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Designing efficient emergency departments: Discrete event simulation of internal-waiting areas and split flow sorting

Benjamin Easter MD, MBA [a,*], Negin Houshiarian PhD [b], Debajyoti Pati PhD, MASA [c], Jennifer L. Wiler MD, MBA [a,d]

[a] University of Colorado School of Medicine, Aurora, CO, United States of America
[b] HKS Inc., Dallas, TX, United States of America
[c] Texas Tech University, Lubbock, TX, United States of America
[d] University of Colorado Denver School of Business, Denver, CO, United States of America

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ABSTRACT

Objective: Evaluate nine different models, the interaction of three flow models (ESI, intake attending physician, and no split flow) and three physical design typologies (zero, one, and two internal-waiting areas), on Emergency Department (ED) flow and patient-centered metrics.

Methods: Discrete Event Simulation (DES) was used to systematically manipulate flow and physical design. Three base models were developed and validated using ED and patient specific data. Subsequently, systematic manipulations of flow and internal-waiting areas were performed on other models. Five outcomes of interest were tracked – length of stay (LOS), bed utilization rate, door to provider time, left without being seen rate, and number of movements per patient. Models were compared for statistical significance and effect size using ANOVA, and linear and non-linear regression.

Results: The shortest LOS (mean 175.2 min) and highest bed utilization rate (5.02 patients/bed/day) were obtained with flow split by an intake attending physician with two internal-waiting areas. These represented improvements of 54 min and 1.48 patients/bed/day over the control model. Two-way ANOVA demonstrated that both physical design and flow type were statistically significant predictors of all outcomes of interest ($p < .0001$). Depending on flow type, adding one additional internal-waiting area resulted in decreased LOS (range 10.6–21.8 min), increased bed utilization (range 0.23–0.40 patients/bed/day), decreased D2P (range 1.3–4.8 min), and decreased LWBS (0.66%–2.0%).

Conclusion: Based on a DES model with empirical data from a single institution, combining flow split by an intake attending physician and multiple internal-waiting areas resulted in improved ED operational and patient-centered metrics.

1. Introduction

1.1. Background

United States Emergency Department (ED) visits climbed to a record 136.3 million in 2014, almost 1 visit for every 2 Americans [1]. Gains in efficiency, however, have not kept pace, leading to significant ED crowding [2,3,4]. A growing body of literature demonstrates direct negative links between crowding and both objective clinical endpoints as well as process measures [5]. In this context, both ED managers and architects have struggled to optimize ED operational efficiencies and patient-centered care.

Split flow models, in which different types or acuities of patients are streamed into different processes or physical areas of the ED, have been proposed to alleviate this burden by both the American College of Emergency Physicians and a study of ED front end operations [6,7]. Although a number of institutions have since reported generally positive results, most of these are descriptive studies [8-14]. In addition, physician intake models have shown promise for improving operational metrics [14].

In contrast, there are a handful of texts that describe physical design solutions, including spaces for expedited nursing triage, low acuity "fast tracks", and internal-waiting areas, to name a few [15,16]. Internal-waiting areas are physical spaces in the ED that accommodate multiple patients who are awaiting their next step in care. They allow for more efficient utilization of other spaces in the ED that may be rate-limiting for patient movement. For example,

* Corresponding author at: Campus Box B-215, Department of Emergency Medicine, 12401 E 17th Ave., Aurora, CO 80045, United States of America.

E-mail addresses: benjamin.easter@ucdenver.edu (B. Easter), nhoushiarian@hksinc.com (N. Houshiarian), d.pati@ttu.edu (D. Pati), jennifer.wiler@ucdenver.edu (J.L. Wiler).

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patients are present in an examination room or on a bed only during periods of active treatment, and otherwise may be assigned to an internal-waiting area. Though a number of EDs have employed a single internal-waiting area, there is limited data to describe the efficiency of this design and if further efficiencies can be gained with multiple, smaller internal-waiting areas [17].

1.2. Importance

While the above studies have examined either process-focused or physical design interventions, they have failed to address ED crowding as a multifaceted problem rooted in the complex interaction between, and interdependence of, design and process [18]. An ED with high quality design is likely to be inefficient if it has the wrong flow model, and an efficient flow design may not succeed in the wrong physical space.

1.3. Goals

We sought to determine the following:

First, what is the ideal combination of ED physical design and flow across different census levels? We studied three different models for ED flow: [1] flow split by Emergency Severity Index score, [2] flow split by an intake attending physician [14], and [3] no split flow. We also studied three different models for ED physical design: [1] no internal-waiting area, [2] one internal-waiting area, and [3] two internal-waiting areas. We determined the impact of the above nine flow-design combinations on both standard ED operational metrics as well as patient-centered metrics.

Second, what is the best choice for design or flow if the other variable is unchangeable? An ED may not be able to afford a costly architectural re-design, and therefore seeks to optimize flow within a given layout. Conversely, a different department may have a fixed flow model based on other inputs (e.g., staffing), but has an opportunity to design a new space.

