# Assignment 2

Your team is a consultancy firm for a major European airport's Operations Research team. The airport has experienced significant passenger growth over recent years, with September being the peak travel month. The Head of Operations is concerned about long security screening wait times during this peak period and has commissioned your team to analyze the situation.

**System Context:** The airport operates approximately 50 parallel security screening lanes . Your task is to model and analyze the queueing dynamics for a single representative lane to evaluate different operational strategies. We will focus only on this single representative lane throughout (unless otherwise stated).

Objective

Model a single security screening lane during the peak month (September). You will:

- Validate your discrete-event simulator against theoretical predictions
- Evaluate two proposed interventions using hypothesis testing
- Make a simulation-driven recommendation to the leadership

Provided Data

File: airport.csv

Monthly aircraft and passenger traffic data, we will focus on columns:

Year: Calendar year

Month: Calendar month

Europe Passengers: Passengers on European flights

Intercontinental Passengers: Passengers on intercontinental flights

Total Passengers: Total monthly passengers

(More details in next page)

**Part 1: System Parameters from a Peak Month**

1.1 Calculate Arrival Rate (λ) in passengers per minute

Using the September data (2015-2019): (Note: We are using the pre-pandemic years 2015-2019 to establish a stable and representative baseline for peak travel, avoiding the effects of the COVID-19 pandemic on passenger traffic.)

- Calculate the average monthly passenger count across these Septembers
- Convert this to an hourly arrival rate assuming: 30-day month, 16-hour operational days

For this idealized model, to keep it simple, we will assume a uniform arrival rate throughout the day

Divide by the number of security lanes (N = 50) to get the per-lane arrival rate (λ) in passengers per minute

Assume arrivals during hours follow a homogeneous Poisson process at rate λ per lane.

System Parameters for All Simulations

Use these parameters consistently throughout Parts 2A and 2B:

Service Time Distribution: Normal with mean E[B] = 1.0 minutes per passanger, standard deviation σ = 0.25 minutes per passenger (If a service time sample is negative, resample until a non-negative value is obtained to maintain the truncated normal distribution)

Number of Lanes: Modeling a single lane (unless otherwise specified in Option A)

(There is a Part 2 in next page.)

**Part 2: Hypothesis Testing & Simulation**

You build a discrete-event simulator from scratch or using SimPy. The simulator should:

Accept: arrival rate ($\lambda$), service time parameters, number of servers, number of passengers to simulate

Simulate: A queueing system until steady-state for Part 2A and until 3000 passengers are served for Part 2B

Return: Individual waiting times for each passenger (discard first 1,000 passengers (Warm-up period))

**Part 2A: Validating Your Simulator**

Before we simulate our complex, terminating peak-period scenario, we will first validate the core logic of our event-driven simulator by testing it in a standard, stable M/G/1 configuration against its known theoretical steady-state solution (the P-K formula). This gives us confidence that the underlying mechanics (event scheduling, random variate generation, and statistics collection) are implemented correctly

Challenge: The arrival rate likely creates an unstable system ($\rho > 1$), where theoretical formulas don't apply. Therefore, you'll validate using a reduced arrival rate that ensures stability.

Steps:

1. Establish a Stable Test Rate

Define a test arrival rate that ensures $\rho < 1$:

Choose a target utilization: $\rho_{target} = 0.85$ (highly loaded but stable)

Calculate: $\lambda_{test} = \rho_{target} / E[B]$ (for single server)

Verify: $\rho_{test} = \lambda_{test} \times E[B] < 1$

2. Theoretical Baseline

Using $\lambda_{test}$, calculate the theoretical average waiting time ($W_{q\_theory}$) using the Pollaczek-Khintchine (P-K) formula for M/G/1:

$W_q = (\lambda \times E[S^2]) / (2 \times (1 - \rho))$

where:

$\lambda = \lambda_{test}$ (arrival rate)

$E[S^2] = E[B]^2 + \sigma^2$ (second moment of service time)

$\rho = \lambda \times E[B]$ (utilization)

3. Simulation Baseline

Run your simulator with:

Arrival rate: $\lambda_{test}$

Service time: Normal($E[B] = 1.0$, $\sigma = 0.25$)

Servers: 1 Perform R = 40 independent replications.

Calculate the simulated average waiting time ($W_{q\_sim}$).

4. Hypothesis Test

Formulate and conduct a hypothesis test to see if our simulator matches thoery, use Significance level: $\alpha = 0.05$.

Does your simulator validate?

**Part 2B: Evaluating Interventions**

For each scenario below, you will simulate transient behaviour of the system with 3000 passengers in total (served). No warm-up is required. Your primary metric will be the average waiting time for all 3000 passengers who complete the security. You will likely find $\rho > 1$ (unstable). This is intentional, simulation can model transient behavior where analytical methods fails.

To achieve statistical power, you must perform R = 40 independent replications for each scenario (i.e., simulate 40 separate 3000 passenger simulations).

Arrival Rate ($\lambda$): Use the per-lane arrival rate calculated in Part 1. Arrival Process: Passengers arrive according to the Poisson process.

Scenarios

| Scenario | Description | Servers | Service σ | E[B] | |
|---|---|---|---|---|---|
| Baseline | Current operations | 1 | 0.25 min | 1.0 min | |
| Option A | Add more servers | 2 | 0.25 min | 1.0 min | |
| Option B | Reduce variability | 1 | 0.1 min | 1.0 min | |

Interpretation:

Option A: We now include an additional server to this queue, making it two service representative in the lane. This system receives the same passenger arrival stream (at rate $\lambda$) that the baseline single lane received. ( Meaning, one lane is now serviced by two servers). (M/G/2)

Option B: Represents process improvements (standardized bins, better signage, trained staff) that reduce service time variability with no infrastructure addition.

Use significance level $\alpha = 0.05$.

Which option between Option A and Option B show statistically significant improvement?

Bonus: Are there any other alternative strategies you would deploy here to tackle this issue? Just in case you need additional stats for this: https://www.schiphol.nl/en/schiphol-group/transport-and-traffic-statistics/