Minimizing Epidemic Viral Total Exposure under the Droplet and Aerosol Models

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Outline

- Introduction
- Time-Evolving Networks
- Proposed Models
- The Optimal Solution of the Problem
- Numerical Calculations and Simulation

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Introduction

- The problem of minimizing the spread of viral infections in daily life has been studied widely in the recent years.

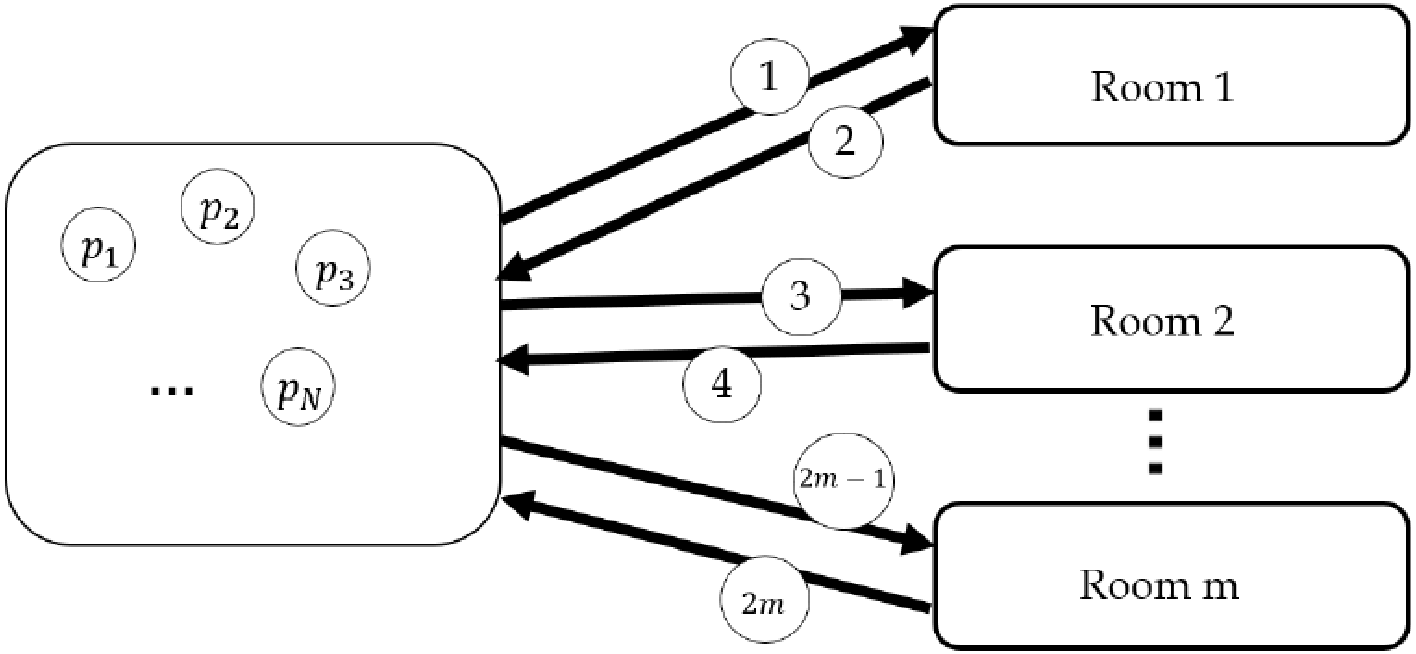
- Various models have been proposed to imitate the propagation of viruses within a society.

- The direct droplet infection, is the one mainly considered with little attention to the indirect contact infection that happens via aerosol spreading.

Introduction

- The aerosol model implies that after an infected person leaves the room, it is still possible to infect another person even if they do not have contact directly.