2. Methods

IRB approval for the study was obtained from the study institution. The study proceeded through five sequential steps: [1] empirical data collection, [2] base model development and validation, [3] discrete event simulation experiments, [4] analysis of experiment data, and [5] examination of each study question against the findings. The following sections briefly describe each step. Expanded descriptions are provided in the Supplementary Methods.

2.1. Study design and setting

This study employed a quantitative, analytic research design that used Discrete Event Simulation (DES) experiments to measure the impact of flow and physical design interventions on both operational and patient-centered metrics. The Emergency Department at University of Colorado Hospital (UCH) served as the study setting. UCH is an urban, academic, tertiary care facility and a primary teaching hospital. The ED cares for approximately 101,000 patients per year. All departmental and patient level data came from this setting. An overview of the methodology is provided here.

2.2. Selection of participants: empirical data collection

Several categories of data were collected, including: [1] ED layout, footprint, and area; [2] ED staffing, including total hours and numbers of physicians, advanced practice providers, nurses, technicians, environmental services, etc.; [3] patient level data, including age, sex, chief complaint, diagnostic testing (laboratory, imaging, other), treatment/interventions, and locations in the ED visited during an individual's ED stay. All relevant patient level data was also time stamped. Information on both ED space and staffing served as "resources" in the DES model that were called into use based on a "demand" profile constructed from the patient level data. Taken as a whole, these data provided a comprehensive picture of both the experiences of individual patients as well as the operational status of the ED at any point in time.

Empirical data collected for base model development and validation involved three different flow-design subtypes with three corresponding time periods: [1] flow split by ESI-based triage performed by a nurse with one internal-waiting area (01/01/2013–04/30/2013), [2] flow split by an intake attending physician with one internal-waiting area (1/1/2015–08/02/2015), and [3] flow split by an intake attending physician with two internal-waiting areas (08/03/2015–06/18/2016). The lengths of the sampling period for each flow-design type represented the longest contiguous periods when no other significant operational changes were being implemented in the ED (based on discussion with operational leaders). Although the sampling period lengths differed, thirty randomly selected days of data were taken from each sample period to drive model development. The collected data were cleaned and organized as described in the Supplementary Methods.

2.3. DES Base model development and validation

Because actual testing of the nine models of ED flow and design would be prohibitively time-consuming and costly, a DES model was created to simulate the ED. DES is well validated in ED operational analysis [19,20].

To create the DES model, first, a stochastic profile of patients and the activities they underwent in the ED was constructed. A Regression and Outlier Removal (ROUT) method using a threshold of Q = 10% was used to remove outliers from the above data in rigorous fashion [21]. This data was then analyzed with IBM SPSS Statistics 24 to create distributions for various inputs based on the empiric data. Second, these distributions were entered into ARENA Input Analyzer (Rockwell Automation: https://www.arenasimulation.com/) to create probability distributions for each input variable. Jupyter Notebook Python programming language (Python http://jupyter.org/) was used to translate location-time stamp pairs into paths of travel from location to location in the ED for each patient. Third, process maps were created to describe various sub-cycles in ED flow (e.g. patient arrival) and the necessary sequencing and resources required for a patient to move through a given process. These process modules were then recreated in ARENA to create simulations for individual patients and the ED as a whole. Fourth, after validation of the base model (see below), the ARENA model was paired with an Excel interface to allow for manipulation of independent variables and study of theoretical flow-design combinations. More complete details of model development are described in the Supplementary Methods.

Internal model validation was performed in two ways. First, the model was subjected to "extreme" conditions (either a 50% reduction in patient arrival rate or a reduction of 10 beds in the ED, approximately 1/7th capacity) to determine if key response variables (e.g. resource utilization and LOS) would change in the predicted manner. Second, model performance was compared to empirical performance for the three flow-design subtypes actually used in the ED. More complete details of model validation are described in the Supplementary Methods.

2.4. Interventions (DES experiments)

A two-factor analysis, examining the effects of three flow typologies and three physical design typologies on the below outcomes of interest, was completed. A graphical summary of these models is contained in Fig. 1.

Flow Model A – Split flow based on the Emergency Severity Index (ESI) score, a "rapid, reproducible, and clinically relevant stratification of patients into five groups" that predicts need for downstream resources [22]. This was performed by a nurse.

