BRNO UNIVERSITY OF TECHNOLOGY
FACULTY OF INFORMATION TECHNOLOGY

IMS project

Simulation study

December 10, 2023

Aleksandr Shevchenko (xshevc01)
Oleksandr Turytsia (xturyt00)

Contents

1 Introduction

This simulation study delves into the entire process of visiting the ”Za Lužánkami Swimming Pool” throughout the day [1]. This project is a part of the IMS course (Modelování a simulace) at VUT FIT of “SHO Model služeb v oblasti sport“ topic.

The project involves model creation using multiple Petri nets and their implementation using C++ with a library Simlib [2, 3].

Primary objective of this study is to compare the visitor's experience before and after the pool's reconstruction and validate improvements made to enhance the lives of professional swimmers using simulation model [1]. The study investigates whether the following aspects have been positively affected:

- Ease of training for professional swimmers.
- Reduction in distractions for professional swimmers caused by other people.
- Bandwidth of the pool after the increase in the number of booths and receptions.
- Changes in the peak number of people at the pool.

Furthermore, the study offers hypothetical insights into how to enhance the overall experience and training efficiency for professional swimmers based on experiments with resulting model.

1.1 Authors and Source of Data

Authors of this study are Oleksandr Turytsia (xturyt00) and Aleksandr Shevchenko (xshevc01).

”Za Lužánkami Swimming Pool” is the only 50-meter pool in Brno open for the public, so it is in great demand among the inhabitants of the city.

The information for our simulation was directly gathered at the mentioned swimming pool through several personal observations conducted by our team. We collected data for the simulation over a couple of days, including working days and weekends. This allowed to calculate average values that can be applied to any day. Also, some data is used based on many years of swimming practice and communication with our colleagues from BUT swimming team.

1.2 Model Validation

Because our model is based on real observations, we can check its accuracy by comparing it with results from actual experiments. This direct comparison makes sure, that what our model predicts matches, hence it can happen in real life. Also it can reveal hypothetical facts, that were not obvious during observation, which can affect insights for improvements.

2 Pool Environment Process

2.1 Data Collection

This section delves into the detailed observations conducted at the ”Za Lužánkami Swimming Pool”. The following report captures the dynamics of visitor interactions, facility usage, and various activities observed during the study. By examining the patterns and behaviors uncovered through these

observations, we aim to provide a comprehensive overview of the pool environment, highlighting the issues that can affect the overall swimming experience.

This section is divided into two key subsections that describe the state of the pool before and after reconstruction efforts. Subsection 2.2 offers insights into the visitor's experience before any reconstruction took place. It provides a detailed account of visitor behaviors and facility utilization. Subsection 2.2.2 describes what changes were made.

2.2 Observation Findings

2.2.1 Before Renovation

The pool has a total capacity of 634 people, and visitors arrive approximately every 1 minute in an exponential manner. There's a single reception, used by 30% of visitors during observation (30 out of 100 people). The remaining 70% wear a bracelet, allowing them to bypass reception and head directly to the changing room.

Changing Room

Changing room is for everyone, whereas showers are separated between men and women. Note, only men's shower was evaluated due to the nature of the authors. There are 40 showers and 659 lockers.

There are also 8 booths, but 60% of people (60 out of 100) choose not to use it, spending a normal distribution of 3 minutes changing clothes right where the lockers are. The other 40% spend a normal distribution of 4 minutes using private room. Sometimes, all booths are occupied, causing most people in the queue to wait up to 2 minutes before deciding not to use them.

On the way to the pool, approximately 30% (30 out of 100 people) decide to use a shower before swimming for an exponential distribution of 1 minute.

Swimming Area

There is a single 50-meter pool in the entire building, which contains 8 lanes for swimming. During specific times (morning 6-9 and evening 15-20), half of the lanes (4 lanes with up to 8 people each) are reserved for the local club Kometa or other organizations. If the pool is full, the training of these groups are canceled. One lane is allocated for professional swimmers, while the remaining 3 lanes are for regular people (children, adults and elders).

Regular People

Out of 100 visitors, 86 are regular people who stick to their allocated lanes. In this context a regular person is an individual who does not mix up any lanes with professional swimmers. They spend a normal distribution of 40 minutes in the pool and, with a positive attitude, an additional normal distribution of 30 minutes in the sauna or wellness area.