Introduction



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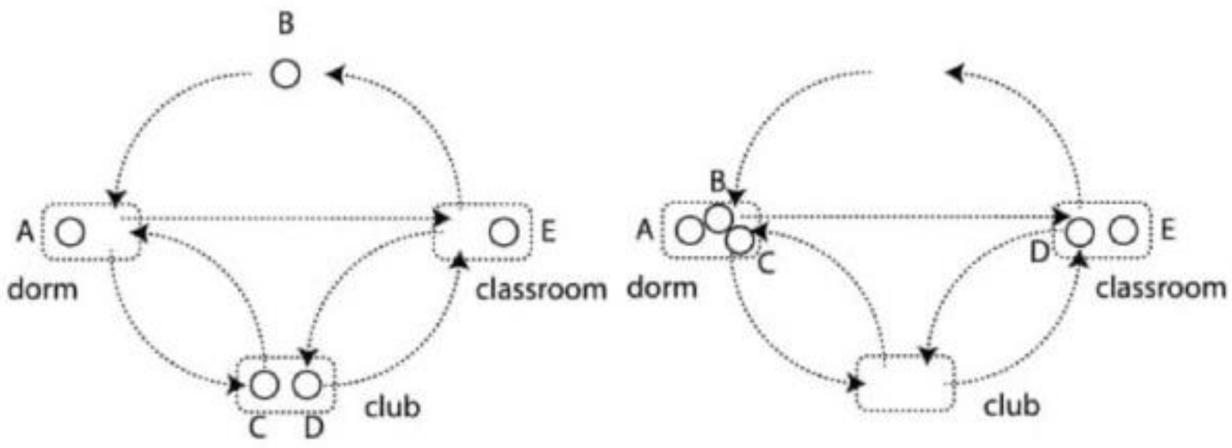
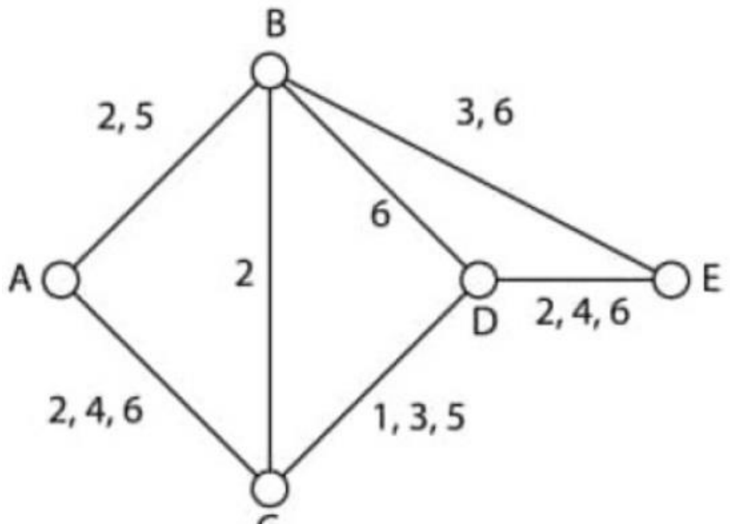
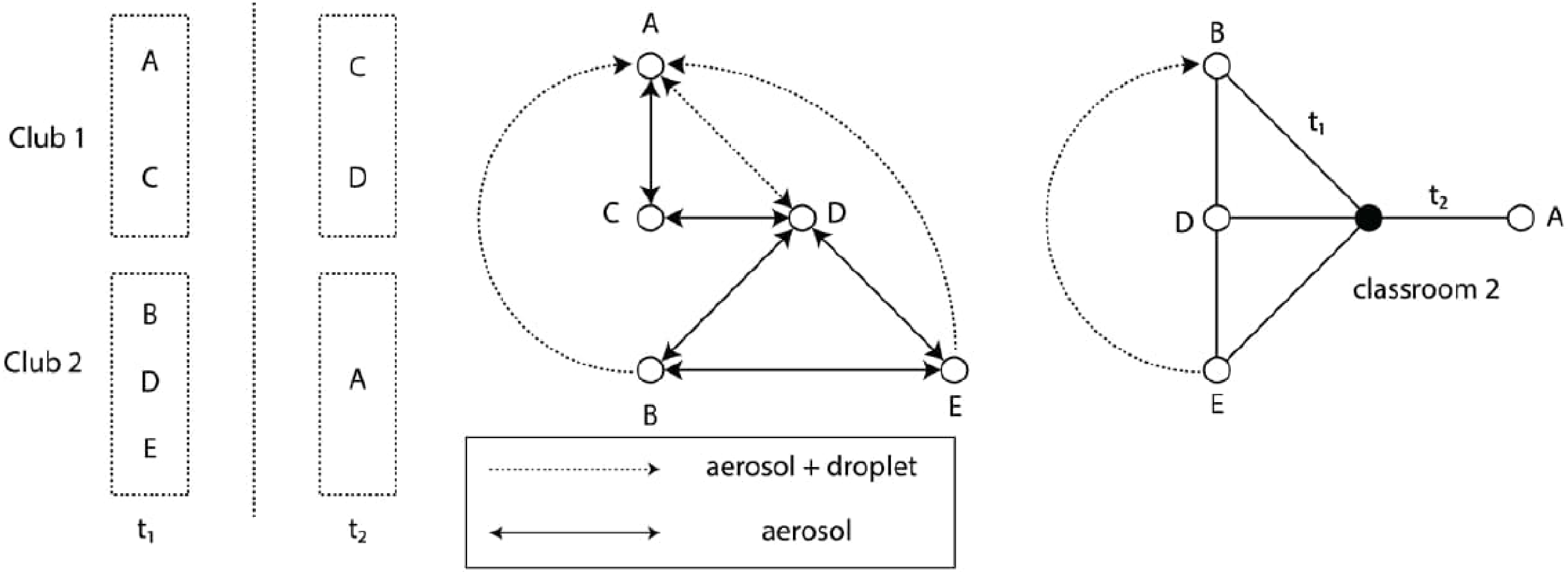
Time-Evolving Networks