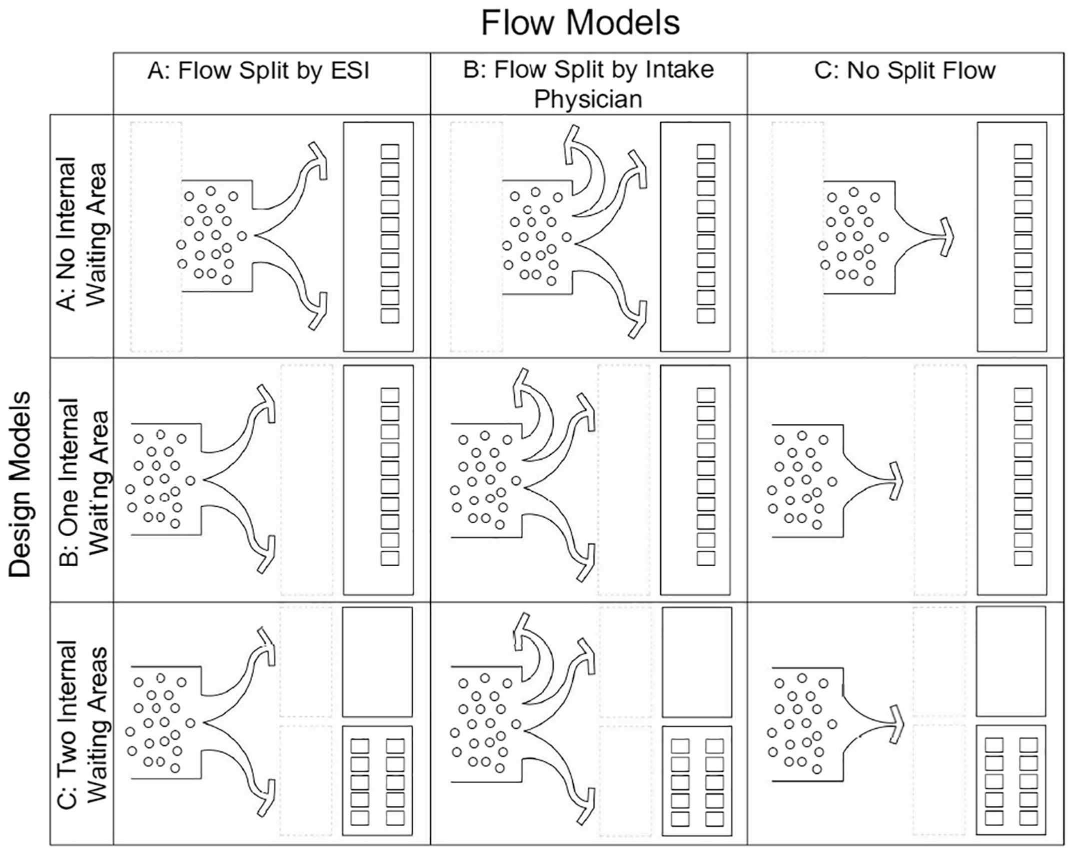

Fig. 1. Nine different flow-design models.This figure depicts the nine different models studied, with flow typologies in the columns and design typologies in the rows. Circle represents patients, dotted boxes represent waiting areas, and solid boxes represent ED treatment rooms.

Flow Model B – Split flow based on an intake attending physician. An intake model is an innovative system which eliminates traditional triage and brings the physician to the patient immediately when (s)he presents for care (after security check). After assessing each patient, the intake physician brings to bear his/her judgment and experience in deciding the best area of the ED to care

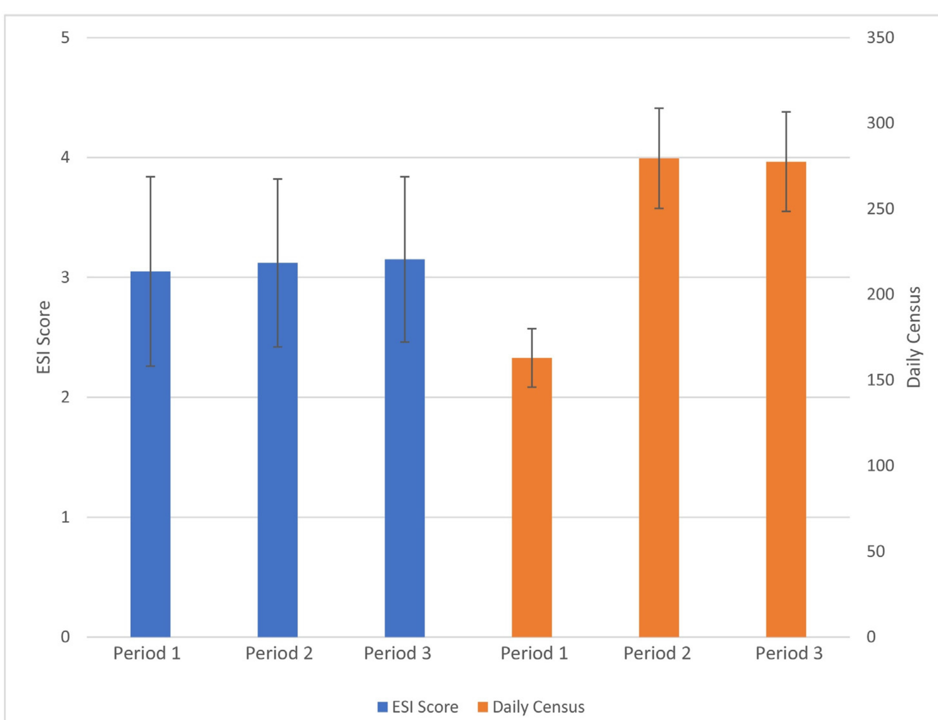

Fig. 2. ESI score and daily census by sample time period (mean ± 1 SD).

for the patient. While there are some guidelines, the flow is split based solely on the decision of the attending physician, a practice featured recently in the *Harvard Business Review* [23].