Professional Swimmers

There are 10 professional swimmers out of 100 people (10%) who, after the changing room, instantly head to their chosen lane for a training session, that lasts a normal distribution of 1 hour. After training they are very tired, hence they don't use additional pool amenities.

Disturbance

The remaining 4% are those who mix up lanes with professionals, causing disturbances. They may not notice or ignore the "PROFI" sign, prompting interruptions from other swimmers. Each interruption subtracts 1 pool from the professional swimmers' training.

Leaving Pool

Upon leaving, visitors spend an exponential 5 minutes in the shower to wash off chlorine. With the same probability, they either change clothes in public changing room with a normal distribution of 5 minutes or in a booth with a normal distribution of 6 minutes before leaving the pool.

Parameter	Value	Details
Overall Capacity	634	Total capacity of the pool
Pools	1	Number of the pools
Arrival Rate	Exponential (1 min)	Arrival rate
Receptions	1	Number of receptions
Reception Usage	30% / 70%	Using reception / Using bracelet
Showers (Men's)	40	Evaluated showers
Booths	8	Number of booths
Booths Usage	40% / 60%	Yes / No
Lockers	659	Number of lockers
Change Clothes (Before Swimming)	Normal (3 min / 4 min, 1 min)	In plain sight / In a booth
Shower Usage (Before Swimming)	30% / 70%	Yes / No
Shower Time (Before Swimming)	Exponential (1 min)	Showering time
Total number of lanes	8	50-meter swimming pool
Number of possibly reserved lanes	4	Kometa and others
Number of PROFI lanes	1	Lane for professional swimmers
Professional Swimmers	10%	Professionals out of all people
Regular Swimmers	86%	People who don't mix up lanes
Other swimmers (Disturbance)	4%	People who mix up lanes
Shower Time (Leaving)	Exponential (5 min)	Wash off chlorine
Change Clothes (Leaving)	Normal (5 min / 6 min, 1 min)	In plain sight / In a booth

Table 1: Observation details before the renovation.

2.2.2 After Renovation

Following the renovation, significant changes were made to enhance the overall dynamics of the pool environment. The primary goal was to eliminate overload in the main pool, especially during peak hours, by adding more swimming pools for certain class of people.

The capacity of a pool did not change. Reception capacity was increased by 1, which allowed stuff members serve 2 visitors at the same time. After a long break, a large number of people want to visit the new pool, so visitors arrive more often, approximately every 50 seconds in an exponential manner.

Changing Room

After the renovation, the number of booths was increased from 8 to 13, which should hypothetically decrease number of people changing cloths in a public place.

Swimming Area

Two more smaller swimming pools (25 and 16 meters) were added to the main swimming area. This reflected the fact, that visitors who do not swim long distances (mainly children and elders) partially moved there and thus reduced the occupancy of the 50 meter pool.

Disturbance

Percentage of those who mix up lanes was reduced to 2% due to the facts stated in subsection 2.2.2

Weekends and Holidays

Even though people who mix up lanes freed up a 50-meter swimming pool, there are so many families with kids on the weekend, that the percentage of them grows back as it was before renovation. No lanes are reserved for Kometa club and other organizations. People come to the pool even more often, every 30 seconds in an exponential manner.

Parameter	**Value**	**Details**
Pools	3	Number of the pools
Arrival Rate	Exponential (50 sec)	Arrival rate
Receptions	2	Number of receptions
Booths	13	Number of booths
Professional Swimmers	10%	Professionals out of all people
Regular Swimmers	38%	People who don't mix up lanes
Other swimmers (smaller pools)	50%	25 and 16 meters pools
Other swimmers (Disturbance)	2%	People who mix up lanes

Table 2: Observation details after the renovation compared to Table 1.

Parameter	**Value**	**Details**
Arrival Rate	Exponential (30 sec)	Arrival rate
Number of possibly reserved lanes	0	Kometa and others
Professional Swimmers	10%	Professionals out of all people
Regular Swimmers	20%	People who don't mix up lanes
Other swimmers (smaller pools)	66%	25 and 16 meters pools
Other swimmers (Disturbance)	4%	People who mix up lanes

Table 3: Observation details for weekends and holidays (after the renovation) compared to Table 2.

