Appendix 1

A Typical Day in the ED

Assume for discussion that 1 patient arrives at our ED approximately every 5 minutes and average patient LOS is 300 minutes (5 hours). Also assume the ED beds and waiting room begin empty. If patients arrive regularly at this rate, 59 new patients will arrive by the time our first patient has made it from triage to discharge. If this rate remains steady, staffing and beds to treat 60 patients should eradicate wait times and keep staff fully occupied. This patient volume does not reflect 60 patients who arrive simultaneously, but 60 at various stages of treatment. Those awaiting laboratory results, phone calls from outside providers or inpatient admission may use few ED personnel/resources, freeing staff to manage more acute patient needs. As long as patient arrivals and treatment times remain close to average, this system should work smoothly. However, when these variables deviate from the mean, their effects on the system can be quite dramatic.

Now consider a more realistic model of a day during which patient arrival times and LOS vary considerably (Figure 1). One third of patients arrive between midnight and noon, and 2/3 arrives between noon and midnight. These numbers change the average rate of arrival from 1 patient every 7 minutes early in the day to every 3 minutes in the afternoon/evening. In other words, during the evening shift patients arrive twice as quickly as they do in the morning.

We will again start our analysis with an empty ED, 60 available ED beds and average treatment time=300 minutes (5 hours). The morning arrival rate predicts 42 more patients will arrive by the time the first patient of the day is processed and leaves the ED. This compares to 59 newly arrived patients using the 24-hour average described in the previous paragraph. At noon, the ED will have 42 occupied beds (70% capacity). After noon, patients start to arrive at the faster evening rate. Yet the rate at which patients

leave remains constant and the ED should fill within 93 minutes. From that time forward, the queue of patients will continue to increase, wait times will increase, and staff workload will peak.

This is particularly evident throughout the afternoon and evening when the majority of arriving patients must wait for those already in the system to leave the ED before their treatment begins. For example, 28 patients arrive between 6pm and 7pm, well below the ED's 60 patient maximum. But since our beds are already full, very few of those arriving during this time period will be evaluated quickly. Most will wait to the next hour *as if they were shifted forward* into the next hour's arrival group. Some will be shifted further into the group two hours later. Because patient arrival rate will slow later in the evening, the ED will eventually equilibrate, assuming the number of clinical staff and available beds remains the same. This *patient carried forward* concept should be kept in mind when planning staff assignments. If patient arrival averages alone were considered, it might seem staffing could decrease around 8pm. However a reduction at 11pm better matches the patient needs for a typical day.

These examples illustrate problems inherent to using averages to model processes that follow a constrained sequence: arrival, triage, bed placement, initial evaluation, laboratory data, etc. In a less constrained scenario, averages might be perfectly reasonable. For example, one can calculate the amount of paint needed to paint several hospital rooms based on average room size because some rooms will use more paint, but others less. Unused paint for smaller rooms carries over to be used in larger rooms. However, for patients arriving to the ED, unused clinician time from a slow period cannot be carried forward to a busier time. Therefore analyses based on averages fail to adequately describe how resources are underutilized at some times and outstripped at others. Queuing theory models patient flow in a manner that predicts these outcomes and shows how changes in several variables can affect efficiency of the system.

Figure Legend

Figure 1. Number of arriving patients is listed numerically at top of figure. Patients awaiting treatment are shown as open circles; those in treatment appear as dots. The number of providers remains constant (9). When idle, they are represented by open boxes at bottom of figure. Boxes with dots represent providers treating patients.

Figure 1. Patient Arrivals to the ED on a Typical Day