Flow Model C – No split flow. Rooms are allocated on a first come, first served basis. Subsequent arrivals queue until a room becomes available, resulting in a first in, first out (FIFO) methodology. While EDs generally do not operate under such a model at peak periods, they may under conditions of unused capacity and a direct rooming strategy.

Design Model A – No internal-waiting area. All excess capacity remains at the "front" of the department, waiting for a space to clear in order to evaluate a patient.

Design Model B – One internal-waiting area, a space to which patients can be assigned when they are not being actively examined or treated. When all rooms are filled and a new patient requires a room, a different patient can be moved to a chair/recliner in the internal-waiting area as they await the next stage of their visit [17].

Design Model C – Two internal-waiting areas spread out in the ED, but associated with functional patient care units in order to minimize staff and patient movement and to assist with continuity of care for providers.

For the flow models, flow split by ESI served as the control as this model is widely implemented across the US and internationally [24,25]. For the design models, no internal-waiting area served as the control as most EDs function with this model. Each internal waiting area was designed to accommodate up to four patients in recliners. Patients with ESI acuity levels 3–5 could be moved to an internal waiting area; level 1 and 2 patients were not moved.

2.5. Outcomes

The primary outcomes were length of stay and bed utilization rate (number of unique patients seen in an ED room in 24 h), both of which are standard ED operational measures. ED boarding time (time spent in the ED by an admitted patient after an admission order is placed) was excluded from LOS because it is primarily driven by hospital, not ED, factors [26,27]. Secondary outcome measures were door to provider time (D2P), left without being seen rate (LWBS), and number of movements per patient. Of these operational and patient-centered metrics, LOS, D2P, and LWBS are nationally-reportable metrics endorsed by the ED Benchmarking Alliance and the Agency for Healthcare Research and Quality [28]. Number of patient movements (number of movements a patient makes between ED locations of either waiting area or treatment space) was included as a balancing measure to account for patients' desire for resources to come to them rather than moving repeatedly.

2.6. Analysis

Simulation result analysis was conducted using R programming language (https://www.rstudio.com). Models were compared and analyzed for statistical significance and effect size using one-way analysis of variance (ANOVA) with Tukey's procedure to find the best performing model, two-way ANOVA to measure the marginal impact of each group of independent variables (flow types and/or design types), and linear and non-linear regression (based on qualitative inspection of the data pattern). For the regressions, the number of internal-waiting areas studied was extended to six to determine the marginal impact of adding additional internal-waiting areas. We limited the analysis to a maximum of six internal-waiting areas because, at four patients per area, this provided sufficient capacity to accommodate the greatest number of patients waiting for care that was observed during the study period.

Table 1
Results of model validation testing.

	ESI and one internal-waiting area			Intake attending physician and one internal-waiting area			Intake attending physician and two internal-waiting areas		
	Empiric data $N = 23{,}786$	Model data $n = 600$	t-Test $\alpha = 0.05$	Empiric data $N = 59{,}831$	Model Data $n = 830$	t-Test $\alpha = 0.05$	Empiric data $N = 89{,}147$	Model data $n = 835$	t-Test $\alpha = 0.05$
Length of stay (min)	229.2 ± 129.2	229.1 ± 129.0	$p = .96$	184.5 ± 114.3	183.3 ± 114.0	$p = .83$	176.4 ± 113.8	175.2 ± 113.1	$p = .83$
Bed utilization rate (Pts/bed/day)	3.5 ± 1.2	3.5 ± 1.0	$p = .53$	4.9 ± 1.1	5.0 ± 0.9	$p = .16$	5.0 ± 1.1	5.0 ± 1.0	$p = .67$
Door to provider time (min)	26.3 ± 22.1	26.3 ± 22.1	$p = .97$	9.8 ± 6.9	9.8 ± 6.9	$p = .90$	9.6 ± 6.8	9.6 ± 6.8	$p = .81$
LWBS rate (%)	3.20%	3.17%	$p = .97$	1.60%	1.60%	$p = 1.0$	1.20%	1.17%	$p = .94$
Movements per patient (#)	4.0 ± 1.9	4.0 ± 1.8	$p = .85$	4.1 ± 1.8	4.1 ± 1.8	$p = .65$	4.3 ± 1.9	4.2 ± 1.8	$p = .31$

Results depicted as mean ± 1 standard deviation.

Table 2
Flow metrics and patient-centered metrics for all models.