3 Concepts

Following real-world aspects were omitted for creating the simulation models due to their complex nature and minimal impact on the outcomes:

- A number of lockers (659) is considered to be unlimited, because its capacity is greater than the capacity of the pool (634).
- A number of showers (40 only for men) is considered as unlimited too, because the probability of full shower utilization is very low and has minimal impact on our research.
- Sauna and wellness capacities are ignored due to the fact, that professional swimmers rarely utilize them, therefore they have minimal impact on a target goal.

3.1 Simulation model

For creating a simulation model to represent the dynamic operations of the swimming pool, this study utilizes Petri nets [3]. Given the various ways visitors use the pool and interact with the facilities, we need a modeling method that can show all these different aspects in a detailed way.

To ensure the validity of the experiments, the decision was made to develop several simulation models:

- Swimming pool during regular working day **before** the renovation.
- Swimming pool during regular working day **after** the renovation.
- Swimming pool during **weekends and holidays** after the renovation.

3.2 Petri Nets

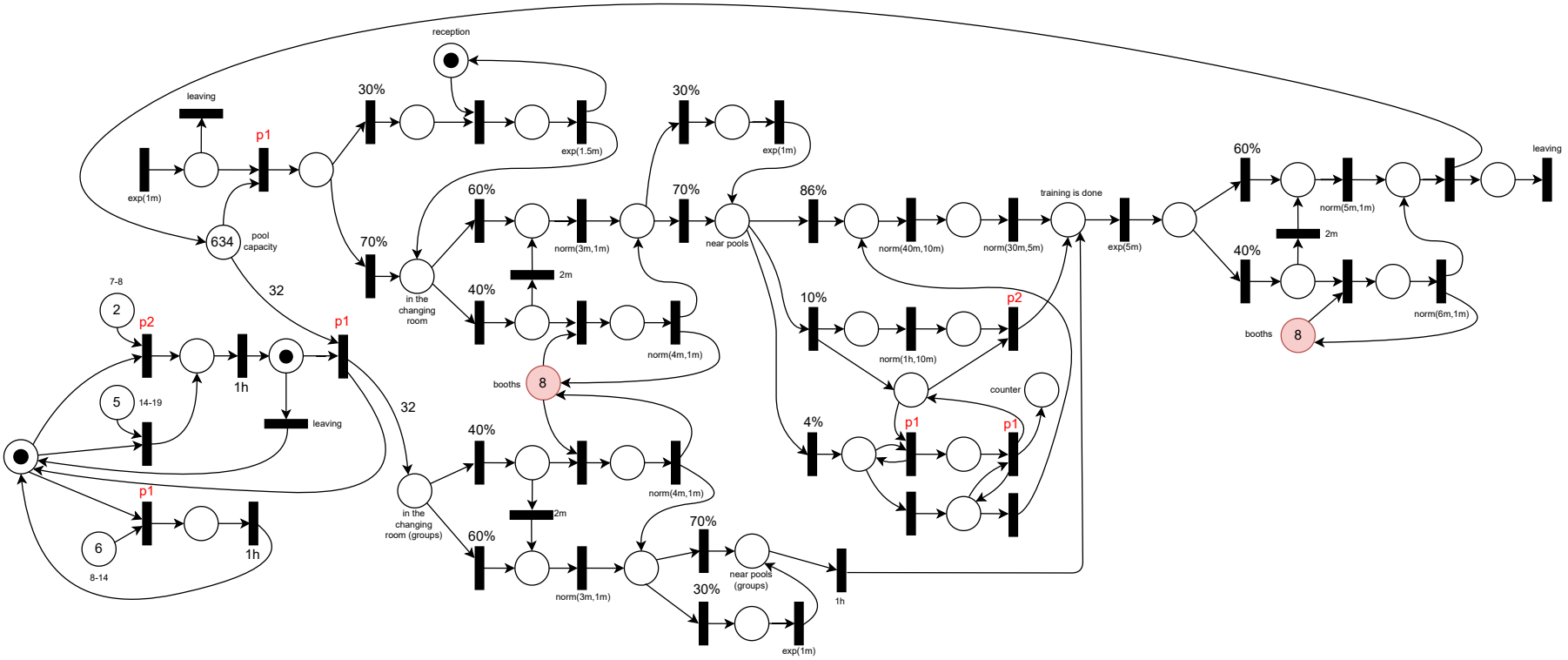

Figure 1: Petri net simulating the pool before the renovation.

