown to have benefits with regards to decreasing operation costs while maintaining patients' quality of care. In order to achieve a successful merger or integration of clinics, an analysis of the effects of integrating patient flows should occur. This is especially important when the merger of clinics involves a transition into a new facility. We utilize a discrete event simulation model to study the effects of integrating three interdependent musculoskeletal clinics, Orthopedics, Rheumatology, and Radiology, into a new facility in advance of implementation. Through use of the simulation, unexpected bottlenecks in the check-in process are identified and the effects of implementing new patient flows, supported by Real-Time Location System (RTLS) technology, are analyzed.

1 INTRODUCTION

While the U.S. Census Bureau projects a 10% population growth over the next decade, the corresponding increase in the number of patients may be even higher due to regulations that increase health insurance affordability (Bureau 2014; Colby and Ortman 2015). Dramatic increases in patient volumes will require the healthcare sector to rework major systems features such as facilities management, services/specialties offered, and staffing requirements.

Many clinics and hospitals have examined consolidation and mergers of departments in response to patient growth and these merging efforts are expected to continue in the future(Bazzoli et al. 2002; Brown Jr et al. 2012). Guglielmo (2012), Curfman (2015) and Budryk (2015) highlight some of the benefits and risks of merging healthcare clinics or institutions. For example, the merger of the pediatric Emergency Room (ER) and the main ER increase efficiency while maintaining a financially healthy system at Stroger Hospital, in Chicago (Sachdev 2015). Ephraim McDowell Medical Center (Preston 1993), and Mercy Hospital (Ochoa 1996) merge different clinics and note beneficial outcomes, such as reductions in patient length of stay and staffing consistency. Some studies show that department mergers may be financially beneficial for the healthcare institution, but may not improve the practice itself and instead may reduce quality of care (Sachdev 2015). Ho and Hamilton (2000) find that mergers and acquisitions of hospitals in California have not shown a measurable impact on inpatient mortality. Instead, readmission rates and early discharges increase in some cases. Therefore, consolidation in healthcare settings in response to expected increases in future demand requires a thorough and systematic analysis before implementation.

Correspondingly, the following research aims to develop a simulation model to identify process improvement requirements during the merger of three outpatient clinics at a major teaching hospital. The

Orthopedics, Rheumatology and Radiology clinics currently operate independently, but the patient flow is interdependent among the clinics. Discrete Event Simulation (DES) is used to assist in the analysis of the design of systems and processes for the joint clinic which will be accompanied by construction of a new healthcare facility. The effectiveness of the integrated clinic is further assessed by several quality-of-care performance metrics such as patient Wait Time (WT) and Length of Stay (LOS). Patient LOS refers to the length of time between when a patient arrives to the clinic and when he or she departs the clinic. The total patient wait time corresponds to the aggregate time that patients are waiting during their visit. Partial WT refers to the time period between when a patient is checked-in and starts waiting in the waiting area, and when the provider calls the patient to the exam room.

Through use of the discrete event simulation, our analysis highlight the importance of utilizing these analysis tools in advance of merging clinics, moving a currently operating system into a new space, and increasing patient volumes. We demonstrate how the use of policies defined for the initial clinic will cause significant inefficiencies and bottleneck in the new space with merged clinics, particularly as the patient volume increases (as is expected). To reduce the effects of such bottlenecks, a potential redesign of patient flow supported by the use of Real-Time Location System (RTLS) technology is examined.

The remainder of the paper is organized as follows. In the following section, a review of relevant literature pertaining to mergers and consolidations of clinics and hospital departments is provided. In Section 3, a summary of the current Orthopedic, Rheumatology, and Radiology clinics' specifications underlying this research with the future changes resulting from the merger are explored. A comprehensive review of the constructed discrete event simulation model, including assumptions, data collection, and validation are presented in Section 4. In Section 5, discussion of the corresponding analytical results from simulation model is provided. Finally, in Section 6, we conclude by reviewing contributions of this research and propose suggestions for future research.

2 BACKGROUND

Considering the expansion of the healthcare industry due to a growing and aging population, many hospitals have invested in the construction of new facilities or the redesign of current facilities to host more physicians, serve more patients, and to offer the community improved quality of care. Additionally, many healthcare organizations have worked to merge departments to control costs and improve quality and coordination (Brown Jr et al. 2012). Whether the merger involves consolidation of departments, or practices, or changes to physical resources, there is a need to understand the effects of these changes, accounting for system complexities, in advance of implementation (Heyeres et al. (2016).

There are multiple examples of integration and mergers of departments in health care systems. For example, urgent care clinics have been consolidated to be provided by pharmacies. Likewise, mental health centers are promoted to provide integrated primary and mental health care in one platform. The goal is to improve the health of serious mental illness patients by merging primary and preventive general medical services into behavioral health settings (Scharf et al. 2016). Although some research shows that merging in practice may not improve all general medical outcomes in a short time period, (Scharf et al. 2016), Krupski et al. (2016) show that such integration can increase patient access to outpatient medical care while limiting hospitalizations for patients with severe mental illness.