			Flow split by ESI	Flow split by intake attending physician	No split flow
			Model 1	Model 2	Model 3
No internal-waiting area	Total encounters		n = 5161	n = 7108	n = 4296
	Flow metrics	Length of stay (min)	268.6 ± 130.1 Effect = +39.4 (+17.9%)	209.6 ± 115.5 Effect = −19.6 (−8.5%)	338.5 ± 168.4 Effect = +109.3 (+47.7%)
		Bed utilization (Pt/bed/day)	3.15 ± 0.95 Effect = −0.39 (−11%)	4.40 ± 0.90 Effect = +0.86 (+24.3%)	2.43 ± 0.57 Effect = −1.11 (−31.4)
	Patient-centered metrics	Door to provider (min)	31.8 ± 23.6 Effect = +5.5 (+20.9%)	13.9 ± 7.4 Effect = −12.4 (−126.5%)	53.8 ± 29.3 Effect = +27.5 (+61.5%)
		LWBS (%)	4.32 ± 1.16 Effect = +1.15 (+36.2%)	2.50 ± 0.93 Effect = −0.67 (−21.2%)	6.24 ± 2.02 Effect = +3.07 (+96.8%)
		Movements per Pt (#)	3.2 ± 1.5 Effect = −0.8 (−20%)	3.4 ± 1.6 Effect = −0.6 (−15%)	1.7 ± 0.6 Effect = −2.3 (−58%)
			Model 4 (control)	Model 5	Model 6
1 Internal-waiting area	Total encounters		n = 5996	n = 8357	n = 5043
	Flow metrics	Length of stay (min)	229.2 ± 129.2	183.3 ± 114.3 Effect = −45.9 (−20%)	303.2 ± 161.3 Effect = +74 (+32.3%)
		Bed utilization (Pt/bed/day)	3.54 ± 1.00	4.97 ± 0.90 Effect = +1.43 (+40.4%)	2.91 ± 0.60 Effect = −0.63 (−17.8%)
	Patient-centered metrics	Door to provider (min)	26.3 ± 22.1	9.8 ± 6.9 Effect = −16.5 (−170.1%)	44.7 ± 27.5 Effect = +18.4 (+46.1%)
		LWBS (%)	3.17 ± 0.73	1.60 ± 0.41 Effect = −1.57 (−49.4%)	4.58 ± 1.47 Effect = +1.42 (+44.7%)
		Movements per Pt (#)	4.0 ± 1.8	4.1 ± 1.8 Effect = +0.1 (+2%)	1.9 ± 0.7 Effect = −2.1 (−53%)
			Model 7	Model 8	Model 9
2 Internal-waiting areas	Total encounters		n = 7040	n = 8427	n = 5328
	Flow metrics	Length of stay (min)	211.4 ± 127.8 Effect = −17.8 (−7.8%)	175.2 ± 113.1 Effect = −54.0 (−23.6%)	274.9 ± 156.8 Effect = +45.7 (19.9%)
		Bed utilization (Pt/bed/day)	4.30 ± 1.00 Effect = +0.76 (+21.5%)	5.02 ± 1.02 Effect = +1.48 (+41.8%)	3.30 ± 0.61 Effect = −0.24 (−6.8%)
	Patient-centered metrics	Door to provider (min)	23.7 ± 19.6 Effect = −2.6 (−10.8%)	9.6 ± 6.8 Effect = −16.6 (−227.4%)	39.9 ± 26 Effect = +13.6 (+39.9%)
		LWBS (%)	2.51 ± 0.52 Effect = −0.66 (−20.9%)	1.17 ± 0.31 Effect = −2.00 (−63.1%)	4.01 ± 1.23 Effect = −0.84 (−26.4%)
		Movements per Pt (#)	4.2 ± 1.8 Effect = +0.2 (+5%)	4.2 ± 1.8 Effect = +0.2 (+5%)	2 ± 0.7 Effect = −2 (−50%)

Data reported as mean ± 1 standard deviation. Effect size is relative to the control model and listed as absolute (relative %).

3. Results

3.1. Model derivation and validation

Prior to model creation, we analyzed the input data from the three sample time periods to assess for differences in acuity and patient arrivals. Fig. 2 shows mean ESI score by time period, and confirms that patient acuity was similar across all input data. Fig. 2 also shows mean daily census. While census was similar between time periods 2 and 3, census was lower during time period 1. Time period 1 contributed to the development of the control model (ESI with one internal-waiting area). Lower census is likely to lead to reduced LOS, bed utilization, D2P, LWBS, and number of patient movements. Thus, if this difference in input data biases the study results, it is likely in the direction of the null hypothesis as it would make the performance of the control model appear improved.

After verification of the input data, we then sought to validate that the DES models described ED flow. We compared the DES outputs with empirical data derived for the three scenarios when ED flow and design matched these scenarios. The results of this comparison are shown in Table 1. In unpaired t-tests, the DES models did not show statistically significant differences for any of the outcomes of interest ($p < .05$ for all comparisons).

