ME 7129 Optimization in Engineering
Team Project Final Report

MAN’S URINAL PROBLEM

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Abstract

In this age where personal privacy is valued, people and regulations are committed to helping everyone's privacy from being invaded. However, when it comes to men’s privacy while peeing, no regulation or study is trying to protect this kind of privacy. Therefore, our study focuses on the best urinal distribution design for solving this problem. In addition, we also try to figure out the balance between protecting privacy and saving time, preventing men from spending too much time waiting in line or walking to the urinal so far away. Due to the formulation of the problem, we have to write our GA to get the result. We also apply different urinal-choosing strategies to simulate different people’s behavior. In conclusion, our study shows the best urinal distribution under specific total peeing men and space and time limitations. Moreover, there is a comparison between different choosing strategies.

Problem Description

Peeing, as one of the most common but important things in our lives, helps clean up our bodies and balance water and electrolytes. Compared with women who can have their own private space while peeing, men use urinals. However, accompanying the convenience of urinals, men must sacrifice their privacy. Despite the dividers, we still feel uncomfortable peeing next to others. In addition, spending time lining up or walking to a faraway urinal is also disturbing. Therefore, to help all the men in the world improve their peeing experience, we try to find out how to maintain everyone’s privacy as well as save time under different urinal selection strategies and distributions. Every man can learn how to choose a urinal and toilet designers can maximize the whole group’s profit with this study.

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Literature Review

We have found a study related to our problem. Although there is a little difference between it and our problem, the strategies for choosing the urinal in the study are important references. In this part, we will briefly introduce the study, and point out the difference from our problem.

I. THE URINAL PROBLEM [1]

A. GOAL OF THIS STUDY

To find out the best strategy for a man to choose the urinal that will provide the biggest privacy.

B. OBJECTIVE FUNCTION

Maximize the time that no one besides you during your peeing.

C. FOUR DIFFERENT STRATEGIES

1. **Lazy Behavior:**
   Always choose the urinal closest to the entrance.
2. **Cooperative Behavior:**
   Consider not only his privacy but also others' at the same time.
3. **Maximize Your Distance Behavior:**
   Always choose the urinal far away from the crowd.
4. **Random Behavior:**
   Just choose randomly.

D. CONCLUSION

The optimum is always that one will always choose the urinal furthest from others.

II. DIFFERENCE FROM OUR PROJECT

The thesis considers only my privacy. Because we are interested in the best peeing experience for the "whole group", our project focuses on overall profit, which is a comprehensive evaluation combing privacy protection and time-saving.

Problem Formulation

We focus on improving the entire peeing process for everyone, which includes saving time and protecting privacy. Therefore, our problem formulation is based on these two factors.

I. OBJECTIVE FUNCTION

A. DESCRIPTION

We define a term called "**Peeing Cost (Φ)**", which is the negative feeling during the peeing process, and we try to minimize it. In peeing cost, we introduce another two terms, **Privacy Cost(P)** and **Time Cost(T)**. Privacy cost evaluates how much privacy is invaded, so it is related to whether other men are peeing next to or behind a man. On the other hand, the time cost is the total time a man must spend to pee.

Moreover, there are two constants in the function, **α**, and **β**. They are the weight constants. **α** helps us decide either privacy or time is more important. For example, if there is a group that considers their privacy is much more important than the time they need to spend, **α** can be close to 1, like 0.9, so the influence of time cost could be very small. And **β** tells us which one bothers more, someone standing next to, or behind.

B. OBJECTIVE FUNCTION

1. Minimize the Peeing Cost (Φ)

$$\boldsymbol{\Phi = \alpha * P + (1 - \alpha) * T}$$

Where P is the privacy cost,
T is the time cost.

$$\boldsymbol{P = \beta * (LT + RT) + (1 - \beta) * (BT)}$$

Where LT is the total time that a man is peeing on your left side during your peeing,
RT is the total time that a man is peeing on your right side during your peeing,
BT is the total time that a man is peeing back at you during your peeing.

$$\boldsymbol{T = (WT + MT + PT)}$$

Where WT is the time for waiting in line,
MT is the time for moving to the target urinal,
PT is the time for peeing.

