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Appendix for "Online Supplement: Evaluation of a Split Flow Model for the Emergency Department"

Juan Camilo David Gomez
Department of Industrial and Systems Engineering, University of Wisconsin-Madison, davidgomez@wisc.edu

Amy L. Cochran
Department of Mathematics & Department of Population Health Sciences, University of Wisconsin-Madison, cochran4@wisc.edu

Brian W. Patterson
BerbeeWalsh Department of Emergency Medicine, University of Wisconsin-Madison, bpatter@medicine.wisc.edu

Gabriel Zayas-Cabán
Department of Industrial and Systems Engineering, University of Wisconsin-Madison, zayascaban@wisc.edu

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Appendix A: Additional results

A.1. Shorter time windows for ED revisits

While ED revisits within a 30-day window is a common outcome in the ED, it may capture revisits that are unrelated to the original index ED visit. For this reason, some researchers recommend using a shorter window to increase the likelihood that the ED revisit is related to the original ED visit at the expense of missing ED revisits related to the original ED visit. For example, Rising et al. (2014) recommend using a 9-day window to best capture revisits related to the original ED visit. We thus repeated the RD analysis with several additional secondary outcomes. We estimate that split flow leads to a non-significant average decrease in 3-, 7-, and 9-day revisits rates of 0.4%, 0.0%, and 0.8% (Table A1). As a final attempt to increase the relevance of a revisit to the original visit, we also repeated the RD analysis with a 3-hour bandwidth (the 1-hour bandwidth had numerical issues) to estimate the change under split flow of a 30-day revisit rates such that the revisit has *the same chief complaint* as the original visit. We find a non-significant increase of 0.03% (95% CI: [-0.94%, 1.00%]) in 30-day revisit rates with the same chief complaint. In other words, analyzing ED revisits in shorter windows after discharge (3-, 7-, or 9-day versus 30-day) or matching the chief complaint leads to a similar conclusion as in the main text: split flow has a non-significant impact of ED revisits.

Analysis	3-day revisits, %	7-day revisits, %	9-day revisits, %	Tests, count
RD with 1 hour bandwidth	-0.4 (-2.0, 1.0)	0.0 (-1.0, 1.0)	-0.8 (-2.9, 1.2)	-0.1 (-0.2, 0.02)
Sensitivity analyses				
Changing bandwidth to 1/2 hour	-1.1 (-3.1, 0.9)	-1.5 (-4.1, 1.1)	-2.2 (-5.1, 0.6)	-0.2 (-0.3, -0.05)
Controlling for physician	-0.4 (-2.0, 1.0)	-0.01 (-1.9, 2.0)	-0.8 (-2.9, 1.1)	-0.1 (-0.2, 0.04)

Table A1 Estimates (95% CIs) for average effects of the split flow model on secondary outcomes.

A.2. Care intensity

In addition, there is empirical evidence that congestion influences the intensity of ED care (Batt and Terwiesch 2017, Pines et al. 2013). Hence, if split flow reduces congestion, then we might expect additional tests are performed under split flow. In contrast to this expectation, however, we actually estimate that split flow leads to a non-significant decrease in average number of tests (electrocardiograms and radiology) of 0.1 (Table A1).

A.3. Log-transformed times

The impact of split flow can be analyzed on a relative scale by applying a log-transformation to time to be roomed and time to disposition and repeating the RD analysis with a 1-hour bandwidth. This led to an estimated relative change in time to be roomed of 18.7% (95% CI: [10.0%, 28.1%]) and relative change in time to disposition of -9.0% (95% CI: [-13.3%, -4.4%]). We also examined moderation effects of congestion on log transformed time to be roomed and time to disposition. We find that split flow reduces the average time to be roomed by 31.8% (95% CI: [20.6%, 41.4%]) during the highest congestion level compared with the traditional nurse-led triage (Table A2). Split flow, however, increases by a greater percent of 57.3% (95% CI: [42.8%, 73.3%]) average time to be roomed for low congestion levels compared with traditional flow. As for time to disposition, we find that split flow reduces average time to disposition for low and middle tertiles by a percent of 11.5% (95% CI: [5.7%, 16.7%]) and 9.7% (95% CI: [4.7%, 14.5%]) respectively.

