Aalto University

MS-E2177 - Seminar on Case Studies in Operations Research

Simulating and Optimizing a Multi-Car Shaft Elevator System

Project Plan

Case Group MLS Lift Consulting

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1 Background

This is a project done in collaboration with MLS Lift Consulting, for simulating and optimizing a multi-car elevator system.

MLS Lift Consulting is a company founded in 2021 by CEO Marja-Liisa Siikonen, who is our contact person. The company offers consultation on people flow in buildings for customers such as architects and construction planners.

Modern-day buildings are increasing in height: the tallest building in 2004, Taipei 101 in Taiwan, was 508 meters tall. But just five years later, in 2009, Burj Khalifa in the United Arab Emirates, stood at an impressive height of 828 meters. Although a large part of the height is so-called vanity height (meaning the height above the highest usable floor), the height trend is pointing upwards. And with taller buildings comes more people.

Tall buildings mean high people flow and a high need for elevators. The height of modern-day buildings imposes restrictions on elevators: a single elevator cannot span the whole height of a really tall building, as the weight of the ropes of the elevator would be too heavy. This leads to elevator groups which serve different sections of the building, and the surface area needed by the elevators increases. Because of this, the floor plans of modern-day buildings are quite inefficient: up to half of the usable core space is consumed by elevators [1].

In order to tackle this inefficiency, multi-car elevator (MCE) systems have been designed. In MCE systems, multiple cars move in the same shaft. Some designs include moving in horizontal direction as well, in addition to the traditional vertical. These systems require thorough design and planning, as the risk of collisions is present and the safety of elevators is non-negotiable. The development of MCEs is still mostly theoretical, as currently there are no MCEs in use in commercial buildings, apart from the old Paternoster design.

Paternoster is an elevator where the cars move in two connected and adjacent shafts. The cars do not have doors and they do not stop at any floor, meaning that the user has to step in and out of the moving car. Paternosters are efficient and have been common especially in Western Europe, but the construction of new Paternosters has been banned due to safety reasons: they pose a risk to old and disabled users, and there have been multiple fatal accidents.

In our project the aim is to examine the efficiency of MCE systems, by simulating and optimizing an MCE system using a traditional Paternoster elevator.

2 Objectives

In order to simulate and optimize an existing MCE system using a traditional Paternoster elevator, we need to simulate and optimize a system that uses multiple traditional Paternoster elevators. The simulation and its optimization would be done using Python, with the aim of finding a path that minimizes the average service time of elevators.

Because we are using a traditional paternoster elevator for simulation purposes, when doing the simulation and its optimization for finding the optimal path, we assume that cars do not have doors, and they do not stop at any floor as given in the Background. Although this may not be optimal for passenger safety, we have selected this method due to its simplicity in describing how the MCE system functions.

In the simulation, we assume that our MCE system can move vertically, with the aim of extending to the horizontal case if possible. The MCE system has 8 paternoster cars that move in the two shafts between the 10 floors. The 8 cars move up in one shaft and go down in the other shaft. The distance between floor i and floor $i+1$ is 5 m. Each car has a speed of 0.5 m/s. The current capacity for each car is one person, but we aim to extend this to 8 people. From this assumption, the time it takes for a car to travel between floor i and floor $i+1$ is given as follows:

$$\text{car travel time between floor } i \text{ and floor } i+1 = \frac{5 \text{ m}}{0.5 \text{ m/s}} = 10 \ s.$$

Also, the time it takes for a car to travel from the entrance to the top floor is

$$\text{car travel time between floor } i \text{ and floor } i+1 = \frac{45 \text{ m}}{0.5 \text{ m/s}} = 90 \ s.$$

We assume that passenger arrivals at each floor i follow a Poisson distribution. Currently, the arrival rate is set so that 5 passengers arrive per minute per floor. Since the simulation runs for 5 minutes, this corresponds to approximately 25 passengers arriving at each floor during a simulation run, resulting in a total of 250 passengers arriving across all 10 floors.

Using the current capacity, a car can carry from floor i to floor $i+1$,

$$60 \text{ s} \times 5 \times \frac{1 \text{ person}}{10 \text{ s}} = 30 \text{ people}.$$

If we expand the capacity to 8 people, this changes to

$$60 \text{ s} \times 5 \times \frac{8 \text{ people}}{10 \text{ s}} = 240 \text{ people}.$$

The goal is to optimally allocate the 8 elevator cars to serve the 250 passengers, minimizing their waiting time and travel time during the simulation.

3 Tasks

- Continue improving and updating the Python script on Github (currently being used to simulate paternosters - more detailed information given in the interim report).
- Communicate with Marja-Liisa for additional information if needed.
- Communicate with Ahti regarding the progress of the project.
- Write up the interim report.
- Write up the final report.

The project consists of two main tasks, Simulating paternoster behavior and optimizing multi-car shaft elevator system. Before doing the technical part, the team familiarizes with the topic by literal reviewing materials on elevators and paternoster elevators. Understanding the background is essential for running simulation and optimizing elevators metrics.

3.1 Simulating paternosters

The team will develop three different simulations with increasing levels of detail and complexity:

- **Basic Simulation** – Models a continuously moving Paternoster elevator with fixed-speed cars. The cars move in two shafts and passenger may enter from the lobbies and leave at their destination floor
- **Intermediate Simulation** – Introduces passengers who board, travel, and exit at designated floors. The cars are big enough to fit 8 people and have doors. Instead of cars continuously moving, they stop when a passenger is entering or leaving the car.
- **Advanced Simulation** – Incorporates real-world constraints such as passenger arrival rates and congestion effects. The cars now move independently from each other and maintain a safety distance between each car.