II. DESIGN VARIABLES

A. DESCRIPTION

We want to find out what kind of distribution of urinals is the best. We are also interested in whether the optimum is to set the urinals as much as possible or not. In order to run the evaluation, we have to determine the distribution of the urinals first.

Thus, we've developed a method to simplify this problem. That is assume the floor area is fixed and set all the urinals as an array. Now, the variable left is barely the number of rows and columns.

B. DESIGN VARIABLES

1. **Rows of the urinal array.**
2. **Columns of the urinal array.**

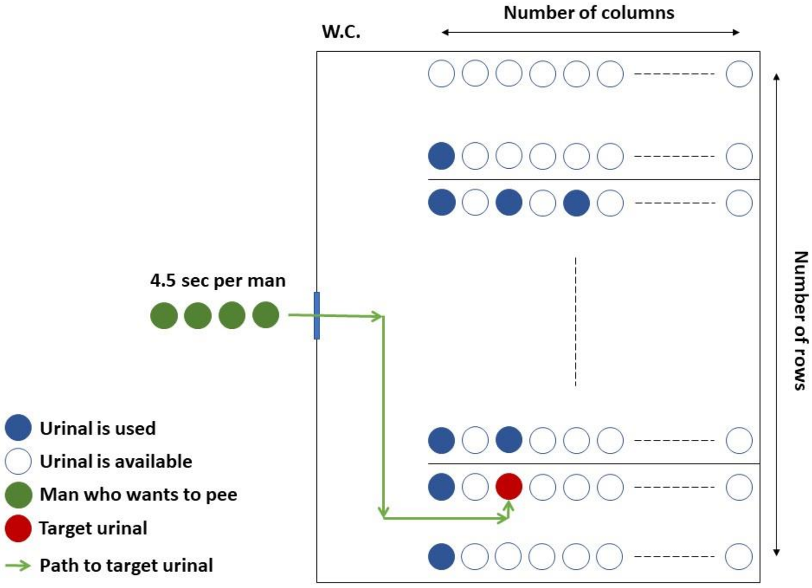


Figure 1 Toilet schematic

III. DESIGN PARAMETERS

A. DESCRIPTION

Because we hope our project can connect with reality instead of just making up some numbers for simulation or algorithm, we refer to the highway service area, especially the Guanxi service area (關西休息站)[10]. The information from the service area tells us the toilet floor area is 300m^2. And there are about 400 parking spaces in the area. We assume that we encounter the peak time that there is no vacancy, and the average number of people in each car is 2.5. All of them must go to the toilet because long trips are waiting for them. Half of them are girls. So, we will have 500 men who need urinals, and we want all of them can finish within 30 minutes, so the gap between each man who comes to the toilet is 4.5 seconds. Moreover, according to research in 2005[2], we learned that the average walking speed of a young man is 1.48m/s, so we can calculate the time everyone needs to move to the urinal. Also, we collect the size of urinals from different brands and choose one of them as the criteria.

B. DESIGN PARAMETERS

1. **The walking speed of a man is an average of 1.48m/s [2].**

2. **The total number of men to pee is 500.**
3. **The time gap between each man who comes to the toilet is 4.5 seconds.**
4. **Toilet floor area = 15(m) * 20(m) = 300(m^2)**
5. **Urinal dimension, length = 0.385m, width=0.375m (Figure 2)**
6. **Weight parameter "α" in our objective function.**
7. **Weight parameter "β" in our objective function.**
8. **Strategy for choosing the urinal.**