Consolidation of physical resources within new facilities are primarily driven by the goals of improving patient care coordination, expanding market share, and increasing negotiating power with health insurance companies (Tijani-Eniola 2016). While hospital mergers extend services, the gain may come at a cost to both patients and insurers (Curfman 2015). Additionally, not all mergers are successful. For example, Hayford (2012) shows that hospital mergers increase intensity of treatments and inpatient mortality rates among heart disease patients. In addition, consolidation may isolate some competition mechanisms among healthcare providers that reduce the incentives for quality improvements that attract patients.

There are few studies examining how merging care in outpatient clinics changes patient quality of care and the efficiency of clinics. In order to achieve best outcomes from consolidation of clinics while transitioning to new facility, a systematic and holistic approach to analyze the current state of each clinic and predict future flows of patients and providers in the new system is needed.

One powerful tool for examining the effects of changes to a complex system is discrete event simulation (DES). This approach models a system and the evolution of the system as a sequence of distinct events in time. Robinson (2005) details the history of discrete event simulation from 1950 on, highlighting the development of the concept and growth in its usage. Simulations have shown to be a promising approach to solve different problems in the healthcare sector (Jacobson et al. 2006; Griffin et al. 2012; Hulshof et al. 2012; Vahdatzad and Griffin 2016; Dehghanimohammadabadi and Keyser 2017; Vahdat et al. 2017).

To address merging and consolidation in healthcare, Stafford Jr and Aggarwal (1979) find, via a simulation model, that although aggregation of two or more homogeneous facilities into a single facility decreases staffing costs, as the population size increases, the savings eventually disappear. Mahachek and Knabe (1984) develop a DES model to analyze the feasibility of combining an obstetric clinic with a gynecology clinic at John Hopkins Hospital. Simulation findings suggest postponing the merger because none of the facilities have adequate space for combined operations and the required waiting area space exceeded the available space at either location. Levy et al. (1989) find the minimum facility design specifications to integrate existing outpatient services inside the Anderson Memorial Hospital with offsite services at the outpatient diagnostic center. Rohleder et al. (2007) construct a simulation model for Calgary Laboratory Services to show the effects of consolidating to fewer, larger facilities, which can improve resource utilization while reducing demand variability.

To the best of our knowledge, minimal research has examined the use of simulation for examining the joint effects of merging clinics in combination with a move to a new facility and in consideration of expected increases in patient volumes, as is completed below. In this application, we use a simulation model to proactively identify bottlenecks and introduce solutions to overcome the expected reduction in timeliness of care, in advance of consolidation and integration into a new space.

3 PROBLEM DEFINITION

3.1 Clinic Interdependencies

This study is conducted in partnership with the ambulatory care of a major teaching hospital. Specifically, we aim to examine the effects of consolidation of three outpatient clinics, Orthopedics, Rheumatology, and Radiology, into an integrated Musculoskeletal clinic in a new facility. The interdependencies of patient flows among these three clinics are shown in Figure 1. The orthopedic and rheumatology clinics are highly dependent on the services provided by the radiology clinic. Some orthopedic patients are expected to visit radiology one hour prior to their orthopedics appointment to get necessary imaging completed. By contrast, many rheumatology patients proceed to radiology after their rheumatology appointment. Correspondingly, the efficiency of operations in the radiology clinic is both affected by and affects the efficiency of operations in the orthopedic and rheumatology clinics. Due to the intrinsic interdependencies, a process or policy change in any of the clinics affects the practices of the other two.

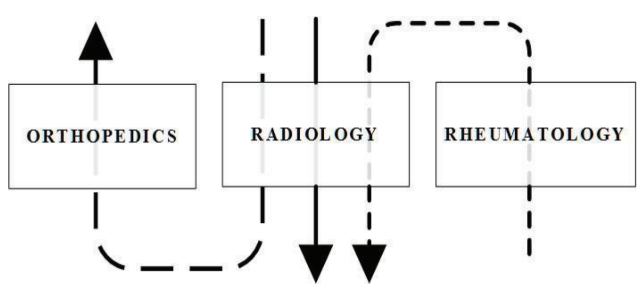

Figure 1: High-level patient flow pattern between three clinics indicating interdependencies between Orthopedics, Rheumatology, and Radiology clinics.

3.2 Current and Future Patient Flows

While interdependent, the orthopedic, radiology, and rheumatology clinics are managed independently and have unique characteristics pertaining to patient flow inside each clinic which are driven by differences in the specialties and the physical layout of the clinics. At the current location, there is a main waiting area with designated check-in stations used by the orthopedic and rheumatology clinics and seven suites, with four dedicated to Orthopedics and three to Rheumatology. Each suite contains between four and six exam rooms, a smaller sub-waiting area, and a dedicated check-out area with staff. The radiology clinic currently has its own check-in staff and waiting area, and each of the x-ray rooms has a dedicated changing area where patients can change into gowns, if required.