Congestion level	Time to be roomed	Time to disposition
High	-31.8 (-41.4, -20.6)	1.4 (-7.9, 11.7)
Medium	5.8 (-2.5, 14.9)	-9.7 (-14.5, -4.7)
Low	57.3 (42.8, 73.3)	-11.5 (-16.7, -5.7)

Table A2 Estimates (95% CIs) for percent change due to split flow in time to be roomed and to disposition.

A.4. RD for split flow end hours

We have analyzed the effect of the split flow model on outcomes by performing an RD design at the start of the intervention (i.e., at 12p). We can also estimate causal effects of split flow on outcomes when split flow ends, i.e., at 9pm. Three features make the latter analysis different from the one presented in the main text. First, the operational context (E.g., congestion, staffing) of the ED at night is substantially different from the context around noon. Second, we expect that patients arriving around the start of split flow are different from those arriving at night, right before and right after the end of the intervention. Third, before July 1, 2017, the end of split flow was 10p, which overlaps with the start of a new shift for physicians. Thus, we expect that the effect of split flow at the start will be significantly different from its effect at the end. In particular, we hypothesize that the effect of split flow will be lower at the end of split flow. Here, we test this hypothesis by evaluating impact of split flow on outcomes using an RD design when the forcing variables is centered at the end of the intervention. As hypothesized, we find that split flow has no significant impact on time to disposition, admission decisions and 30 days revisits (all confidence intervals contain zero) (Table A3). By contrast, the average time to be roomed decreases by 3.7 minutes (95% CI: [1.1, 6.4]).

Outcome	Estimate	95% confidence interval
Time to be roomed (min.)	-3.7	(-6.4, -1.1)
Time to disposition (min.)	2.2	(-8.7, 13.1)
Admission decision (%)	-0.6	(-4.4, 3.1)
30 days revisits (%)	-0.1	(-3.5, 3.3)

Table A3 RD estimates (95% confidence intervals) the impact of split flow on outcomes when the arrival time is centered at the end of the intervention. A bandwidth size of 1 hour was used (two hours in total).

A.5. RD Figures

We illustrate the RD estimates found in Section 5.2 and Section 5.4. Each figure depicts the average value of outcomes (in blue) for multiple ED encounters (orange triangles) inside the 1 hour bandwidth. Fitted regression lines (dashed lines) are also shown on the left and the right of start hour of the split flow (vertical dashed line). Causal effects are measured as the discontinuity formed by left and right regressions at the cutoff. Figure A1 illustrate the results for time to be roomed (Panel A) and time to disposition (Panel B). We observe a negative impact of the split flow model on average time to be roomed and a positive effect on average time to disposition at the cutoff. Figure A2 depicts the analogue for binary outcomes, i.e. admission decision (Panel A) and 30 day revisits (Panel B). We note a significant discontinuity for the number of admissions, but not for revisits. We also illustrated the RD estimates for time to be roomed and time to disposition by different levels of the moderators in Section 5.3 (Figure A3).

