

hillmaker: A Python package for occupancy analysis in discrete entity flow systems

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Summary

hillmaker is a Python package that computes time-of-day and day-of-week-specific arrival, departure, and occupancy statistics from transaction data containing arrival and departure timestamps. Typical use is for capacity planning problems in places like hospital emergency departments, surgical recovery rooms, or any system in which entities arrive, occupy capacity for some amount of time, and then depart. It gets its name from the hill-like nature of summary occupancy plots - see [Figure 1](#).

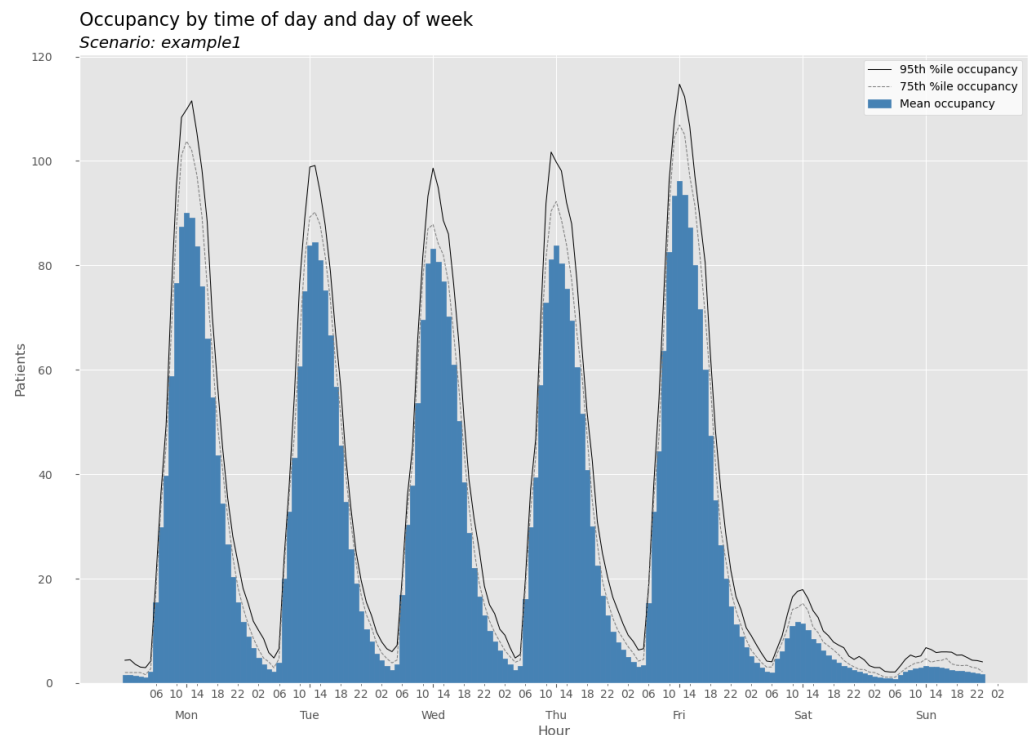


Figure 1: Weekly occupancy plot.

The hillmaker package can be used as a command line application as well as an importable library from Jupyter notebooks or Python scripts. There is an object-oriented API as well as a function-based API. Under the hood, hillmaker relies primarily on numpy ([Harris et al., 2020](#)), pandas ([The pandas development team, 2020](#)), matplotlib ([Hunter, 2007](#)), seaborn ([Waskom, 2021](#)), and Pydantic ([Colvin et al., 2024](#)). Transaction data can be in CSV format or a pandas

DataFrame. The primary outputs of hillmaker are:

- pandas DataFrames and CSV files with arrival, departure, and occupancy summaries by time of day, day of week and, optionally, an entity category.
- customizable weekly and daily plots of arrivals, departures, and occupancy by time of day and day of week.
- summary tables and plots for length of stay and implied operating hours.

The [documentation](#) includes several tutorials on using hillmaker for typical occupancy analysis problems in healthcare.

Statement of need

The original motivation for hillmaker was a series of capacity planning problems faced by a management engineering group at a large healthcare system. Such problems are characterized by patient flow and capacity use that exhibit significant and important time-of-day and day-of-week patterns. For example, a huge component of hospital costs are related to labor. Staffing and scheduling relies on effectively matching capacity to demand that varies significantly by time of day and day of week. Another motivating problem involved developing a surgical patient rerouting plan to temporarily accommodate patients while a post-surgical holding area renovation project was underway. Proper statistical analysis of patient arrival, departure, and occupancy patterns, including computation of percentiles, are a critical part of such projects. Traditional statistics packages do not include this type of functionality and one-off SQL based approaches are tedious to create and generalize. Additionally, the implementation of percentile functions in SQL is dialect-dependent.

Early versions of hillmaker were used in hundreds of projects in multiple healthcare engineering departments and consulting firms. It was written in Microsoft Access ([Microsoft Corporation, n.d.](#)) and released as an open source project in the early 2000s. You can still find it on SourceForge at sourceforge.net/projects/hillmaker/. An academic paper about this early version was published ([Isken, 2002](#)) after the first author left industry and joined Oakland University. Unfortunately, development on this version languished for a variety of technical and logistical reasons. So, hillmaker continued to get significant use but few improvements were made.

In addition to industry use, hillmaker is well-suited for healthcare operations research projects involving patient ([Broyles et al., 2010](#); [Helm & Van Oyen, 2014](#); [Isken et al., 2011](#); [R. Konrad et al., 2012](#)), material ([Isken & Littig, 2002](#)), and even information flow ([R. A. Konrad et al., 2008](#)). Discrete event simulation is widely used in such research projects, and hillmaker can aid in the statistical analysis needed for modeling entity arrival patterns and for analyzing and validating simulation output. While problems in the healthcare industry spurred the development of hillmaker, it has been used in other domains such as [bike share systems](#), freight operations ([Castrellon et al., 2023](#)), customer contact centers, and even for analyzing usage patterns of a high performance computing cluster by engineers at a large automobile manufacturer. Any system for which you have data on start and stop times of events, or entry and exit times of entities, is amenable to using hillmaker for characterizing temporal patterns in arrivals, departures, and occupancy (or task starts, task completions, and work in progress).

Given the rise of Python in the scientific computing world, rewriting hillmaker in Python made a lot of sense for its future as an open source project. The first Python version was [released in 2016](#). A series of improvements followed over the next several years, culminating in the recent release of version 0.8.0 in November of 2023. Many of the recent improvements were motivated by the second author's use of hillmaker at UNC Health Rex, part of a large healthcare system in North Carolina. They used hillmaker to better understand patient throughput and capacity management in their surgical services division as well as to determine the optimal bed size for a potential same day recovery unit.

By creating an easy to use Python version with extensive documentation, we are hoping that hillmaker can gain greater traction now that Python has become so widely used in the data analysis community. Our plan is to add a form-based GUI (much like the one in the original MS Access version) in the next major release which should make it even easier to use for non-programmers.

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