In the orthopedic clinic, there is variety in the practice patterns by different physicians. Some physicians work with a team of providers (i.e. Physician Assistant (PA), residents, and fellows) and some physicians visit patients individually. Each physician is assigned to multiple rooms, generally between two and four rooms, depending on the number of patients scheduled and the size of the team. For all patients, a Medical Assistant (MA) calls the patient from the sub-waiting area in the suite, routes him or her to the exam room, takes the patient's vital signs, and leaves the room. The MA notifies the physician's team that the patient is ready to be seen. Patients then will be visited by a single provider or multiple team members. In most cases, the primary physician or the PA completes the patient visit. Finally, the patient leaves the exam room, goes to the suite check-out area, and leaves the clinic. Some patients may require another x-ray and consultation with a provider prior to checking out. In this case the patient travels back to the radiology clinic for additional imaging and then returns to the clinic, where the patient is prioritized to be seen by the provider.

In the rheumatology clinic, physicians don't have teams of providers and are assigned to a single exam room. The MA calls patients from the suite's sub-waiting area to take their vital signs in the MA workstation. The patient is then routed back to the sub-waiting area and the MA notifies the physician that the patient is ready for his or her appointment. The physician walks to the sub-waiting area, escorts the patient to the exam room, and completes the visit. After the visit, the patient schedules his or her next appointment at the check-out station in the sub-waiting area, if required.

In the radiology clinic, patients are seen by technologists on a first-come first-serve basis after checking-in with radiology staff. The technologist prepares the x-ray equipment prior to calling the patient into the room. The patient may be required to change into a gown before the imaging is completed. After the procedure is complete, and a patient changes into their clothes, the patient will check-out in the radiology clinic and exit or proceed to the orthopedic clinic.

While this describes the current system, in the new building layout and with the merger into one MSK clinic, there will be no suites, and all sub-waiting areas will be consolidated into a single spacious area. This is important because the walking distances from exam rooms to waiting area are considerably higher than in the previous setting, and thus a change in patient flows is required. Check-in processes for all three departments will be combined into one desk and provided by staff in the waiting area. By pooling the check-in staff, which are currently located in the main waiting area and radiology suite, there is expected to be enough capacity to meet the future patient growth requirements. In terms of the facilities' capacity, the new building area is approximately three times larger than the current facility. Correspondingly, the number of rooms for orthopedics, rheumatology, and radiology clinics will increase by 66%, 40%, and 42%, respectively, compared with the initial system.

In the new orthopedics section of the combined clinic, instead of vital stations, all rooms will be equipped with the necessary equipment to take vital signs. In the rheumatology section, most physicians will have two rooms, eliminating the need to route patients back to the waiting area after the vital signs are taken and for physicians to walk to waiting area to call the patient to the exam room. The radiology section is designed to provide services mainly for MSK patients and the number of non-MSK walk-ins are expected to decrease significantly, causing the overall radiology exam volume in the new to reduce by approximately 40%, compared with the current setting. Also, in the new combined clinic there will be a designated changing area space, separate from the x-ray rooms. If a patient is required to change into a gown, he or she will be routed to the changing area first and, once ready, the technologist will take the patient to an x-ray room, reducing the amount of time in which x-ray rooms are in use for non-imaging tasks.

Consolidating the clinics and moving to new healthcare facility, involves many changes including to the physical structure resources (e.g. capacity expansions, walking distances, and x-ray room configuration) and to the system processes (e.g. patient and provider flows, check-in processes, patient volumes). With many changing features there is a critical need to study and explore the effects of these changes on operations prior to the opening of the new facility. Correspondingly, the directors of the ambulatory care practice sought the development of a systems model that captures the current state of the clinics and can predict the behavior of the system within the new building, with a combined MSK clinic. Beyond predicting future behavior, this model is also informative in proactively adapting the system to ensure a smooth transition for patients after the merger and consolidation.

4 METHOD

A discrete-event simulation model is constructed to be consistent with the operations of the orthopedic, rheumatology, and radiology clinics in the current and new facilities, as described above, using Arena 14.70. Development of the simulation model involves multiple steps(Law 2008). First, prior to building the simulation model, an analytical study of the system including flow patterns, durations of processes, and interdependencies among processes, is conducted. Correspondingly, informed by this analysis, simulation model parameters, including statistical distributions, are defined. These parameters are then integrated with valid assumptions in the construction of the simulation model. After the simulation model logic is tested and verified, it is validated to ensure the accuracy of the subsequent analysis and results.

4.1 Data Collection

Required inputs were gathered through clinic observations and extraction of one year of data (Dec. 2013-Dec. 2014) from the internal management system in all of the clinics. An analysis of the datasets led to the development of model parameters as statistical distributions for use in the simulation.

The hourly and daily patient volumes for each clinic, patterns of early and late patient arrivals, ratios of patients to physicians, and physician scheduling patterns were extracted by analyzing more than 97,000 data records from internal management systems. Figure 2, depicts the hourly patient arrival patterns for the orthopedic, rheumatology, and radiology clinics. Rheumatology patient arrivals are distinguished by whether or not allergy clinics are conducted for the particular day, as it affects the average patient volume. Radiology clinic volumes correspond only to those patients who only visit radiology. In addition to the hourly variability of arrivals, the clinics experience additional variability that is captured by the simulation model. For instance, based on the analysis of historical data it is found that the number of physicians in each clinic can vary from day to day.