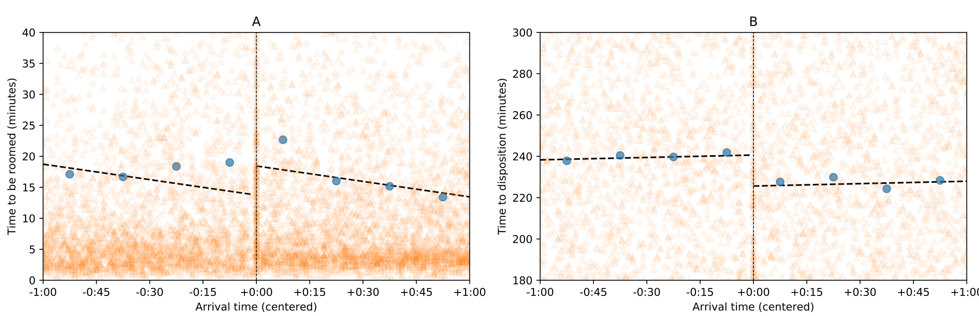

Figure A1 RD for continuous outcomes. Average time to be roomed (blue dots, Panel A) and average time to disposition (Panel B) for different visits (orange triangles) grouped in 15 minutes bins and fitted regression lines (dashed line). Arrival hour is centered at the start of split flow.

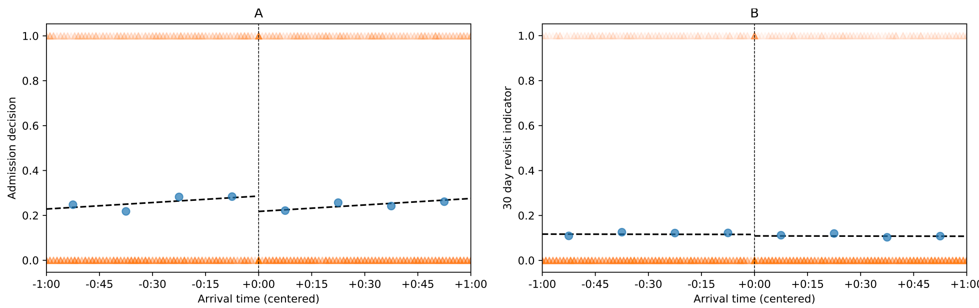

Figure A2 **RD for binary outcomes. Average number of admissions (blue dots, Panel A) and average number of revisits (Panel B) for different ED encounters (orange triangles) grouped in 15 minutes bins and fitted regression lines (dashed line). Arrival hour is centered at the start of split flow.**

A.6. Moderation analysis for binary outcomes

We next investigated the influence of moderator variables (i.e., congestion, day of the week, physician workload, and start time of the split flow model) on the effect of split flow on admission decision rates and revisits within 30 days of discharge rates. When adding, one at a time, each possible moderator and their interaction with the split flow indicator to the baseline regression model and testing whether simultaneously the interactions terms are significant, we found that day of the week, physician workload and split flow start hours did not yield a significant results in the model for either admission decision or 30 days revisit rates (Table A4). Therefore, day of the week, physician workload and split flow start hours do not appear to moderate the effect of split flow on downstream outcomes. Similarly, congestion was not significant in the model for 30 days revisits ($P = 0.91$) indicating that congestion is not a variable moderating the effect of split flow on 30 days revisit rates.

In contrast, the only moderator that yield significant results was congestion in the model for admission decision ($P = 0.05$). Thus, the effectiveness of the split flow model does appear to be moderated by congestion. Upon closer examination, we find that the split flow model decreases average admission rates during the highest congestion level, and to a lesser degree, during the medium and low congestion levels (Figure A4).All this might suggest that fewer patients are being admitted under the split flow, especially under high congestion, without impacting revisit rates.

As we did with continuous outcomes, we also estimate a model including all moderators and their pairwise interactions with the split flow indicators. In this scenario, we still find that day of week, physician workload, and split flow start hours did not yield significant interaction terms ($P < 0.05$ for all outcome, see Table A5) for either admission decision and 30 days revisit rates. Surprisingly, congestion was not significant in the full model for either admission decision and 30 days revisits. These findings reinforce the observation that, except for possibly congestion, downstream consequences might be not affected by the operational context of the ED.