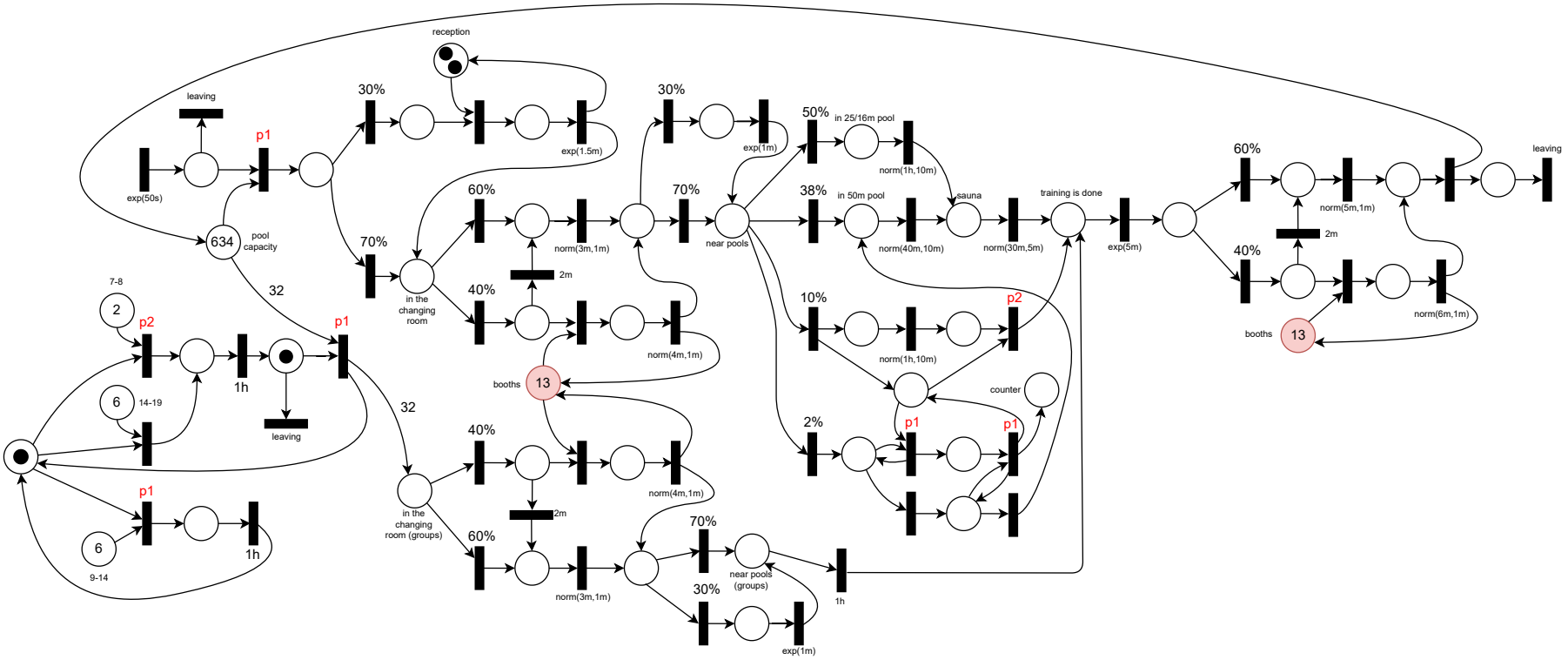

Figure 2: Petri net simulating the pool after the renovation.