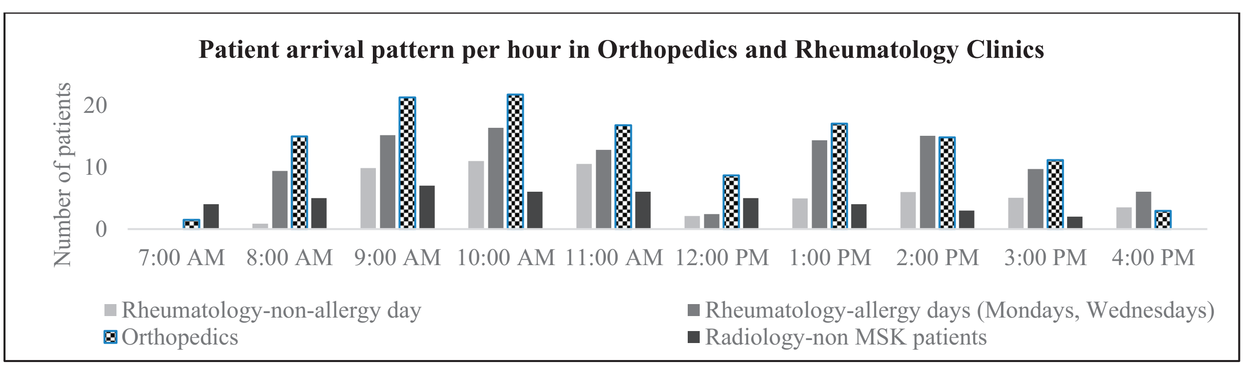

Figure 2: Average patient arrivals per hour to orthopedic, rheumatology, and radiology clinics. Rheumatology clinic patient arrivals are distinguished by whether allergy clinics are scheduled.

While the number of physicians may vary, in the simulation the average number of patients per physician per day is assumed to be constant among physicians with 25 patients per physician per day in the orthopedics clinic and 10 patients per physician per day in the rheumatology clinic. Hence, the volume of patients varies according to the number of attending physicians that is simulated for each day. The consistency of the patient:physician ratio is not completely reflected in the data collected, although it is a necessary step as a simplifying assumption of the model and agreed to be a reasonable assumption by the clinic managers.

Accounting for variability among clinics by hourly patient arrival rates and attending physicians per day, the patient arrivals to each of the clinics are simulated based on early/late patient arrival pattern distributions. For this purpose, all patients are initiated at the beginning of the simulation model, and the actual time a patient arrives to the clinic would be obtained by deviation to appointment time. Additionally, for modeling arrivals to the rheumatology clinic, parameters varied based on whether the simulated day included allergy clinics.

Not all of the necessary simulation parameters could be obtained by analyzing the internal management database system. Data collection forms were designed and utilized to capture other information such as physician visit time and duration of all other value-added processes that a patient may experience during the visit. Data was collected by observing 1,008 patients, across the three clinics, during two weeks in November 2015. The data collection process was designed to allow for studying the interdependencies that occurred when a patient visited multiple clinics during the visit. The data collection involved deidentification of records to ensure that no personal information was stored.

To aid in expert validation of the underlying model inputs, triangular distributions, defined by the minimum, mode, and maximum values, are used to model the process times within the simulation. Within the validation procedure, it is found that the simulation appropriately modeled the system despite this simplifying assumption. Table 1 summarizes the simulation inputs for the processes in each clinic. The same process times are used in the simulation and analysis of both the current and future facility.

Table 1: Triangular distribution parameters (min, mode, and max) for durations of clinic processes.

Clinic Type	Visit Processes in each Clinic	Total Service Time (min)		
		Minimum	Mode	Maximum
Orthopedics Clinic	Check-in	5	6	7
	Time with Medical Assistant (MA)	2	3	9
	Time with Physician Assistant (PA)	2	5	46
	Time with resident	2	7	36
	Time with physician (Individual visit)	3	10	28
	Time with physician (team based visit)	3	10	24
	Check-out	1	3	9
Rheumatology Clinic	Check-in	5	6	7
	Time with Medical Assistant (MA)	1	2	9
	Time with physician	5	21	49
	Check-out	1	2	8
Radiology Clinic	Check-in	2	3	3
	Order correction by check-in staff	5	7	10
	Time with technologist	5	10	48
	Changing time	3	5	10

4.2 Model Development

With the simulation of three interdependent clinics, with significant complexities, it is necessary to incorporate simplifying assumptions to ensure that the outputs of the simulation provide an accurate representation of the real system. For this simulation, it is assumed that the number of rooms for each physician team and the team size is consistent over each day of simulation. Patients are classified based on the treatment requirements and for each class, a early/late patient arrival pattern is incorporated into the simulation model. Additionally, walking distances are assumed to be the shortest path from the center of source unit to destination unit and the walking velocity is assumed to be 3.1 mph. While this velocity is representative of a healthy individual, further analysis demonstrated minimal sensitivity to this value.

The clinic is modeled as a terminating system with no warm-up period in which each day operates independently and all resources and patients are initialized at the beginning of each simulation run. Correspondingly, for each scenario the model is replicated 250 times to generate tight confidence intervals on all metrics of interest, such that the half-width is within 5% of the average.