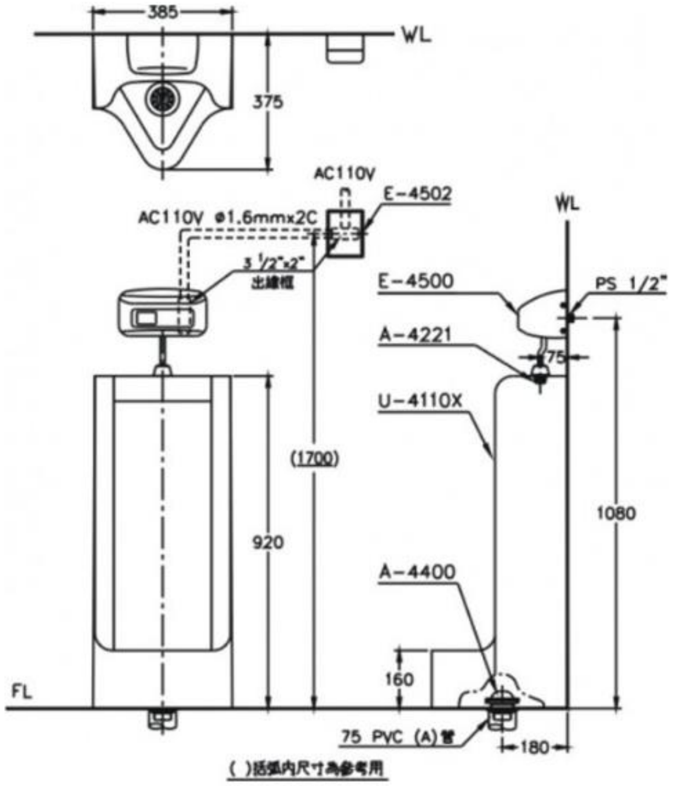


Figure 2 Dimension of the urinal [13]

IV. CONSTRAINTS

A. DESCRIPTION

From the rules set by our ministry of the interior[4], we have a minimal distance between the urinals and between the urinal and the wall. Also, from the literature review[10], we know that the smallest width for a person to walk through comfortably is 70cm[5], and for bi-direction passing, we get double is 1.4m. Besides, the number of rows, also known as the number of parallel walls should be greater than 2. Which means there should be at least two parallel walls in the toilet. The number of columns, equivalent to the number of urinals in each row, should be greater than 0.

B. CONSTRAINTS

1. **Distance between center of urinals ≧ 0.8m (Figure 3)**

2. **Distance between center of urinal and wall ≧0.4m (Figure 3)**
3. **Distance between rows ≧1.4m**
4. **The number of rows > 2**
5. **The number of columns > 0**
6. **All time functions must be greater than 0.**

3-2.4 小便器中心點間距應為 80 公分以上，距離側牆 40 公分以上。加裝隔板時，應選用離地式隔板，隔板高度上緣距離地面 120 公分以上。

※解說：小便器設置間距需符合下列規定：

1.小便器中心點間距至少 80 公分。

2.為確保如廁空間，位於角落之小便器其中心至牆面之距離應達 40 公分以上。

3.若設置隔版，應選用離地式，以方便清潔。

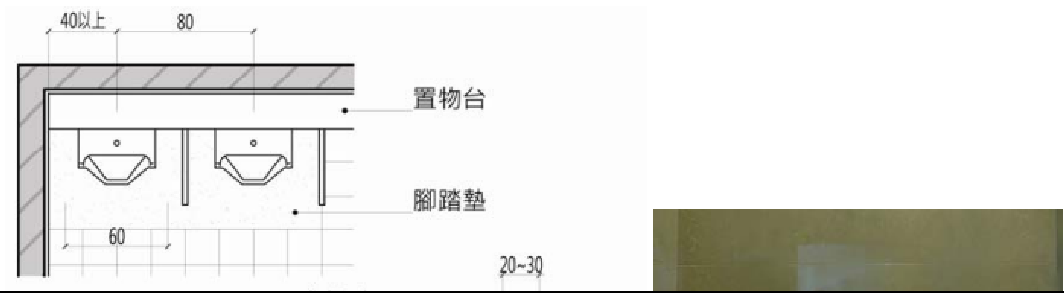


Figure 3 Urinal spacing constraints (內政部營建署[4])

★走道留寬些，好走不擁擠

人體面寬一般是50～60公分，想要身體不被碰撞，走道就要拉寬到70公分以上，桌几和沙發之間的寬度可以稍微縮小，25公分最剛好，可以輕鬆伸腿放腳。

Figure 4 Comfortable distance between rows[5]

V. ASSUMPTION

1. **Everyone has the same moving speed.**
2. **Everyone has the same strategy for choosing the urinal.**
3. **Peeing time is 21 seconds for everyone[3].**
4. **Cutting in line is not allowed.**
5. **Everyone who comes to the toilet must pee.**
6. **A urinal can only be used by one man at the same time.**
7. **Waiting is not allowed if there is an empty urinal.**
8. **Ignore all behavior and time costs after peeing.**

VI. DESIGN ALTERNATIVES

A. DESCRIPTION

In the literature review, there are four different strategies for choosing the urinal. Thus, we guess the strategy will affect the result. Second, as we mentioned before, **α** and **β** in the objective function represent the preference of the group. Different values represent different groups. Therefore, we are also interested in how these parameters affect the result.

