Design Problem used in the Class and Shown in the Videos using the HARint Plane Methodology and the RTT MCS Calculator
Monte Carlo Simulation to evaluate the round trip time and the average travelling time

For the elevator system shown below, calculate the round trip time and the average travelling time using the Monte Carlo simulation method (MCS). Do only one scenario.

In generating passenger origins and destinations, use the table of random numbers shown on the next page. Assume a target interval of 30 s, an arrival rate of 7% and a pure incoming traffic (i.e., find the value of P from these two values).

Assume the following parameters:

a. Number of floors above ground is 8 floors.
b. One ground floor and two basement car park floors.
c. Rated speed, \( v \), is 2.0 m·s\(^{-1}\).
d. Rated acceleration, \( a \), is 1 m·s\(^{-2}\).
e. Rated jerk, \( j \), is 1 m·s\(^{-3}\).
f. Passenger transfer time out of the car is 1.2 s.
g. Passenger transfer time into the car is 1.2 s.
h. Door opening time is 2 s.
i. Door closing time is 3 s.
j. Total building population of 1000 persons.
k. Unequal floor heights and unequal floor populations.

Other building parameters are shown below.

<table>
<thead>
<tr>
<th>Type of floor</th>
<th>Floor</th>
<th>Population</th>
<th>Arrival percentage</th>
<th>Floor Height (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Occupant floors</td>
<td>L8</td>
<td>50</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>L7</td>
<td>100</td>
<td>N/A</td>
<td>3.8</td>
</tr>
<tr>
<td></td>
<td>L6</td>
<td>100</td>
<td>N/A</td>
<td>3.8</td>
</tr>
<tr>
<td></td>
<td>L5</td>
<td>150</td>
<td>N/A</td>
<td>4.0</td>
</tr>
<tr>
<td></td>
<td>L4</td>
<td>150</td>
<td>N/A</td>
<td>4.0</td>
</tr>
<tr>
<td></td>
<td>L3</td>
<td>150</td>
<td>N/A</td>
<td>4.0</td>
</tr>
<tr>
<td></td>
<td>L2</td>
<td>150</td>
<td>N/A</td>
<td>4.0</td>
</tr>
<tr>
<td></td>
<td>L1</td>
<td>150</td>
<td>N/A</td>
<td>4.0</td>
</tr>
<tr>
<td>Entrance/exit floors</td>
<td>Ground</td>
<td>N/A</td>
<td>80%</td>
<td>5.0</td>
</tr>
<tr>
<td></td>
<td>B1</td>
<td>N/A</td>
<td>10%</td>
<td>3.5</td>
</tr>
<tr>
<td></td>
<td>B2</td>
<td>N/A</td>
<td>10%</td>
<td>3.5</td>
</tr>
</tbody>
</table>

This problem has been solved in class using an RTT Calculator, as shown on the following page.
when solved using the HARINT Plane and the RTT MCS Calculator:

\[ V_1 = 2.5 \text{ m/s}, \quad \text{INTact} = 20.83 \text{ s}, \quad \text{CC} = 8 \text{ passengers} \]
\[ V_2 = 2.0 \text{ m/s}, \quad \text{INTact} = 22.57 \text{ s}, \quad \text{CC} = 8 \text{ passengers} \]
\[ V_3 = 1.6 \text{ m/s}, \quad \text{INTact} = 25.22 \text{ s}, \quad \text{CC} = 8 \text{ passengers} \]

All three solutions give

\[ \text{CC} = 8 \text{ passengers} / 630 \text{ kg} \]
\[ L = 4 \text{ elevators} \]

\[ V_1, 2.5 \text{ m/s: First iteration} \implies (25.2 \text{ s, 8.3%}) \]
\[ \text{last iteration} \implies (20.83 \text{ s, 7.0%}) \]
\[ P = 4.868 \text{ passengers}, \quad \text{CC} = 8 \text{ passengers} \]

\[ V_2, 2.0 \text{ m/s: First iteration} \implies (26.04 \text{ s, 8.06%}) \]
\[ \text{Second iteration} \implies (22.57 \text{ s, 7.0%}) \]
\[ P = 5.27 \text{ passengers}, \quad \text{CC} = 8 \text{ passengers} \]