Each simulation will be validated to ensure it accurately reflects the behavior of a real Paternoster system.

3.2 Optimizing multi-car shaft elevator system

Building on the information gained from the Paternoster simulations, the team will build an optimization model for multi-car shaft elevator systems. Optimization is done in the following order:

- Analyzing traffic patterns and demand distribution in buildings.
- Evaluating different elevator dispatching strategies to minimize waiting and travel times.
- Implementing optimization algorithms to improve the handling capacity and efficiency of multi-car elevator systems.

The simulation will provide us with meaningful metrics that can be used to calculate various elevator performance parameters such as cabin capacity [2].

4 Schedule

The project schedule is planned to serve the entire project team, our client and contact person Marja-Liisa Siikonen, and the professor of the course, Ahti Salo.

4.1 Schedule Objectives

The objectives of the project schedule are:

- Dividing the workload into smaller manageable parts for the spring semester 2025.
- Scheduling the initial time frame for meetings with cross-functional contacts, including our client, the course professor, and all project members.
- Scheduling the initial time frame for the relevant tasks to be completed until specific dates.
- Providing structure during the project management process.
- Being updated when adjustments are made to the schedule.

4.2 Initial time frame for the meetings

The initial time frame for project meetings:

- **Initial project meeting with our client, Marja-Liisa Siikonen.**
  Achieved date: Thursday 23rd January 2025, at 12:30

- **Interim project team meeting with members.**
  Achieved date: Friday 7th February 2025, at 14:30
- **Initial project meeting with the professor Ahti Salo.**
  Achieved date: Wednesday 26th February 2025, at 16:00
- **Second project meeting with Marja-Liisa Siikonen.**
  Planned date: Wednesday 12.3.2025
- **Visit at Stockmann.**
  Planned date: Wednesday 12.3.2025
- **Visit at KONE.**
  Planned date: March-April
- **Excursion 1.**
  Set date: Friday 7.3.2025
- **Excursion 2.**
  Set date: Friday 4.4.2025
- **Excursion 3.**
  Set date: Friday 16.5.2025
- **Summary meeting.**
  Planned date: May-June

4.3 Initial time frame for the tasks

The initial time frame for the project tasks:

- **Project Plan.**
  Planned date: February
- **Simulator 1: Basic Simulation.**
  Planned date: February-March
- **Interim Report.**
  Planned date: March-April
- **Simulator 2: Intermediate Simulation.**
  Planned date: March-April
- **Simulator 3: Advanced Simulation.**
  Planned date: May

- **Optimization of Multi-Car Shaft Elevator System.**
  Planned date: May
- **Final Report.**
  Planned date: May

5 Resources

This project is done by a team of four Master's students from the Department of Mathematics and Systems Analysis. Three members are majoring in Systems and Operations Research and one is majoring in Applied Mathematics. Through the compelling coursework at Aalto University, all members have gained valuable resources for this project. The team's resources consist of wide analytical skills, knowledge of applied mathematics, programming in, e.g. Python, teamwork abilities, project management skills, and reporting skills. The client and contact person of MLS Lift Consulting, Marja-Liisa Siikonen, has provided the team with valuable information, files, and scientific articles to review during the project work, and regular meetings are organized with her. In addition, the course professor, Ahti Salo, provides feedback and guidance to the team during the project. If something unexpected occurs, the team will explore strategies to solve problems and find solutions.

6 Risks

The key risks associated with the project, their likelihood, possible consequences, and ways to mitigate them are presented in Table 1. The likelihood of risk is estimated on the scale [Low, Medium, High]. The risk management plan may be adjusted along the way while the project is worked on and the need for changes is discovered.

Risk	Likelihood	Consequences	Mitigation
Unrealistic (too optimistic, not considering all the relevant tasks, not understanding the workload of each task) schedule	High	Slow progress, inability to complete the project on time. Interim and/or final goals not achieved on time/at all. Increased stress levels. Unsatisfied client.	Analyze and try to understand the scope of the project. Make a planned schedule. If necessary, make adjustments. Be open. Communicate a lot with team members.
Lack of programming and simulation skills	Low	Inability to complete the simulation part of the project.	Try to understand the existing team resources in programming. Study the areas that need improvement. Ask for advice.
Incorrect mathematical modeling or optimization or misunderstanding in key concepts	Medium	The results not reliable. The project tends to fail.	Re-evaluate all the equations, models, and results in different stages. Review the literature carefully to understand the concepts. Ask for advice and outside evaluation.
Inactive team members	Medium	The workload not balanced between members. The progress may slow down. The team dynamics may get worse.	Make clear plans together. Communicate sufficiently. The project manager observes the activity levels and tries to keep the team together.
The quality does not meet the client's expectations	Low	Unsatisfied client. High disappointment for the team, because one of the most important goals not achieved.	Communicate with and meet the client regularly. Ask for advice and opinions. (What could be improved or changed? Is it correct and coherent?) Also, communicate about expectations and satisfaction.

Table 1: The key risks of the project

References

[1] Marja-Liisa Siikonen. *People Flow in Buildings*. Wiley-Blackwell, 2021.

[2] PR Tregenza. "The prediction of lift performance in multi-storey buildings". PhD thesis. University of Nottingham, 1971.