B. DESIGN ALTERNATIVES

1. **different strategies for choosing the urinal**
2. **different values of α and β**

VII. FORMAL OPTIMIZATION FORMULATION

We want to minimize the **Peeing Cost (Φ)**, and the variables and constraints as above discussed. However, our problem can't be simply expressed as a negative null form. Furthermore, due to the form of the problem, we can't use the algorithm in Matlab. We must write GA by ourselves, which will be discussed in the next section.

Problem Solution

I. ALGORITHM

A. CHOSEN ALGORITHM

Genetic Algorithm.

B. PROGRAMMING LANGUAGE

C#, due to the object-oriented characteristic.

II. FLOW CHART AND PSEUDO-CODE

A. FLOW CHART OF GA

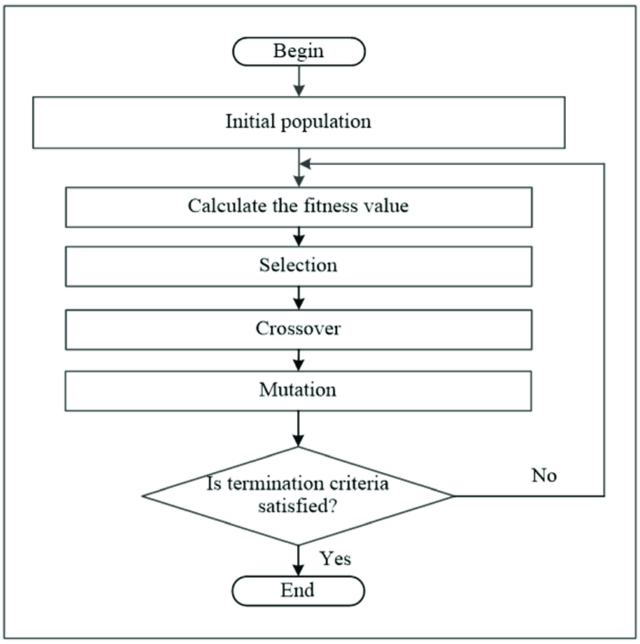


Figure 5 Flow Chart of the Genetic Algorithm

B. CALCULATE THE FITNESS VALUE PSEUDO-CODE

Algorithm: fitness.evaluate()

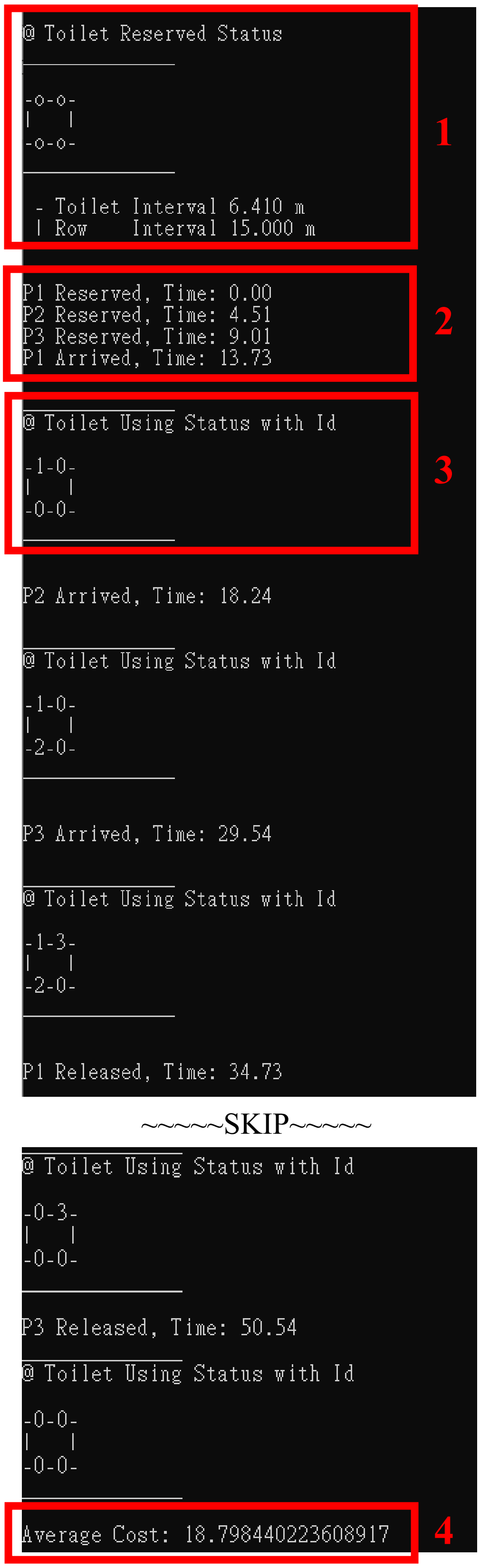
Input: **wallAmount**, the number of the center walls (the necessary two walls are not included)
urinalAmount, the number of urinals per row.
peopleAmount, the length of people.