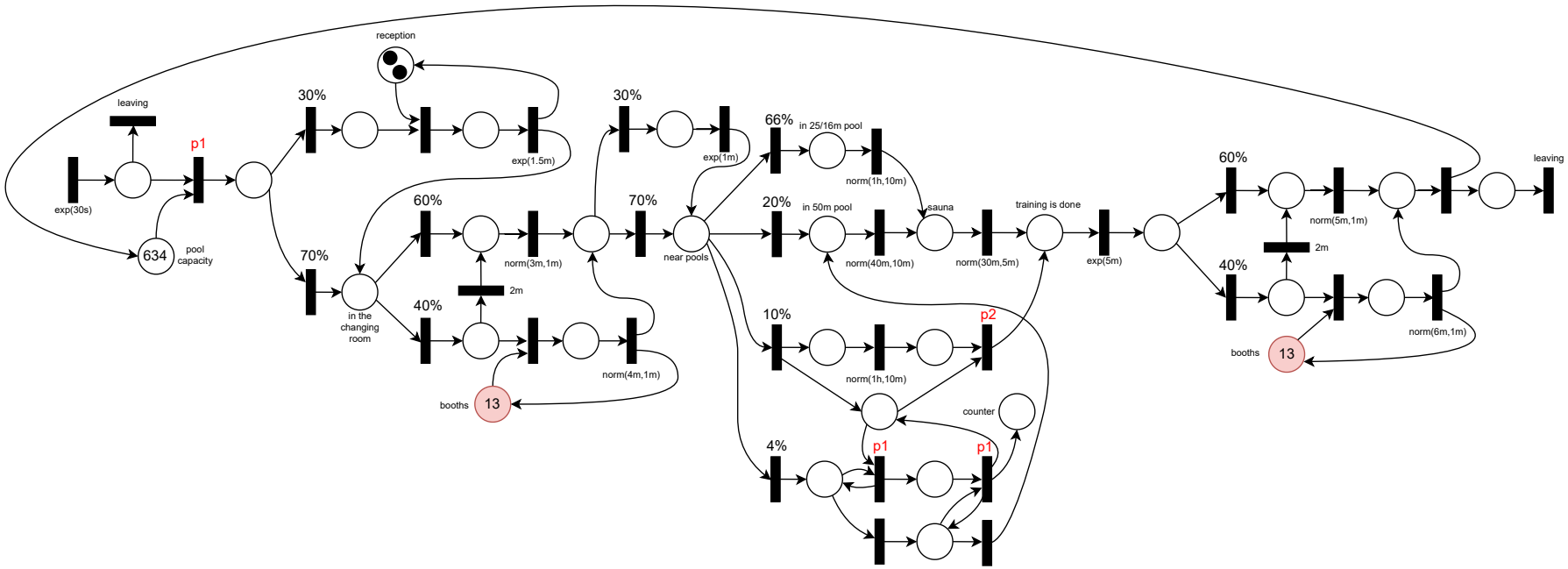

Figure 3: Petri net simulating the pool on weekends and holidays (after the renovation).

4 Implementation

The C++ implementation of the simulation model utilizes the SIMLIB library and is primarily founded on the concept provided in the section 3.2, presented in the form of a Petri net [3, 2]. This representation is easily transferable into the program.

4.1 Structure

This research includes several source files, containing the implementations of the Petri nets presented in the section 3.2:

- **pool.cpp:** This file contains the implementation of a Petri net modeling the dynamics of the pool before undergoing any renovation (Figure 1).
- **pool_weekend.cpp:** Within this file, a Petri net is implemented to capture the specific characteristics of the pool during the weekend (Figure 2).
- **pool_after.cpp:** The code in this file represents a Petri net designed to depict the behavior of the pool after it has undergone renovation (Figure 3).
- **pool_after_improved.cpp:** In this particular file, a Petri net is implemented with enhanced parameters, aiming to present a more efficient pool system and provide insights on potential improvements for the existing pool structure. This model is implemented according to figure 2, but with slightly modified parameters, that are mentioned in section 5.4.

4.2 Usage

In order to run a simulation, there is a Makefile in the root of a project, that contains following rules:

- **pool**: Compile pool.cpp source file.
- **pool_after**: Compile pool_after.cpp source file.
- **pool_weekend**: Compile pool_after.cpp source file.
- **pool_after_improved**: Compile pool_after_improved.cpp source file.
- **all**: Compile all the source files and run them.
- **run**: Run all the binary files after the compilation.
- **clean**: Removes all the created binaries and .out files.

Utilize the program in accordance with the rules mentioned above:

```
make <rule>
```

Here is an example of running a specific simulation (for instance pool):

```
make pool
./pool
```

After completion of the simulation, an automatically generated *.out file containing statistical data will be available for analysis.

5 Simulation Experiments and Results

The main purpose of the experiments was to find out whether the conditions for professional swimmers improved after the pool was repaired. We also found out how much the increase in the number of receptions and booths affected the bandwidth of the pool.

In total, 4 experiments were conducted: the pool before and after the renovation, during weekends or holidays, and our own experiment with possible improvements. As improvements, we tried to increase the number of receptions and booths and a small change in the lane for professional swimmers. Each experiment simulates a full day of the pool.

In each experiment, the following measurements took place: the number of people in the pool, the occupancy of receptions and booths, the number of interruptions of professional swimmers and the total time spent in the pool.