Time-Evolving Networks



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Proposed Models

- 1) Instant-Visiting Model

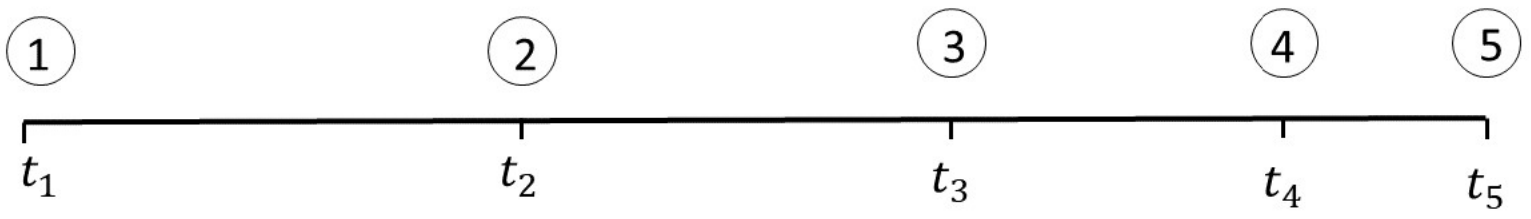
$$p_{ij}(T) = \begin{cases} 0.5 p_i^f(T) \times e^{-\frac{t_j - t_i}{\tau_1}} & i \neq j \\ p_i & i = j \end{cases}$$