Output: f, the fitness value (value of the objective function)

```
IF the toilet violates the constraints THEN
    PRINT message of violated constraint
    RETURN inf
Let sequence be a list of Person
Add all persons with ID, and predicted arrival time to sequence
Let waitingList be an empty queue
Let walkingList be an empty list
Let peeingList be an empty list
finishCount = 0
WHILE finishCount < peopleAmount
    IF a person in sequence arrived at the toilet THEN
        Add the person to waitingList
    IF a person in waitingList is ready to go THEN
        IF there are one or more urinals available THEN
            Chose the target urinal, reserved it
            Calculate the time to the urinal on-foot
            Set startPeeingTime as the time he arrived at the urinal
            Remove the person from waitingList
            Add the person to the walkingList
    IF a person in walkingList arrived at the urinal THEN
        Set finishPeeingTime = time
        Remove the person from walkingList
        Add the person to the peeingList
        IF a person is nearby THEN
            Record the duration when they're peeing at the same time.
    IF a person in peeingList finished peeing THEN
        Release the urinal
        Remove the person from peeingList
        finishCount += 1
RETURN average cost as f
```

C. *CALCULATE THE FITNESS VALUE DEMO*

To calculate the fitness value, we wrote 4 C# classes. Then the output result will be liked the following picture. This program was written as a real-world simulator, we followed the time flow, and see what was happening. We will explain it step by step.



1. Toilet status

At the beginning of the evaluation, the program first illustrates the status of the toilet, “o” means an available urinal. The toilet interval is the distance between urinals with the unit “meter”.

2. Take actions

Then, when a person takes action the program will print the person's ID with the action he takes and the timestamp.

The actions include: “Reserved” which means he is ready to move and has decided on the target urinal. “Arrived” means he has arrived at the target urinal and is ready to pee. “Released” means he has finished peeing and is ready to leave the toilet.

3. Toilet using status

When a person arrived at or left the urinal, the program will print the using status diagram of the toilet. “0” means the urinal is available. Otherwise, the urinal is occupied, and the number is the ID of the person who is using the urinal.

4. Average Cost (Fitness Value)

As all the people in the sequence finish peeing, the program will calculate the value of the object function, then, print it on the console.

D. *RESULT AND DISCUSSION*

1. GA Parameters

- Population size = 500
- Crossover probability=0.3
- Mutation probability = 0.3
- Iteration=10

2. Optimization Result

- Row = 4, Column = 24 (Cooperative Behavior)
- Row = 5, Column = 7 (Lazy Behavior)

3. Discussion

After we modified some parameters and run the prediction several times we found some facts:

(1) The total number of people is not critical

We guess that since our calculation assumes people will come in the same frequency, that is the critical parameter will be the time gap. On the other hand, we can see the problem as a flow, not a summation.

(2) The time gap affects little

Due to fact (1), we did some tests for the time gap, however, we also found that the effect of the time gap is small.

(3) The strategy of choosing the target toilet is critical

This fact is easy to imagine since the different strategy affects a lot, from walking time to privacy.