3.2. Main results

Table 2 shows the five outcomes of interest (including both flow and patient-centered metrics) for all nine design-flow subtypes. In general, the shortest length of stay (mean 175.2 min, 95% CI 172.8–177.6) and highest bed utilization rate (mean 5.02 patients/bed/-day, 95% CI 5.00–5.04) were obtained in the model with flow split by an intake attending physician with two internal-waiting areas. These outcomes represented mean improvements of 54 min in LOS (95% CI for difference 48.1–59.9) and 1.48 patients/bed/day (95% CI for difference 1.47–1.49) in utilization rate, respectively, compared with the control model (flow split by ESI with a single internal-waiting area). This same model also generated the best D2P time (mean 9.6 min, 95% CI 9.5–9.7) and LWBS rate (mean 1.17%, 95% CI 1.16–1.18), which were mean improvements of 16.7 min (95% CI for difference 15.8–17.6) and 2% absolute for LWBS, respectively, over the control model. One-way ANOVA testing demonstrated the superiority of this model compared to the control in all comparisons ($p < .0001$ for all). Not surprisingly, the use of internal-waiting areas increased the number of movements per patient by approximately 5% to a mean of 4.2 (95% CI 4.16–4.24) movements per patient, an increase of 0.2 movements (95% CI 0.13–0.27).

Two-way ANOVA analysis demonstrated that both physical design and flow type, as well as the interaction of these variables, were statistically significant predictors of all outcomes of interest ($p < .0001$ for all comparisons).

Figs. 3–7 depict the linear regressions that show the impact of both physical design and flow type on the outcomes of interest. For all linear regressions, the R^2 value exceeded 0.84, suggesting strong goodness of fit. The marginal impact of adding one additional internal-waiting area depended on flow type and outcome of interest, and is depicted in Table 3. Addition of successive

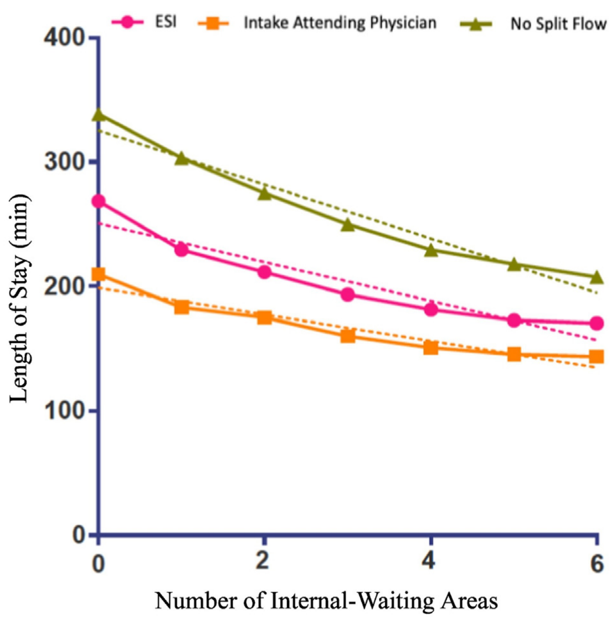

Fig. 3. Length of stay by flow type and number of internal-waiting areas.

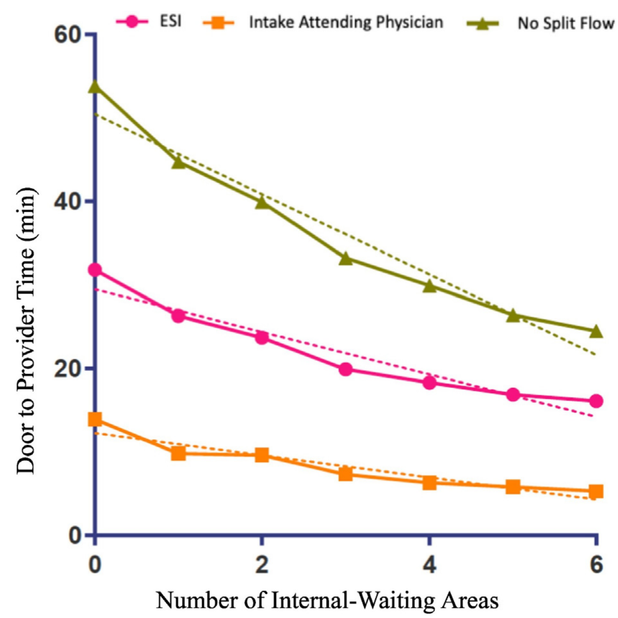

Fig. 5. Door to provider time by flow type and number of internal-waiting areas.

internal-waiting areas led to statistically significant improvements in all outcomes of interest with a trade-off of increased movements per patient.

The effect of various ED census levels of 20 k, 50 k, and 80 k, was also tested in order to represent volumes across a broad range of EDs [29]. Although the magnitude of the changes differed at each census level, flow split by an intake attending physician with multiple internal-waiting areas was consistently the most operationally favorable.

4. Discussion

Split flow models separate patients into different streams where resources can be better tailored to the need of each cohort. Generally speaking, a lower acuity cohort of patients can be evaluated and treated more efficiently because they do not "own" a bed, and are moved to common spaces except when they are receiving active evaluation or treatment. These patients consume fewer resources, are evaluated more expeditiously, and are able to be discharged more quickly because patient processing occurs in parallel. Beds in the more resource-intensive area(s) are reserved for a higher acuity group of patients that require constant attention and are unable to move as easily [7].