$$p_i^f(T) = 1 - \prod_{j=1}^{j=i} (1 - p_{ji}(T))$$

$$\min_T \sum_{i=1}^{i=N} p_i^f(T)$$

Proposed Models

- 1) Instant-Visiting Model



Proposed Models

- 2) Interval-Visiting Model

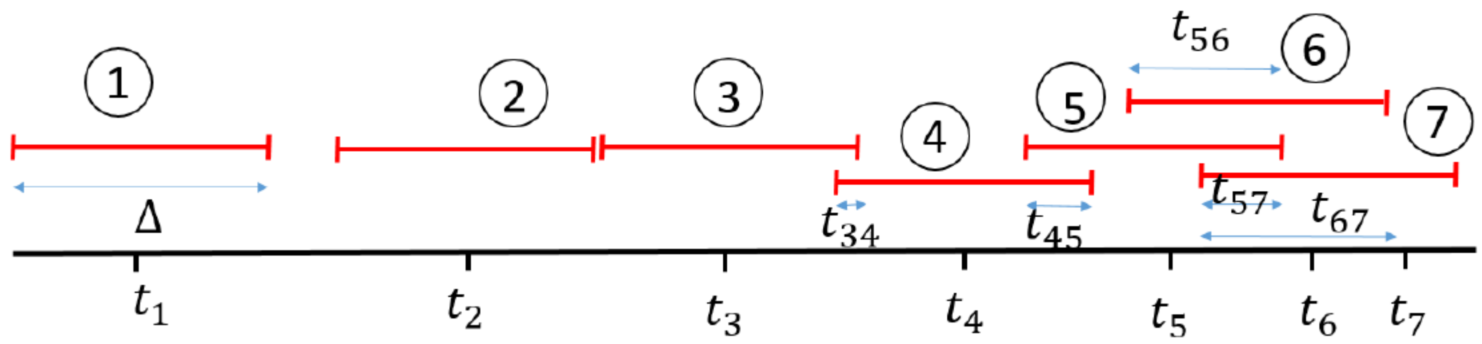
$$g_{ij}(R) = p_i(1 - e^{-\frac{t_{ij}}{\tau_2}})$$

$$p_{ij}(T,R) = \begin{cases} p_{ij}(T) + g_{ij}(R) - p_{ij}(T)g_{ij}(R) & i \neq j \\ p_i & i = j \end{cases}$$

$$p_i^f(T) = 1 - \prod_{j=1}^{j=i}(1 - p_{ji}(T))$$

Proposed Models

- 2) Interval-Visiting Model



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The Optimal Solution of the Problem

- First: Determining the Optimal Order of the People:

- From lowest initial probability to the highest.

- Proof: By contradiction.

The Optimal Solution of the Problem

- Second: Determining the Optimal Time Assignment of the People:

$$\boldsymbol{\nabla} \sum_{i=1}^{i=N} p_i^f(T) = \begin{bmatrix} \frac{\partial \sum_{i=1}^{i=N} p_i^f}{\partial t_2}(t_2, t_3, \ldots, t_{N-1}) \\ \frac{\partial \sum_{i=1}^{i=N} p_i^f}{\partial t_3}(t_2, t_3, \ldots, t_{N-1}) \\ \vdots \\ \frac{\partial \sum_{i=1}^{i=N} p_i^f}{\partial t_{N-1}}(t_2, t_3, \ldots, t_{N-1}) \end{bmatrix} = \mathbf{0}$$

The Optimal Solution of the Problem

Algorithm 1 One-room optimal time assignment

Input: Initial exposure probabilities $\{p_1, p_2, \ldots, p_N\}$ and the availability time of the room $t_N - t_1$.

Output: The optimal time assignment for the visiting people.

1: Sort the probabilities in increasing order and set them to $[p_1, p_2, \ldots, p_N]$.

2: Compute $t_2, t_3, \ldots, t_{N-1}$ from equation (6).

3: **Return** the optimal time assignment T.

The Optimal Solution of the Problem

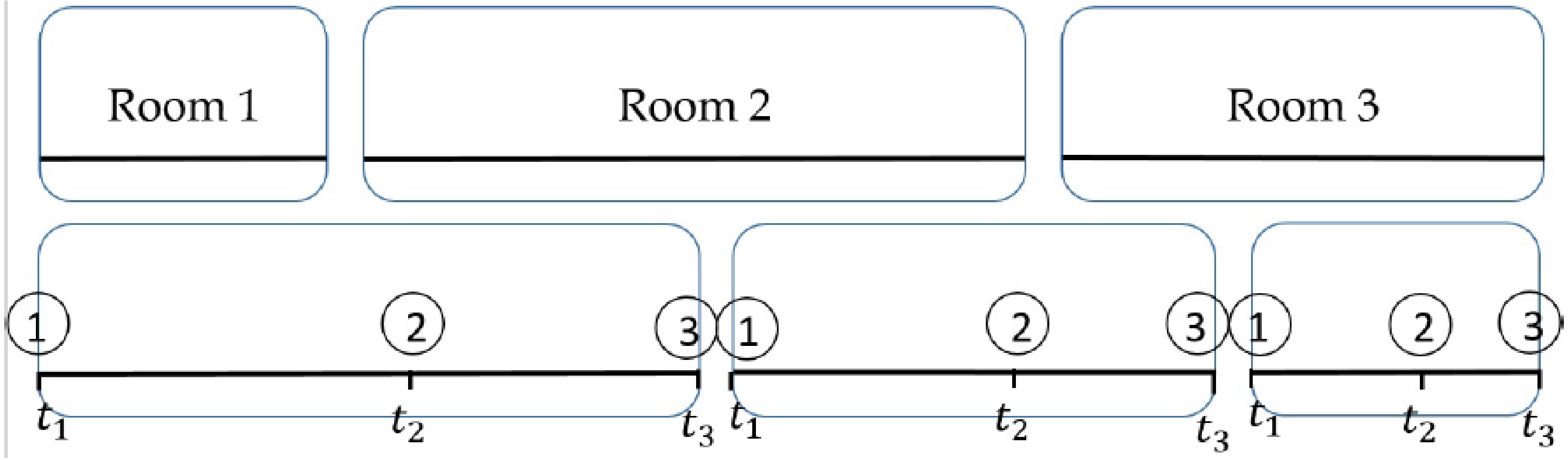
Algorithm 2 Multiple-rooms optimal time assignment