(4) The size of the toilet is critical

This fact is also intuitive, the bigger the toilet is, the more urinals should be inside the toilet. Notice that, the answer is not just as much as it could be, since the small interval will affect privacy, there is still an optimum difference from the constraints.

(5) $\boldsymbol{\alpha}$ and $\boldsymbol{\beta}$ are not critical

This is a tricky fact, At the beginning, we guess the weight in the objective function is very critical. However, after some tests, we found $\boldsymbol{\alpha}$ and $\boldsymbol{\beta}$ didn't affect that much, only when $\boldsymbol{\alpha}$ and $\boldsymbol{\beta}$ be highly extreme we can get different results.

E. *ACTIVE CONSTRAINTS*

Our solution only has one active constraint at one time, but with different strategies, the active one will be different. Unfortunately, we can't determine the reasons. We only know that if the urinal amount is insufficient, the effect will be very big since the time cost will raise for everyone in the waiting line. Thus, the constraint will be active.

1. Distance between center of urinals

This constraint will be active when the strategy is "Cooperative Behavior".

2. Distance between rows

This constraint will be active when the strategy is “Lazy Behavior”.

Uncertainty Analysis

According to different optimal points based on different strategies, we analyzed their uncertainty separately. For “Cooperative Behavior”, we get the optimal solution [4, 24] for urinal distribution, and also its corresponding distance between urinals and walls is [0.43(m), 2.25(m)]. For “Regardless of privacy choose the nearest”, we get the optimal solution [5, 7] and its corresponding distance between urinals and walls is [2.163(m), 1.75(m)]. We use Monte Carlo Simulation (MCS) with 1 million samples, and 0.3 standard deviations to check its uncertainty and the probability values of the optimal violating each constraint.

```
%% Uncertain analysis of urinals distribution

mux = [0.43, 2.25]; % x* = [4, 24] (Cooperative Behavior)
% mux = [2.163, 1.75]; % x* = [5, 7] (Lazy Behavior regardless of privacy)

stdx = [0.3, 0.3];
covX = [stdx(1)^2, 0; 0, stdx(2)^2];

% Basic MCS
N = 1000000;
RandX = mvnrnd(mux, covX, N);
X1 = RandX(:, 1);
X2 = RandX(:, 2);

%% Check constraint violation

Y1 = X1 - 0.8; % [m] Distance between center of urinals
Y2 = X2 - 1.4; % [m] Distance between rows

muY1 = mean(Y1); stdY1 = std(Y1);
Nf1 = sum(Y1<0); pf1 = Nf1/N;

muY2 = mean(Y2); stdY2 = std(Y2);
Nf2 = sum(Y2<0); pf2 = Nf2/N;

fprintf('G1 mean = %0.2g, std = %0.2g\n', muY1, stdY1);
fprintf('G1 failure probability using MCS with %d samples is %0.5g percent.\n', N, pf1*100);
fprintf('G2 mean = %0.2g, std = %0.2g\n', muY2, stdY2);
fprintf('G2 failure probability using MCS with %d samples is %0.5g percent.\n', N, pf2*100);
```

Command Window

```
G1 mean = -0.37, std = 0.3
G1 failure probability using MCS with 1000000 samples is 89.129 percent.
G2 mean = 0.85, std = 0.3
G2 failure probability using MCS with 1000000 samples is 0.2274 percent.
```

Figure 6 Uncertainty analysis Matlab program (Cooperative Behavior)

```
% mux = [0.43, 2.25]; % x* = [4, 24] (Cooperative Behavior)
mux = [2.163, 1.75]; % x* = [5, 7] (Lazy Behavior regardless of privacy)
```

Command Window

```
G1 mean = 1.4, std = 0.3
G1 failure probability using MCS with 1000000 samples is 0.0001 percent.
G2 mean = 0.35, std = 0.3
G2 failure probability using MCS with 1000000 samples is 12.173 percent.
```

Figure 7 Uncertainty analysis Result (Lazy Behavior) (The rest code is the same as Figure 6)

The results show: For “Cooperative Behavior”, it has 89.129% chance to violate the first constraint (Distance between urinals should be larger than or equal to 0.8m) and has 0.2274% chance to violate the second constraint (Distance between walls should be larger than 1.4m). For “Regardless of privacy choose the nearest”, it has only a 0.0001% chance of violating the first constraint and a 12.173% chance to violate the second constraint. In our problem, if the constraints are violated, the only thing that will happen is that it will fail under the rules, it’s not critical since it won’t cause any safety problems. But in different domains, the uncertainty analysis should be conducted carefully.