Consistent with these purported benefits, a number of institutions have reported generally positive results with split flow [8,9]. Both the Studer Group, a national emergency medicine consultant group, and ACEP's Emergency Department Directors Academy recommend splitting of horizontal and vertical patients in their solutions to improve ED flow [10,11]. However, methods used to split flow vary significantly. The Banner Health system, a pioneer of the practice, splits flow based on a "quick look" evaluation conducted

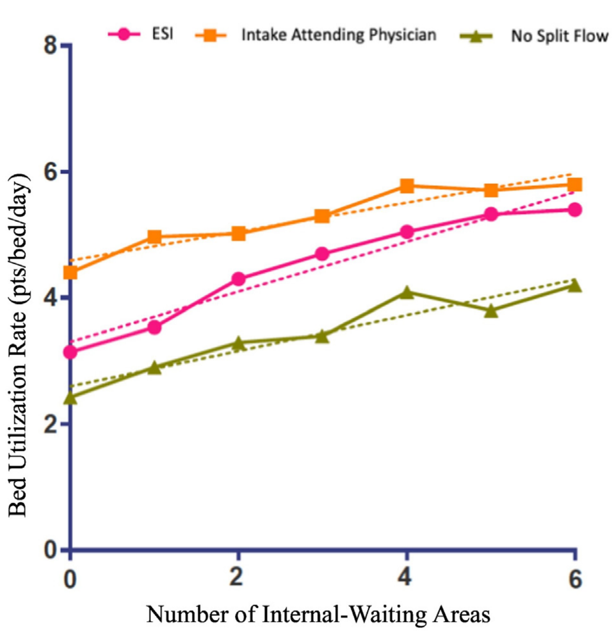

Fig. 4. Bed utilization rate by flow type and number of internal-waiting areas.

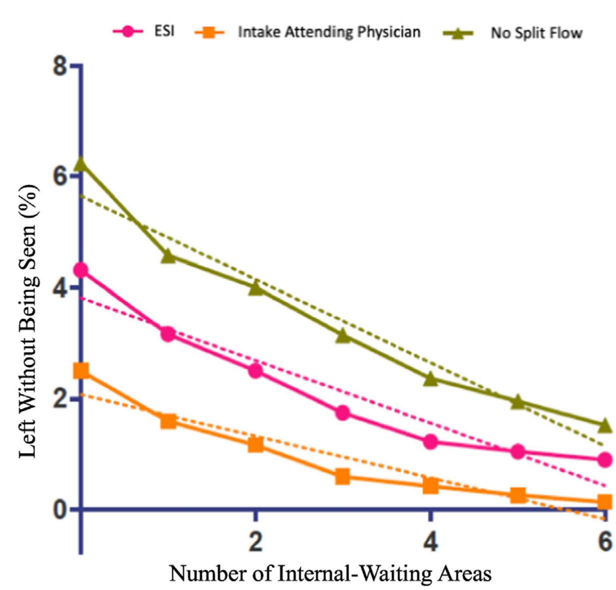

Fig. 6. Left without being seen rate by flow type and number of internal-waiting areas.

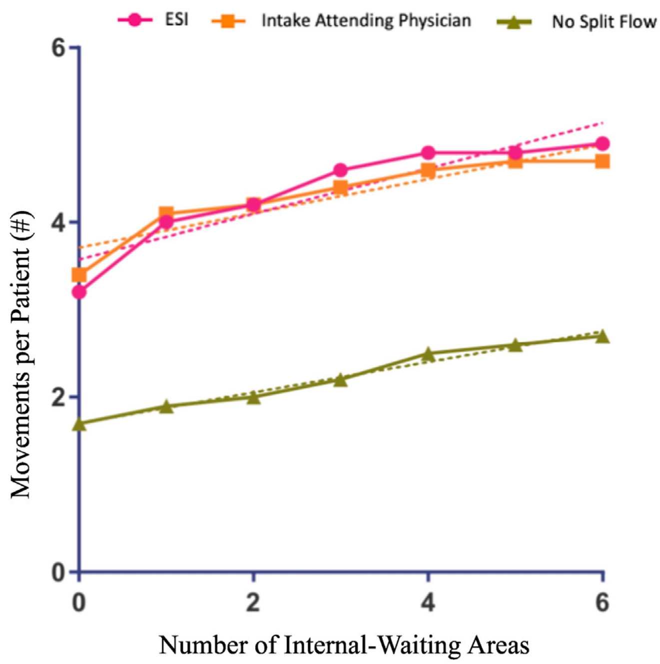

Fig. 7. Number of movements per patient by flow type and number of internal-waiting areas.

jointly by a physician and a nurse [12]. Others separate patients based on acuity, but the decision is made by a triage nurse [13]. In addition, these studies were largely descriptive and without a rigorous scientific comparison of the methodologies used to split flow.