References

Batt RJ, Terwiesch C (2017) Early task initiation and other load-adaptive mechanisms in the emergency department. *Management Science* 63(11):3531–3551. 2

Pines JM, Mullins PM, Cooper JK, Feng LB, Roth KE (2013) National trends in emergency department use, care patterns, and quality of care of older adults in the united states. *Journal of the American Geriatrics Society* 61(1):12–17. 2

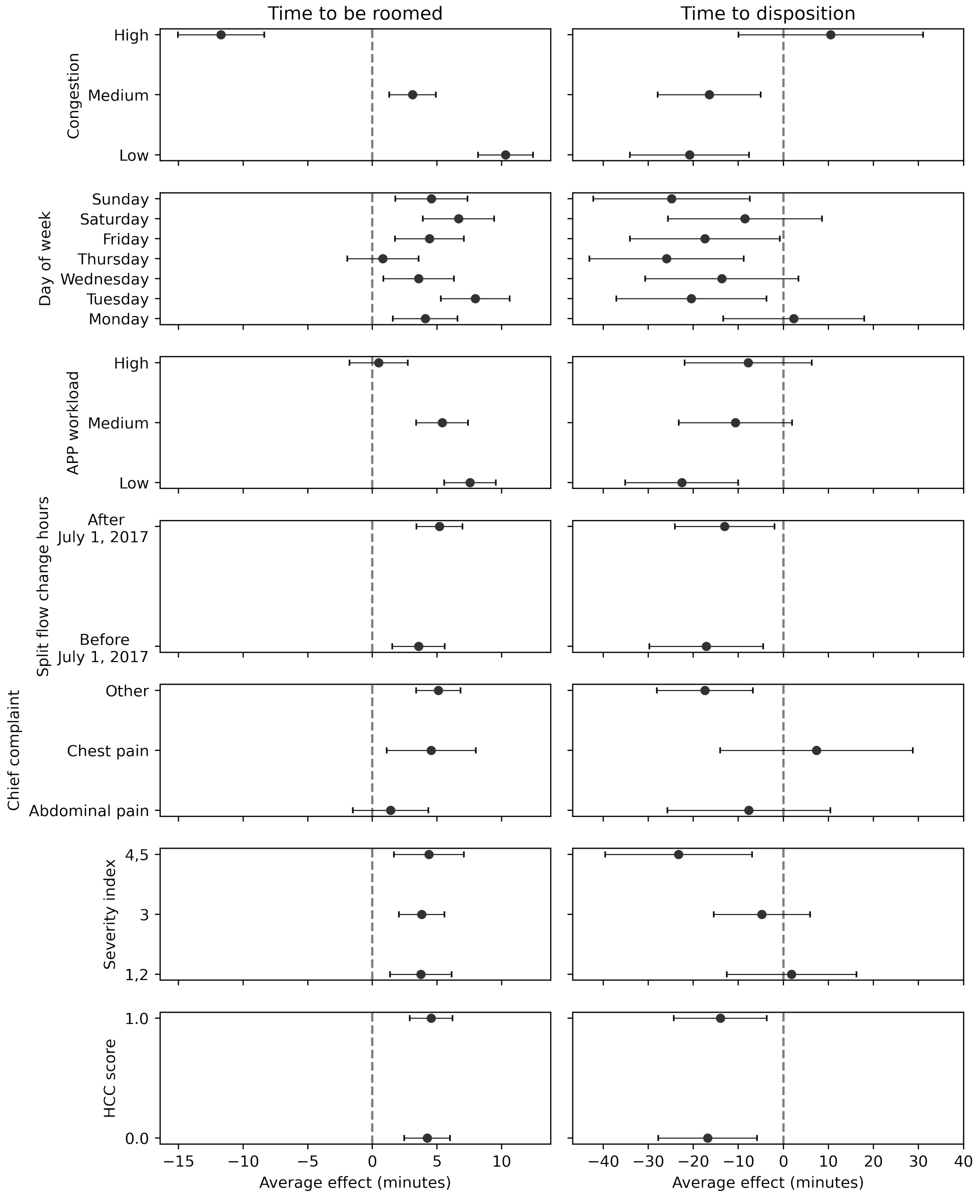

Figure A3 **Average effect (in minutes) of split flow on time to be roomed (left) and time to disposition after being roomed (right) during each level of moderator variables.**