Conclusion

For the search and calculation above, we conclude some points.

1. The optimized urinal amount is as much as possible. In our problem, we simplified the urinal distribution into rows and columns whose physical meaning is the wall amount inside the toilet and the urinal amount in each row. It is obvious that the cost of adding a wall in the center of the toilet is much higher than adding some urinals in the existing row. So as we can see in the real world the design of toilets nearly follows this rule.

2. The strategy of choosing the urinal does matter, however, we can't say which strategy is better through our work. Besides, we can't control the strategy used by everyone, especially in the real world. Therefore there is a good suggestion for you, similar to the conclusion of reference [1], to use cooperative behavior. With this behavior, you can maintain the privacy of you and others in the toilet as possible. Besides, even though the best choice of the urinal with cooperative behavior is farther, the difference won’t be that big. In other words, you may only need to go a few more steps.

3. No matter whether you care more about time cost or private cost, the best toilet distribution is almost the same. This point supports why we don’t need to care more about the different feelings of different people. The fact is when we consider the total benefit, there is only one optimum.

Finally, with these findings, we can fully understand why the urinal distribution would be in our world. And know how to make a choice for the urinal when you go to the toilet next time.

Reference

[1] E. Kranakis and D. Krizanc, "The Urinal Problem," Springer Berlin Heidelberg, 2010, pp. 284-295.

[2] K. Aspelin and N. Carey, "Establishing Pedestrian Walking Speeds," 2005.

[3] P. J. Yang, J. Pham, J. Choo, and D. L. Hu, "Duration of urination does not change with body size," *Proceedings of the National Academy of Sciences,* vol. 111, no. 33, pp. 11932-11937, 2014, doi: 10.1073/pnas.1402289111.

[4] 內政部營建署,公共建築物衛生設備設計手冊 (2010)，取自：https://www.cpami.gov.tw/最新消息/業務新訊/39-建築管理組/10118-公共建築物衛生設備設計手冊.html

[5] 小宅放大！行內才懂的尺寸關鍵術：從人體工學開始，抓出最好的空間比例、傢具尺寸，人就住得舒適(2016), 麥浩斯出版社

[6] 一天該上幾次廁所(2018), 天下雜誌

[7] 每天尿尿超過這個次數 當心你的腎臟、膀胱或子宮出問題了(2019). https://heho.com.tw/archives/45118

[8] 一天排尿幾次才算頻尿？醫師揭曉正常次數，出現 3 種情況最好就醫檢查(2021), 瘋傳媒. https://www.storm.mg/lifestyle/4067036

[9] 一天排尿幾次是正常？頻尿、膀胱過動 5 大危機別只當發炎(2020), 早安健康. https://www.edh.tw/media_article/820

[10] 關西服務區-服務設施-公廁. https://www.freeway.gov.tw/NorthService/Guanxi/facilityDetail.aspx?FID=23

[11] 大弧屋頂下的放鬆，新營服務區公共廁所／林憲忠建築師事務所+原型結構 陳冠帆. https://forgemind.net/media/%e9%99%b3%e5%86%a0%e5%b8%86-%e6%9e%97%e6%86%b2%e5%bf%a0-%e6%96%b0%e7%87%9f%e6%9c%8d%e5%8b%99%e5%8d%80%e5%85%ac%e5%85%b1%e5%bb%81%e6%89%80/

[12] 東山服務區公廁 - 建築師. http://www.twarchitect.org.tw/works/%e6%9d%b1%e5%b1%b1%e6%9c%8d%e5%8b%99%e5%8d%80%e5%85%ac%e5%bb%81/

[13] 《 阿如柑仔店 》TENCO 電光牌 SU4110X-A 立式 小便斗 自動沖水器 感應式 落地式便斗, 蝦皮購物. 取自：蝦皮購物.