4.3 Model Validation

The simulation model is developed to be representative of both the current and the new facility patient flows, with corresponding changes to simulation parameters such as capacities and routing probabilities, in order to facilitate the comparison of two systems. Validation of the model, with comparison of the simulation output and the observation data, is conducted using the parameters pertaining to the current system. Patient lengths of stay and waiting times are defined as key outputs for model validation. First, operational validation are obtained by comparing LOS histograms of the simulation outputs versus observation data for each clinic, as shown for the orthopedic clinic in Figure 3. Similar results with consistent distributions between the simulation output and observation data are found for the other clinics.

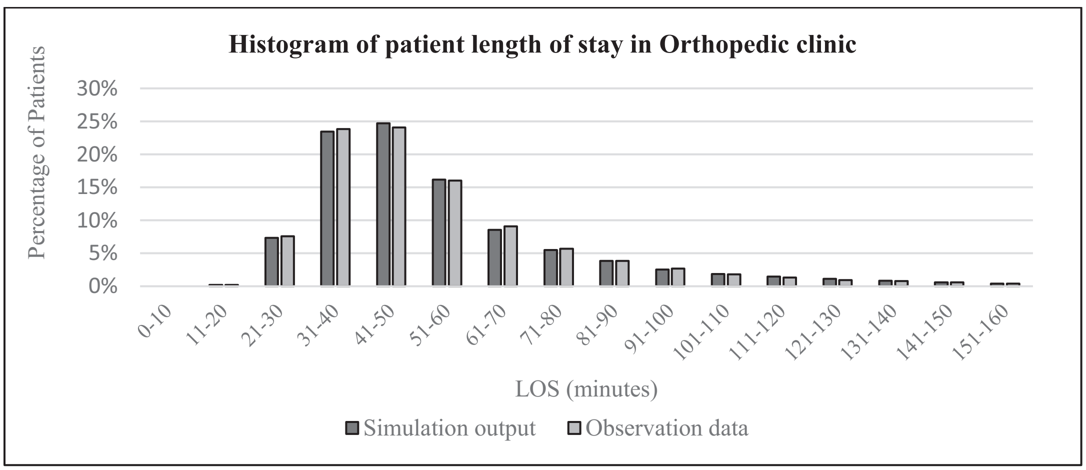

Figure 3: Histogram comparison of simulated vs observed data for patient LOS in Orthopedic clinic.

In addition to graphical validations, a statistical t-test on patient length of stay and wait times is conducted. As presented in Table 2, the results show no significant difference between the simulation and actual data sets, indicating that the logic of the model is accurate. Additionally, clinic experts validated the results.

The simulation with parameters pertaining to the new facility cannot be directly validated due to the lack of observation data. The same input data for process time distributions and patient flows remain consistent among simulations of the current and new facilities to ensure appropriateness of the model of the new facility where possible (see Section 3.2). Animation of the simulation model for the new facility was presented to hospital directors and staff for feedback and it was confirmed to be an appropriate representation.

Table 2 Simulation model validation results for comparing patient LOS and WT in waiting area in simulation model output and observed data.

Metric	Clinic	Simulated		Observed	
		Mean	95% CI	Mean	95% CI
Patient length of stay in each clinic	Orthopedic	65.24	[64.73, 65.76]	63.8	[60.40, 67.20]
	Rheumatology	55.81	[55.39, 56.23]	53.51	[48.11, 56.91]
	Radiology	41.01	[40.72, 41.47]	42.17	[39.33, 45.01]
Patient wait time in each clinic	Orthopedic	32.41	[31.94, 32.88]	33.41	[31.65, 35.17]
	Rheumatology	16.02	[15.65, 16.46]	14.56	[12.98, 16.14]
	Radiology	14.94	[14.61, 15.34]	15.09	[13.67, 16.51]

5 RESULTS AND FINDINGS

The simulation model is used to evaluate patient length of stay (LOS) and wait time (WT) as a result of consolidating the three clinics. Table 3 compares LOS and WT in the current and future facilities for each clinic individually, under the assumptions that the sequences and durations of all processes remain unchanged. In the orthopedics clinic, results show a 12% reduction in patient LOS and 43% decrease in wait time due to the increase in the physical space. In the rheumatology clinic, the impact of transitioning to new facility is minimal due to the nature of the practice. In the radiology clinic, the wait time significantly decreases from 15 minutes to 1 minute as a result of a 40% decrease in patient volume, from no longer having non-MSK walk-in patients, and a 33% increase in x-ray room capacity.

Table 3: Comparison of average patient length of stay and wait time(95% confidence interval) for the current and future clinic consolidations.