Moderator	Admission decision	30-days revisit
Congestion	0.05	0.91
Day of week	0.72	0.81
Physician workload	0.66	0.61
Split flow change hours	0.74	0.73

Table A4 P **values for the joint test of interaction terms of moderator variables with split flow equal to zero for the regression model where each moderator is added one by one.**

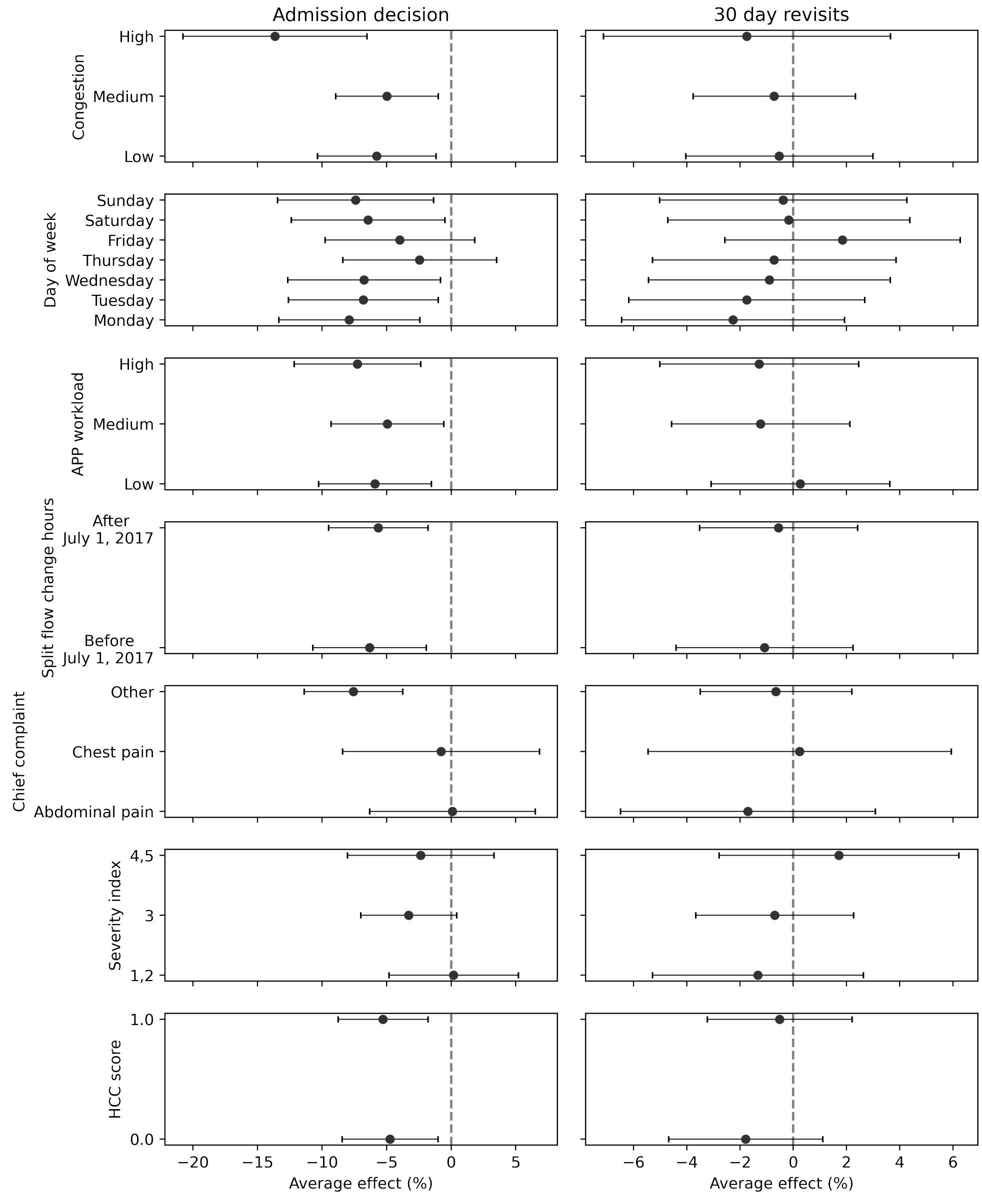

Figure A4 Average effect (%) of split flow on admission decision (left) and 30 days revisits (right) during each level of moderator variables.

Rising KL, Victor TW, Hollander JE, Carr BG (2014) Patient returns to the emergency department: the time-to-return curve. *Academic Emergency Medicine* 21(8):864–871. 1

		Admission decision		30 days revisits		Number of tests	
Moderator	Level	Interaction (95% CI)	P	Interaction (95% CI)	P	Interaction (95% CI)	P
Congestion	Medium	1.9 (-3.0, 6.8)	0.2	0.7 (-3.2, 4.6)	0.9	0.1 (-0.05, 0.2)	0.3
	High	-3.9 (-0.1, 4.3)		0.4 (-6.1, 7.0)		0.1 (-0.07, 0.4)	
Day of week	Monday	0.1 (-6.4, 6.8)	0.6	-1.1 (-6.4, 4.2)	0.8	-0.09 (-0.3, 0.1)	0.5
	Tuesday	-0.2 (-7.1, 6.6)		-1.3 (-6.8, 4.1)		0.02 (-0.1, 0.2)	