5.1 Pool before the renovation

All the parameters used in this experiment are described in the Table 1 and in Figure 1. The simulation showed the following results:

Parameter	**Value**
Total number of visitors per day	1185
Maximal amount of visitors at once	166
Average amount of visitors	103.313
Average usage of booths	4.49617 (out of 8)
Average time of visit	4880.46 sec
Maximal value of interruptions	6
Average amount of interruptions	2.40217
Average time in reception	115.009 sec
Average usage of reception	0.415779

Table 4: 1 experiment results.

From this experiment, we can immediately see that the number of interruptions of professional swimmers is too high.

5.2 Pool after the renovation

All the parameters used in this experiment are described in the Table 2 and in Figure 2. The simulation showed the following results:

Despite the fact that the total number of visitors per day increased by almost 200, the remaining indicators showed a better result than the first experiment. Booths were used 26% more often, the total time spent in the pool increased by 10%. The reception is now used 36% longer, and the average number of interruptions of professional swimmers has decreased by more than 2 times.

5.3 Pool on the weekends and holidays after the renovation

All the parameters used in this experiment are described in the Table 3 and in Figure 3. The simulation showed the following results:

Parameter	Value
Total number of visitors per day	1358
Maximal amount of visitors at once	196
Average amount of visitors	129.657
Average usage of booths	5.68173 (out of 13)
Average time of visit	5359.67 sec
Maximal value of interruptions	5
Average amount of interruptions	1.19231
Average time in reception	36.8237 sec
Average usage of reception	0.561289 (out of 2)

Table 5: 2 experiment results.

Parameter	Value
Total number of visitors per day	1779
Maximal amount of visitors at once	227
Average amount of visitors	181.488
Average usage of booths	7.35496 (out of 13)
Average time of visit	5767.65 sec
Maximal value of interruptions	10
Average amount of interruptions	3.48901
Average time in reception	61.3739 sec
Average usage of reception	0.833653 (out of 2)

Table 6: 3 experiment results.

Comparing to the previous experiment, due to the large flow of people, the use of booths has increased significantly (by 29%), same for the receptions (by 48%). However, the small percentage of regular visitors worsened the quality of swimmers' training by almost 3 times.

5.4 Pool with our own suggestions

As already mentioned, the number of lockers in the changing room is more than the capacity of the pool (by 25). Let's assume that instead of them, it would be possible to accommodate 5 more booths. We also add 1 reception and an improved version of the "PROFI" sign. Now it is not an inscription near the lane, but a small partition from the neighboring lanes. Thus, it will reduce the percentage of disturbers to 1%. These changes are applied to the workdays of the pool after the renovation.

With the increase in the number of booths, interest in them, on the contrary, began to fall. The additional reception reduced the average waiting time by only 5 seconds. Considering all the possible costs of installing it and hiring staff, there is no point in it. However, installing of the partition significantly reduced the average number of interruptions (by 55%).

Parameter	Value
Total number of visitors per day	1314
Maximal amount of visitors at once	185
Average amount of visitors	124.202
Average usage of booths	5.63917 (out of 18)
Average time of visit	5309.88 sec
Maximal value of interruptions	2
Average amount of interruptions	0.536082
Average time in reception	31.9664 sec
Average usage of reception	0.533886 (out of 3)

Table 7: 4 experiment results.

6 Summary

The result of this project is a discrete simulation model of the ”Za Lužánkami Swimming Pool”, created on the basis of data obtained during a visit to this facility. The resulting model helped us to get a deep understanding of the bandwidth of the pool, which, due to the presence of many factors, is not so obvious at first glance.

A comparison of the pool before and after the renovation revealed that the renovation definitely benefited everyone: ordinary visitors, professional swimmers and families with children or elders. Based on our experiment on possible innovations (regarding reception, booths and lane for professionals), we can conclude that the existing system copes well with the flow of visitors. The only thing missing is new methods of distinction of the lane for professional swimmers.

7 References

[1] Anu Maria. Introduction to modeling and simulation. In *Proceedings of the 29th conference on Winter simulation*, pages 7–13, 1997.

[2] Petr Peringer. Simlib/c++ == simulation library for c++. [Online] `https://www.fit.vutbr.cz/~peringer/SIMLIB/`, 1991.

[3] James L Peterson. Petri nets. *ACM Computing Surveys (CSUR)*, 9(3):223–252, 1977.