In the present study, flow split by an intake attending physician was superior to both a traditional model of ESI-based flow as well as a first-in, first-out methodology for both operational and patient-centered metrics. As expected, such an intake model performed similarly to ESI in the number of patient movements. While this study supports the generally positive results described above, it is, to our knowledge, the first quantitative comparison of multiple split flow models.

In terms of physical design typology, the study of internal-waiting areas is novel. In an ED with no internal-waiting area, all excess capacity remains at the "front" of the department, waiting for a treatment space to clear. This leads to significant inefficiencies as many patients do not constantly require the resources of the rooms that they occupy. To combat this, some have described an internal-waiting area with isolated routes for different patient acuity levels (i.e. split flow) [17]. Rooms are used more efficiently, and patients spend the less active times of their ED visit in a more space-efficient internal-waiting area.

While many EDs have employed this solution with a single internal-waiting area, some research suggests that further efficiencies can be gained with multiple, smaller internal-waiting areas [17]. These would be placed throughout the ED but associated with functional patient care units in order to minimize staff and patient movement and to assist with continuity of care for providers. To our knowledge, while the above studies have proposed theoretical benefits of multiple internal-waiting areas, they have not been previously studied.

Our results provide quantitative support to the purported benefits of internal-waiting areas. Namely, increasing the number of internal-waiting areas led to improvements in both operational and patient-centered metrics with the exception of number of patient movements.

There is scant literature that seeks to unify the architectural and operational analyses of ED flow. By studying the interaction of physical design and flow typologies, we emphasize the need for solutions that account for both variables. In particular, the use of a two-factor analysis to allow for the best choice of physical design or flow when the other variable is unchangeable is novel. Moreover, DES simulation of our single ED showed that use of split flow by an intake attending physician with multiple internal-waiting areas can provide substantial benefits (LOS decreased by 54 min, D2P decreased by 16.6 min) over a traditional ED with ESI-based flow and a single waiting area.

Opportunities for future research include the role of advanced practice providers in the intake area, the use of "team triage" models as a mechanism to split flow, and how different flow-design combinations impact provider metrics and productivity, such as patients seen, RVUs, and patient satisfaction.

4.1. Limitations

This model was derived and validated using data from a single, academic, tertiary care ED, which may limit generalizability. In addition, the empiric data that informed the derivation of the model was taken from three different time periods when different design-flow combinations were in use. During one such period (ESI with one internal-waiting area), the ED existed in a different physical space than in the other two periods; however, the number of ED treatment spaces was similar (and adjusted for in the model) and there were not significant changes in the external environment (e.g. boarding) between these time periods. The daily census was also lower during this time period, which may bias the results, but likely in the direction of supporting the null hypothesis. In addition, because boarding time is representative of external factors and was excluded from the LOS definition used in the model, the LOS reported in this study is not directly comparable with typical benchmarks. Finally, for purposes of the model, use of each internal-waiting area was restricted to a maximum of four simultaneous patients with ESI levels 3–5. In practice, the number of patients in each internal-waiting area varied and ESI level 2 patients were included. Another limitation of internal-waiting areas is that their scalability may be limited by available staff. Each internal-waiting area requires its own staffing, and EDs with smaller numbers of staff may be unable to utilize a design model with multiple internal-waiting areas.

4.2. Conclusion

In summary, the present study supports the use of multiple internal-waiting areas and flow split by an intake attending physician as strategies to improve LOS, bed utilization, D2P, and LWBS.

Table 3
Marginal change in outcomes of interest by flow type for adding each successive internal-waiting area to the ED.

	ESI	Intake attending physician	No split flow
Length of stay (min)	−15.6 (−11.0, −20.2)	−10.6 (−7.8, −13.4)	−21.8 (−17.8, −25.7)
Bed utilization rate (Pts/Bed/Day)	0.40 (0.31, 0.48)	0.23 (0.16, 0.30)	0.28 (0.20, 0.36)
Door to provider time (min)	−2.5 (−1.9, −3.2)	−1.3 (−0.9, −1.7)	−4.8 (−3.8, −5.7)
Movements per patient (#)	0.26 (0.16, 0.36)	0.20 (0.12, 0.27)	0.18 (0.15, 0.20)

Results depicted as mean (95% CI).

Further studies are needed to validate these results across multiple institutions.

Presentations

Easter B, Houshiarian N, Pati D, Wiler J. Rethinking the Emergency Department: Designing for Flow and Efficiency. Presented at: Healthcare Facilities Symposium and Expo. October 8, 2018. Austin, TX.

Easter B, Houshiarian N, Pati D, Lennon J, Wiler J. Designing Emergency Departments to Provide Efficient, Patient-Centered Care: An Analysis of Split Flow and Sub-Waiting Area Models. Presented at: American College of Emergency Physician Research Forum. October 29, 2017. Washington, DC.

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Author contributions

BE, NH, DP, and JW conceived the study and obtained research funding. BE and JW created the study design and supervised the data collection. NH and DP created the DES models and analyzed the data. BE and NH drafted the manuscript, and all authors contributed substantially to its revision. JW takes responsibility for the paper as a whole.

Declarations of interest

None.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ajem.2019.03.017.

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