Input: Initial exposure probabilities $\{p_1, p_2, \ldots, p_N\}$ and the availability times of the rooms.

Output: The optimal time assignment for the visiting people and the order of the rooms.

1: Sort the rooms by the decreasing order of their time periods.
2: **For** each one of the rooms **do**
3: Call Algorithm 1 and set the exposure probabilities to $\{p_1^f, p_2^f, \ldots, p_N^f\}$.
4: **Return** the optimal time assignments for all of the rooms.

The Optimal Solution of the Problem



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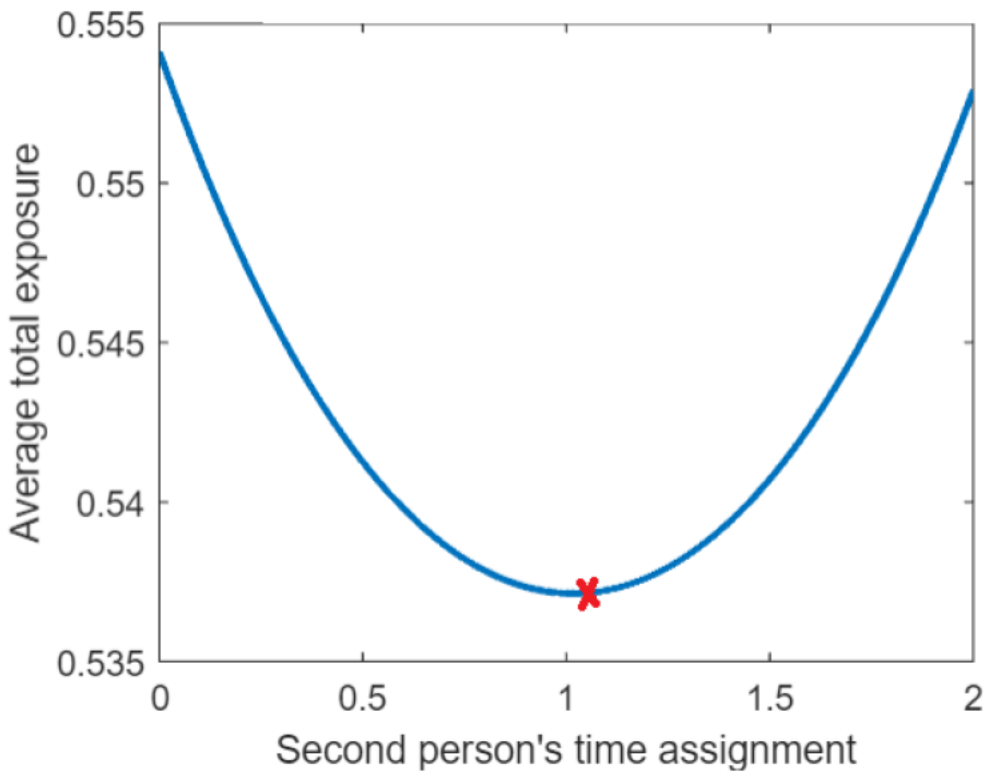
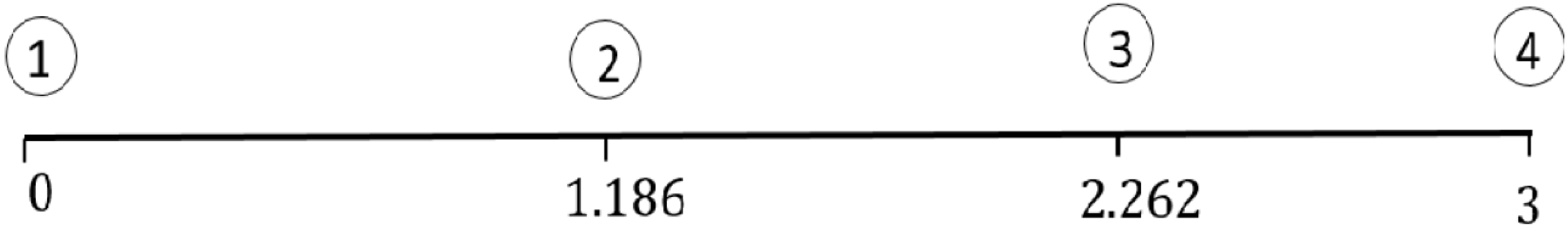
Numerical Calculations and Simulation