Clinic Type	Patient LOS (min)		Patient wait time (min)	
	Current	Future	Current	Future
Orthopedics Clinic	65.24(±0.51)	57.12(±0.48)	32.41(±0.47)	18.43(±0.35)
Rheumatology Clinic	55.81(±0.42)	55.01(±0.40)	16.02(±0.37)	15.71(±0.34)
Radiology Clinic	41.01(±0.29)	28.32(±0.15)	14.84(±0.36)	1.10(±0.12)

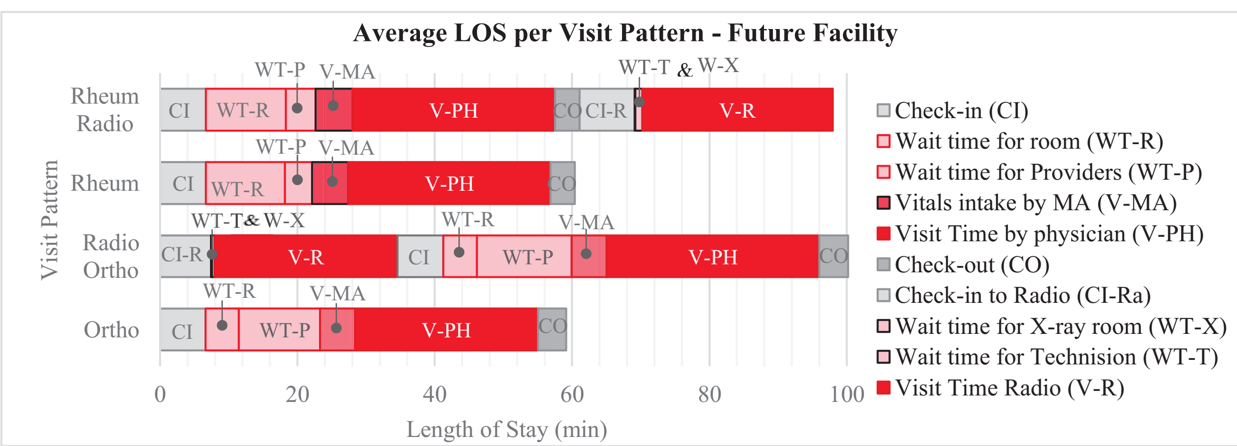

Figure 4: Average patient length of stay breakdown for orthopedic and rheumatology patients in new clinic.

While Table 3 findings show the performance of each clinic independently, to better capture the effects of interdependencies, an analysis of average patient LOS for patients visiting more than one clinic is conducted. The distribution of the average patient's experience during a visit in the new facility is presented in Figure 4 (previous page) with a distinction for those patients that visit radiology in addition to another clinic. Due to the large increase in capacity for the same patient volume, the wait times are expected to be minimal.

The construction of a new facility was chosen with the expectation that patient volumes, and correspondingly the number of physicians per day, in the MSK clinics will increase in the near future. Correspondingly, the simulation model is able to capture the effects on wait time and length of stay when the number of physicians, and correspondingly the number of patients, increases by 33%, 66%, and 100% (Table 4). The average patient LOS and partial wait time is reported for each patient time. Partial wait time refers to the aggregate time spent waiting from the check-in time to departure. In both Orthopedics and Rheumatology, although the average patient lengths of stay substantially increase with growth in patient volume, the partial wait time inside each clinic is minimally affected.

Table 4: Impact of patient volume increment in average patient length of stay and wait time (95% confidence interval).

Patient volume	**Orthopedics patients**		**Rheumatology patients**		**Radiology patients**	
	LOS (in clinic)	**WT (in clinic)**	**LOS (in clinic)**	**WT (in clinic)**	**LOS (in clinic)**	**WT (in clinic)**
Base Case	57.12(±0.48)	18.43(±0.35)	55.01(±0.40)	15.71(±0.34)	28.32(±0.15)	1.10(±0.12)
33% inc.*	64.71(±0.62)	21.01(±0.32)	59.94(±0.54)	14.82(±0.31)	28.79(±0.16)	2.65(±0.15)
66% inc.	83.24(±0.75)	21.41(±0.34)	74.61(±0.84)	14.74(±0.40)	29.81(±0.16)	3.49(±0.14)
100% inc.	113.26(±1.4)	22.12(±0.27)	106.5(±1.12)	14.71(±0.39)	29.01(±0.15)	3.05(±0.14)

*inc represents increase in patient volume per day.

As shown in Table 4, as overall LOS increases minimal increases in partial WT are observed. Correspondingly, from this analysis it is found that the increase in LOS is driven by long waits in the check-in queue, which are not captured in partial wait time calculations. Correspondingly, since check-in acts as a bottleneck on the flow into the clinics, minimal increase in partial wait time is observed. This is as a result of the preliminary patient flow design for the new facility which requires a return to the check-in desk between visiting different clinics. For example, this design requires multiple check-ins for patient requiring radiology services in addition to their scheduled appointments. Due to a limited physical capacity for check-in staff in the facility design, a more agile check-in process is deemed to be necessary, since addition of check-in staff is infeasible.

Effective communication is essential for the clinics to be running truly integrated and towards the same goal, which is increasing efficiency and maintaining the best service level. To develop a more agile system, requiring less patient check-ins, a technology-driven solution is proposed to improve communication between clinics. Specifically, with the implementation of RTLS (real-time location systems) technology, patients would no longer need to return to the check-in desk to update the staff about their status.