\[ V_3, 1.6 \text{ m/s: First iteration} \implies (27.355 \text{ s, 7.68%}) \]
\[ \text{Last iteration} \implies (25.22 \text{ s, 7.0%}) \]
\[ P = 5.88 \text{ passengers} \]
\[ \text{CC} = 8 \text{ passengers} \]
The Problem has also been solved using manual Monte Carlo Simulation (just one iteration) for the RTT and the average travelling time (ATT).
<table>
<thead>
<tr>
<th>Passenger no.</th>
<th>Random Numbers Table</th>
</tr>
</thead>
<tbody>
<tr>
<td>#</td>
<td>Use for the origin floor</td>
</tr>
<tr>
<td>1</td>
<td>0.614</td>
</tr>
<tr>
<td>2</td>
<td>0.293</td>
</tr>
<tr>
<td>3</td>
<td>0.300</td>
</tr>
<tr>
<td>4</td>
<td>0.199</td>
</tr>
<tr>
<td>5</td>
<td>0.231</td>
</tr>
<tr>
<td>6</td>
<td>0.918</td>
</tr>
<tr>
<td>7</td>
<td>0.536</td>
</tr>
<tr>
<td>8</td>
<td>0.696</td>
</tr>
<tr>
<td>9</td>
<td>0.577</td>
</tr>
<tr>
<td>10</td>
<td>0.536</td>
</tr>
</tbody>
</table>

The random numbers shown above are to be used in generating origin-destination pairs.
\[ N = 8 \ (1 \rightarrow 8) \]
Enhance Floors B2, B1, G

Let us develop the pdf for the enhance floors:

pdf

\[
\begin{array}{c|c}
\text{Floor} & \text{pdf} \\
\hline
\text{G} & 0.8 \\
\text{B1} & 0.1 \\
\text{B2} & 0.1 \\
\end{array}
\]

cdf

\[
\begin{array}{c|c}
\text{Floor} & \text{cdf} \\
\hline
\text{G} & 0.8 \\
\text{B1} & 0.9 \\
\text{B2} & 1 \\
\end{array}
\]

cdf table

\[
\begin{array}{c|c}
\text{pdf} & \text{cdf} \\
\hline
\text{G} & 0.8 \\
\text{B1} & 0.9 \\
\text{B2} & 1 \\
\end{array}
\]

For the destination floor, we can also develop the pdf and cdf in table form as shown below:

<table>
<thead>
<tr>
<th>( A )</th>
<th>pdf</th>
<th>cdf ( L )</th>
<th>cdf ( H )</th>
<th>pdf ( C )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>0.15</td>
<td>0</td>
<td>0.15</td>
<td>0.15</td>
</tr>
<tr>
<td>0.2</td>
<td>0.15</td>
<td>0.15</td>
<td>0.3</td>
<td>0.45</td>
</tr>
<tr>
<td>0.3</td>
<td>0.15</td>
<td>0.3</td>
<td>0.45</td>
<td>0.63</td>
</tr>
<tr>
<td>0.4</td>
<td>0.15</td>
<td>0.45</td>
<td>0.6</td>
<td>0.83</td>
</tr>
<tr>
<td>0.5</td>
<td>0.15</td>
<td>0.6</td>
<td>0.75</td>
<td>0.95</td>
</tr>
<tr>
<td>0.6</td>
<td>0.15</td>
<td>0.75</td>
<td>0.85</td>
<td>0.97</td>
</tr>
<tr>
<td>0.7</td>
<td>0.15</td>
<td>0.85</td>
<td>0.95</td>
<td>0.98</td>
</tr>
<tr>
<td>0.8</td>
<td>0.15</td>
<td>0.95</td>
<td>1</td>
<td>0.99</td>
</tr>
</tbody>
</table>

We now need to find the passengers, \( P \).

\[ A_{\text{hat}} = 1000 \text{ persons} \]

\[ \lambda = \frac{(AR)(A)}{100} = 7.30 \text{ pass/seconds} \]

\[ \lambda = \frac{(AR)(A)}{300} = 7.30 \]
\[
\rho_{\text{ini}} = \frac{\lambda}{\text{cap}} = \left(\frac{4}{30}\right) \cdot 30 = 7 \text{ passengers}
\]

We now generate origins and destinations for all \( \rho \) passengers:

<table>
<thead>
<tr>
<th>#</th>
<th>origin floor</th>
<th>destination floor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>G</td>
<td>L1</td>
</tr>
<tr>
<td>2</td>
<td>G</td>
<td>L3</td>
</tr>
<tr>
<td>3</td>
<td>G</td>
<td>L5</td>
</tr>
<tr>
<td>4</td>
<td>G</td>
<td>L5</td>
</tr>
<tr>
<td>5</td>
<td>G</td>
<td>L4</td>
</tr>
<tr>
<td>6</td>
<td>B2</td>
<td>L3</td>
</tr>
<tr>
<td>7</td>
<td>G</td>
<td>L5</td>
</tr>
</tbody>
</table>

So the full journey becomes:

\[B2 \rightarrow G \rightarrow L1 \rightarrow L3 \rightarrow L4 \rightarrow L5 \rightarrow B2\]

We need to prepare the kinematic number before calculating the round trip time and the average waiting time:

- \( d_{B2 \rightarrow G} = 3.5 + 3.5 = 7 \text{ m} \)
- \( d_{G \rightarrow L1} = 5 \text{ m} \)
- \( d_{L1 \rightarrow L3} = 4 + 4 = 8 \text{ m} \)
- \( d_{L3 \rightarrow L4} = 4 \text{ m} \)
- \( d_{L4 \rightarrow L5} = 4 \text{ m} \)
- \( d_{L5 \rightarrow B2} = 4 + 4 + 4 + 5 + 3.5 + 3.5 = 28 \text{ m} \)

\(\boxed{6}\)
Let us check the crossover point after which the top speed is attained or not attained.

\[
\frac{a^2 v + v^2}{aj} = \frac{2 + 4 \cdot 6}{1} \quad m
\]

so where the distance to be travelled in a journey is more than 6 m, then top speed of 2 m/s is attained and we use the following equation to find the journey time:

\[
t = \frac{d}{v} + \frac{v}{a} + \frac{d}{j} = \frac{d}{2} + \frac{2}{1} + \frac{1}{1}
\]

\[
= \frac{d}{2} + 3 \quad \text{seconds}
\]

where the distance to be travelled in a journey is less than 6 m (and more than 2 m) then top speed is not attained (but top acceleration is attained) and we use the following equation to find the journey time:

\[
b = \frac{a}{j} + \sqrt{\frac{4d}{a} + \left(\frac{a}{j}\right)^2}
\]

\[
= 1 + \sqrt{4d + 1} \quad \text{seconds}
\]
Kinematics

\[
t_{32G} = 6.5 S \\
t_{G4} = 5.6 S \\
t_{l23} = 7 S \\
t_{l34} = 5.1 S \\
t_{t4} = 5 S \\
t_{t5} = \frac{28}{2} + 2 + 1 = 17 S
\]

Timeline

\[
\begin{align*}
\text{P6} & \downarrow \gamma_1 P1 \\
& 1.2 + 3 + 6.5 + 2 + 1.2 + 1.2 + 1.2 + 1.2 + 1.2 + 1.2 + 1.2 + 1.2 \\
& P1 \downarrow 12.7 \uparrow 13.9 \uparrow 15.1 \uparrow 16.3 \uparrow 17.5 \uparrow 18.7 \\
& \text{P6} \downarrow 44.9 \downarrow 46.1 \\
& 3 + 5.6 + 2 + 1.2 + 3 + 7 + 2 + 3 + 5.1 + 2 + 1.2 + 3 + 5.1 \\
& \text{P5} \downarrow 57.4 \\
& 5.1 + 2 + 1.2 + 1.2 + 1.2 + 1.2 + 3 + 17 + 2 \\
& \text{P3} \downarrow 68.7 \downarrow 69.9 \downarrow 71.1 \\
& \text{end of run} \\
& 93.1
\end{align*}
\]
The travelling time for all 7 passengers is

\[ TT_{P1} = 31.7 - 12.7 = 19 \text{ s} \]
\[ TT_{P2} = 44.9 - 13.9 = 31 \text{ s} \]
\[ TT_{P3} = 53.6 \text{ s} \]
\[ TT_{P4} = 53.6 \text{ s} \]
\[ TT_{P5} = 39.9 \text{ s} \]
\[ TT_{P6} = 46.1 \text{ s} \]
\[ TT_{P7} = 52.4 \text{ s} \]

\[ ATT = 42.23 \text{ s} \]

\[ RTT = 93.1 \text{ s} \]