	Wednesday	0.2 (-6.6, 7.1)		-0.6 (-6.1, 4.9)		-0.1 (-0.3, 0.1)	
	Thursday	5.7 (-1.2, 12.7)		-0.4 (-6.1, 5.1)		-0.01 (-0.2, 0.2)	
	Friday	3.1 (-3.6, 9.8)		2.4 (-2.9, 7.9)		0.05 (-0.1, 0.2)	
	Saturday	1.1 (-5.5, 7.9)		0.4 (-4.9, 5.9)		0.02 (-0.1, 0.2)	
Physician workload	Medium	0.9 (-3.7, 5.6)	0.6	-1.4 (-5.1, 2.2)	0.7	-0.04 (-0.1, 0.1)	0.7
	High	-1.5 (-7.7, 4.5)		-1.8 (-6.7, 3.0)		-0.07 (-0.2, 0.1)	
Start hour	After July 1, 2017	-0.5 (-4.3, 3.3)	0.8	-0.01 (-3.0, 3.0)	0.9	-0.01 (-0.1, 0.1)	0.8
Chief complaint	Abdominal pain	7.1 (1.5, 12.8)	0.02	-0.5 (-5.0, 3.9)	0.7	0.1 (-0.05, 0.3)	0.4
	Chest pain	4.5 (-2.2, 11.3)		2.1 (-3.2, 7.6)		0.04 (-0.1, 0.2)	
ESI	Group 3	-4.5 (-9.2, 0.08)	0.1	1.0 (-2.7, 4.7)	0.2	-0.06 (-0.2, 0.1)	0.6
	Groups 4 and 5	-2.1 (-8.5, 4.2)		4.5 (-0.6, 9.6)		-0.01 (-0.2, 0.1)	
HCC		-0.5 (-1.7, 0.7)	0.4	1.3 (0.3, 2.3)	0.006	0.0 (-0.03, 0.04)	0.9

Table A5 Estimates for the coefficients of the interaction terms between split flow and moderator variables for the regression model including all moderators, and P values for the null hypothesis testing whether the interactions of a given moderator are zero simultaneously.