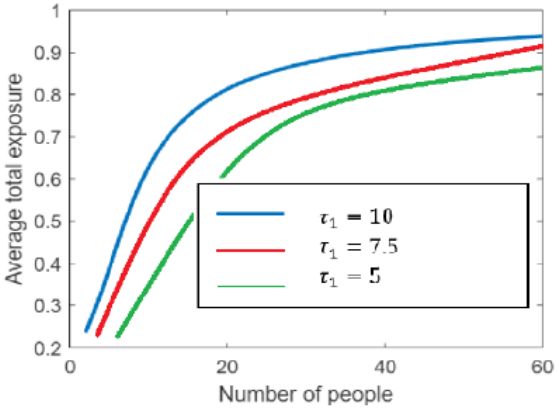


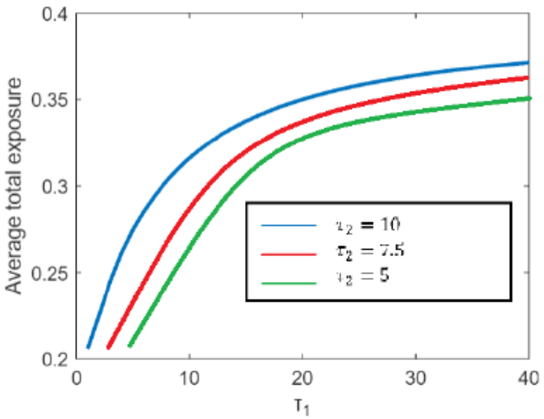
Numerical Calculations and Simulation

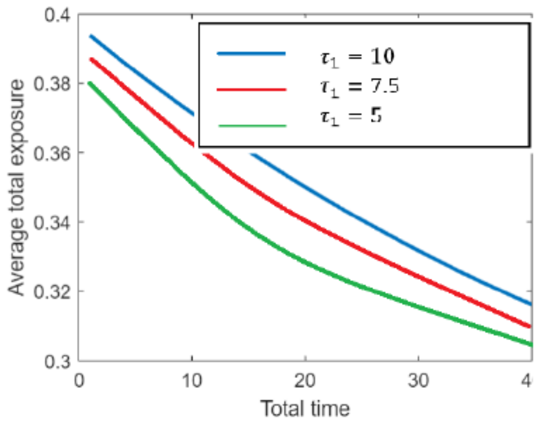


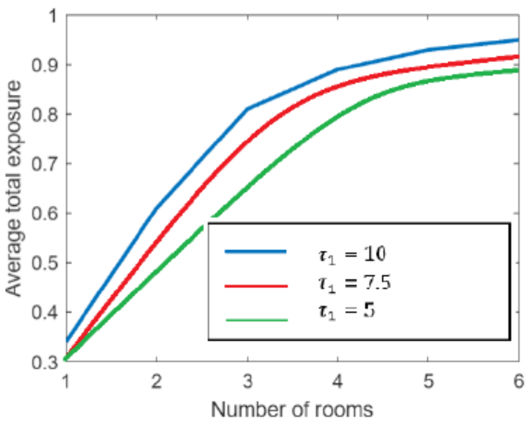
Numerical Calculations and Simulation

- Instant-Visiting Model:





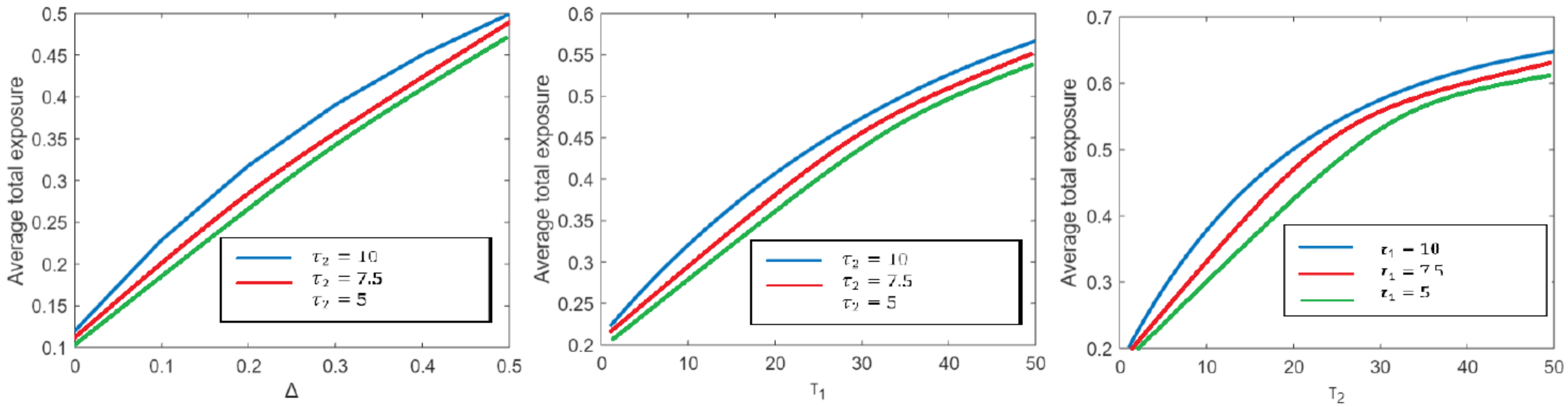




	Optimal visiting time			Uniform visiting time			Clustered visiting time		
	$\tau_1 = 1$	$\tau_1 = 5$	$\tau_1 = 9$	$\tau_1 = 1$	$\tau_1 = 5$	$\tau_1 = 9$	$\tau_1 = 1$	$\tau_1 = 5$	$\tau_1 = 9$
Increasing order	0.45	0.51	0.57	0.53	0.59	0.67	0.68	0.70	0.73
Decreasing order	0.65	0.70	0.72	0.69	0.72	0.73	0.71	0.73	0.75
Uniformly random order	0.59	0.62	0.63	0.62	0.64	0.66	0.69	0.71	0.74
Clustered random order	0.62	0.64	0.66	0.74	0.75	0.76	0.76	0.77	0.78

Numerical Calculations and Simulation

- Interval-Visiting Model:



	Optimal visiting time			Uniform visiting time			Clustered visiting time		
	Δ = 1	Δ = 2	Δ = 3	Δ = 1	Δ = 2	Δ = 3	Δ = 1	Δ = 2	Δ = 3
Increasing order	0.57	0.52	0.58	0.54	0.62	0.68	0.69	0.71	0.73
Decreasing order	0.66	0.70	0.73	0.70	0.73	0.73	0.73	0.74	0.76
Uniformly random order	0.61	0.63	0.64	0.63	0.65	0.67	0.70	0.71	0.75
Clustered random order	0.63	0.65	0.67	0.76	0.77	0.78	0.77	0.77	0.79