RTLS and Indoor positioning systems (IPS) belong to a class of technologies which are capable of tracking the time and location of any tagged item, such as individual objects or people, in the indoor setting(Jones and Chung 2007). RTLS have been widely used in managing the inventory (e.g. risk pooling) in supply chains(Vahdatzad et al. 2012). When applied in healthcare setting, these technologies allow for identifying room utilization patterns, improving scheduling, and supporting ongoing process improvement (Stahl et al. 2011). The primary data generated by the tags are the location of each patient at varying time points. The resulting data stream shows the sequence of locations visited, the duration of time that the patient is in each location, and next location that the patient is required to visit before leaving the clinic.

The effects of implementing this new technology, and the corresponding changes to flow patterns and process times, are examined with the simulation model. RTLS tags are assigned to patients by the check-in staff, resulting in an additional minute of time to the check-in process. Tags are automatically unassigned upon check-out without the requirement for additional processing by staff. Corresponding changes are made to process times in the updated model. Additionally, with the implementation of this system patients are no longer required to return to check-in, as the location of the patients can be observed in real-time by MAs and providers.

Simulation results from the system with RTLS technology are provided in Table 5. With the reduction in multiple check-ins the patient LOS is reduced significantly, particularly as the total patient volume increases. Thus, through the use of simulation for analysis of a new facility with integrated clinics, it is determined that changes to patient flows, beyond those originally planned, with the assistance of tracking technology will allow for more timely patient care, particularly as the volume of patients increases.

Table 5: Average patient LOS and wait time (95% confidence interval) in each clinic by the use of an RTLS system with the presence of future patient volume growth

Patient volume	Orthopedics patients		Rheumatology patients		Radiology patients	
	LOS (in clinic)	WT (in clinic)	LOS (in clinic)	WT (in clinic)	LOS (in clinic)	WT (in clinic)
Base Case	57.12(±0.48)	18.43(±0.35)	55.01(±0.40)	15.71(±0.34)	28.32(±0.15)	1.10(±0.12)
33% inc.	62.11(±0.51)	23.50(±0.37)	59.42(±0.54)	18.74(±0.39)	28.84(±0.16)	2.15(±0.21)
66% inc.	75.82(±0.59)	33.61(±0.41)	63.01(±0.51)	24.12(±0.40)	31.11(±0.17)	2.94(±0.16)
100% inc.	93.37(±0.78)	47.31(±0.65)	75.68(±0.59)	31.42(±0.43)	35.38(±0.20)	5.59(±0.29)

*inc represents increase in patient volume per day.

Correspondingly, the partner hospital chose to invest in this technology for the integrated clinic as a pilot to better understand where this technology could further support improved quality of care in outpatient clinics.

6 CONCLUSIONS

Merger and consolidation of outpatient clinics is often implemented in order to achieve potential increases in quality of care and cost reductions. Due to the complexity of the clinics, simulation methods can be beneficial to estimating the effects of integration of clinics and identify potential challenges prior to implementation. The value of such an approach is demonstrated in the presented work in which a hospital plans to integrate three interdependent clinics into a newly constructed facility. Discrete Event Simulation (DES) is used to assist in the analysis of the design of systems and processes for the joint clinic. Our findings show that integration of patient flow can lead to new and unexpected bottlenecks. In this system, the shared check-in feature is demonstrated to be a bottleneck which will cause significant decreases in timeliness of care as patient volumes increase. Correspondingly, the simulation is used to measure the effects of using Real-Time Location System (RTLS) technology in conjunction with new patient flows to minimize the effects of this bottleneck.

REFERENCES

Bazzoli, G. J., A. LoSasso, R. Arnould, and M. Shalowitz. 2002. "Hospital Reorganization and Restructuring Achieved through Merger". *Health Care Management Review* 27 (1):7-20.

Brown Jr, T. C., K. A. Werling, B. C. Walker, R. J. Burgdorfer, and J. J. Shields. 2012. "Current Trends in Hospital Mergers and Acquisitions: Healthcare Reform Will Result in More Consolidation and

Integration among Hospitals, Reversing a Recent Trend in Which Hospitals Tended to Stay Away from Such Transactions". *Healthcare Financial Management* 66 (3):114-120.

Budryk, Z. 2015. Consolidation in Healthcare Will Continue in 2015. *FierceHealthcare*, 01/04/2015

Bureau, U. S. C. 2014. 2014 National Population Projections Tables.

Colby, S. L., and J. M. Ortman. 2015. "Projections of the Size and Composition of the Us Population: 2014 to 2060". *Current Population Reports* (P25-1143).

Curfman, G. 2015. "Everywhere, Hospitals Are Merging — but Why Should You Care? *www.health.harvard.edu/blog/everywhere-hospitals-are-merging-but-why-should-you-care-201504017844*.

Dehghanimohammadabadi, M., and T. K. Keyser. 2017. "Intelligent Simulation: Integration of Simio and Matlab to Deploy Decision Support Systems to Simulation Environment". *Simulation Modelling Practice and Theory* 71:45-60.

Griffin, J., S. Xia, S. Peng, and P. Keskinocak. 2012. "Improving Patient Flow in an Obstetric Unit". *Health Care Management Science* 15 (1):1-14.

Guglielmo, W. J. 2012. Combine or Decline: Mergers and Consolidations Impact the Health Care Ecosystem. *New Jersey Monthly*, 2012-10-15

Hayford, T. B. 2012. "The Impact of Hospital Mergers on Treatment Intensity and Health Outcomes". *Health Services Research* 47 (3pt1):1008-1029.

Heyeres, M., J. McCalman, K. Tsey, and I. Kinchin. 2016. "The Complexity of Health Service Integration: A Review of Reviews". *Frontiers in Public Health* 4.

Ho, V., and B. H. Hamilton. 2000. "Hospital Mergers and Acquisitions: Does Market Consolidation Harm Patients?". *Journal of Health Economics* 19 (5):767-791.

Hulshof, P. J., N. Kortbeek, R. J. Boucherie, E. W. Hans, and P. J. Bakker. 2012. "Taxonomic Classification of Planning Decisions in Health Care: A Structured Review of the State of the Art in or/Ms". *Health Systems* 1 (2):129-175.

Jacobson, S. H., S. N. Hall, and J. R. Swisher. 2006. "Discrete-Event Simulation of Health Care Systems". In *Patient Flow: Reducing Delay in Healthcare Delivery*, 211-252. Springer.

Jones, E. C., and C. A. Chung. 2007. *Rfid in Logistics: A Practical Introduction*: CRC press

Krupski, A., I. I. West, D. M. Scharf, J. Hopfenbeck, G. Andrus, J. M. Joesch, and M. Snowden. 2016. "Integrating Primary Care into Community Mental Health Centers: Impact on Utilization and Costs of Health Care". *Psychiatric Services* 67 (11):1233-1239.

Law, A. M. 2009. "How to Build Valid and Credible Simulation Models". In *Proceedings of the 2009 Winter Simulation Conference*, ed. M. D. Rossetti, R. R. Hill, B. Johansson, A. Dunkin and R. G. Ingalls, 24- 33. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Levy, J. L., B. Watford, and V. Owen. 1989. "Simulation Analysis of an Outpatient Services Facility". *Journal of the Society for Health Systems* 1 (2):35-49.

Mahachek, A. R., and T. L. Knabe. 1984. "Computer Simulation of Patient Flow in Obstetrical/Gynecology Clinics". *Simulation* 43 (2):95-101.

Ochoa, G. 1996. "Changing the Face of Radiology: Redesigning Patient-Focused Care". *Radiology Management* 19 (1):42-45.

Preston, R. 1993. "Patient-Centered Care through Consolidation of Outpatient Services". *Radiology Management* 16 (1):20-22.

Robinson, S. 2005. "Discrete-Event Simulation: From the Pioneers to the Present, What Next?". *Journal of the Operational Research Society* 56 (6):619-629.

Rohleder, T. R., D. P. Bischak, and L. B. Baskin. 2007. "Modeling Patient Service Centers with Simulation and System Dynamics". *Health Care Management Science* 10 (1):1-12.

Sachdev, A. 2015. "Stroger Hospital Slammed for Plan to Merge Pediatric, Adult Emergency Rooms". *ChicagoTribune*.

Scharf, D. M., N. Schmidt Hackbarth, N. K. Eberhart, M. Horvitz-Lennon, R. Beckman, B. Han, H. A. Pincus, and M. A. Burnam. 2016. "General Medical Outcomes from the Primary and Behavioral Health Care Integration Grant Program". *Psychiatric Services* 67 (11):1226-1232.

Stafford Jr, E. F., and S. C. Aggarwal. 1979. "Managerial Analysis and Decision-Making in Outpatient Health Clinics". *Journal of the Operational Research Society* 30 (10):905-915.

Stahl, J. E., M. A. Drew, D. Leone, and R. S. Crowley. 2011. "Measuring Process Change in Primary Care Using Real-Time Location Systems: Feasibility and the Results of a Natural Experiment". *Technology and Health Care* 19 (6):415-421.

Tijani-Eniola, O. 2016. "Hospital Mergers: Mixed Impact on Price, Quality of Patient Care, and Hospital Performance". *International Journal of Scientific and Research Publications* 3 (1):361-363.

Vahdatzad, V., and J. Griffin. 2016. "Outpatient Clinic Layout Design Accounting for Flexible Policies". In *Proceedings of the 2016 Winter Simulation Conference*, edited by T. M. K. Roeder, P. I. Frazier, R. Szechtman, E. Zhou, T. Huschka, and S. E. Chick, 3668-3669. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Vahdat, V., J. Griffin, and J. E. Stahl. 2017. "Decreasing Patient Length of Stay Via New Flexible Exam Room Allocation Policies in Ambulatory Care Clinics". *Health Care Management Science* In press.

Vahdatzad, V., H. Mohammadi Bidhandi, and R. Tavakkoli-Moghaddam. 2012. "A Modelling Framework for Closed-Loop Supply Chain Network Design under Uncertainty". In *Proceedings of The 3rd System & Industrial Engineering Conferenc*e, May 2012, at Tehran, Iran.

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