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Walking through the City: Which strategy is faster?

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Abstract

When selecting a route to walk from point A to point B in the city, multiple options are typically available. One can choose city streets with longer or shorter blocks and decide when to cross the street depending on the traffic light pattern. I was arguing with my father about whether strategy details affected travel time. To clarify this issue, I tested a hypothesis stating that the choice of longer versus shorter blocks combined with the choice of when to cross to the other side of the street has a noticeable influence on the overall travel time. I used computer simulations to investigate how walking time is affected by strategy choices. I developed a computer program to simulate potential routes with random traffic light switching, which accounts for realistic traffic light scenarios along the route chosen. In the model, I assumed that there was a traffic light at every block. Repeated runs of computer simulations enabled me to identify the noticeable travel time difference between strategies and indicate the most effective city walking strategy from a travel time perspective, providing insights valuable in everyday life.

Contents

1 Introduction

1.1 Background

Oftentimes while walking in the city one may wonder how specific strategy choices such as crossing the street, choosing an alternative block, etc. affect travel time.

The problem of route optimization is interesting not only from the point of view of an individual pedestrian but also from a city planning perspective. Some research in the engineering literature involves sophisticated simulations [1]. My objective in this work is to take a simplified angle at the problem from a pedestrian perspective and investigate pertinent details using a simple model that captures the core of route planning.

While riding my bicycle along North Point Street in San Francisco, I noticed that the lights always turned green when I approached them. Later I noticed a sign that said that a so-called "green wave" was designed on that street specifically for cyclists. However, this is not a frequent occurrence, particularly for pedestrians. When **walking** in the city under normal circumstances, the average pedestrian frequently encounters red lights when approaching crosswalks. This poses a question about how to plan walking routes in an optimal way to minimize the overall delay due to red lights. This also implies the need to optimize when and how to cross the street depending on traffic light states.

1.2 Research question

My father and I often argued about whether different strategies for choosing when to cross the street affect travel time. This argument prompted me to write a computer simulation that would clarify this aspect of route planning.

Specifically, the question was whether it is more effective to continue going straight until you reach a red light as opposed to crossing to the other side the moment a green light is available. Another related question is whether the length of the blocks affects travel time, i.e. would it be more time effective to choose longer over shorter blocks.

1.3 Variables and hypothesis

There are several variables that may affect the time it takes to complete a full route between a starting point and a walking destination. Such variables are likely to include:

- City block length (choosing longer vs. shorter blocks);
- The timing of crossing on green lights (e.g., keep walking straight vs. cross to the other side);
- The total number of blocks to walk;
- Specific traffic light patterns (if any) present along a specific route.

I hypothesized that a smaller number of longer blocks is faster due to less traffic lights overall along the route. In addition, I hypothesized that the best strategy concerning when to cross the street is to keep going until you encounter a red light. If you cross over to the other side when you can still continue going straight, travel time could be delayed.

Since walking routes may vary widely I did not focus on any specific traffic light patterns within the scope of the current investigation.

2 Model development

2.1 Model description

The model I used in this study is schematically presented in Figure 2.1. Multiple blocks of equal length are considered, separated by crosswalks. I assume that there is a traffic light at every crosswalk, and all traffic lights have the same duration. This simplified model already captures important features of the problem under consideration, and it can be extended as further discussed in Section 6.

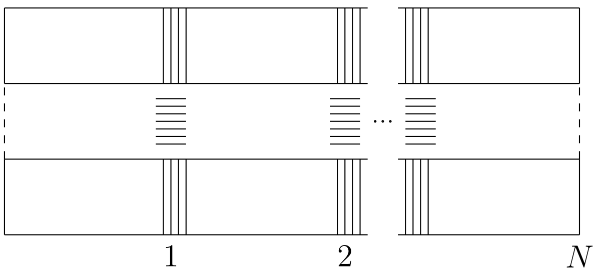


Figure 2.1: City block model considered in the current study. N blocks of equal length are separated by crosswalks with traffic lights.

In the model, I chose street crossing time as the basic time unit. All other times are measured in such units. Specifically, to admit variable block length, I assume constant walking time and define W as the ratio of the time needed to walk through one block, to the time needed to cross the street. Realistic city blocks correspond to W being 2 or larger; that is, it takes at least twice as long to walk through a block than to cross the street.

Let N be the total number of blocks along the route. If all traffic lights at each crosswalk were always green for the pedestrian (a "green wave"), the walking time t_{gw} measured in the chosen time units (i.e. crossing time) would be:

$$t_{gw} = N(1 + W), \tag{1}$$

since each block requires W time units to cover the block distance itself, plus an extra time unit to cross the street after the block. In reality, such time is not attainable, and I define the **relative travel delay** R as

$$R = \frac{t}{t_{gw}} = \frac{t}{N(1 + W)}, \tag{2}$$

where t is the total walking time observed in the model measured in the time units of a single crosswalk.

The value R is convenient because it shows the most important aspect: not the travel time itself, but rather the actual *delay*. I also use the value R when averaging the time delay (see Section 4). Again, I am not averaging the travel time, but rather the average of the time *delay*.

The relative delay R is easy to understand intuitively: for instance, $R = 1.15$ means the total travel time is delayed by 15% as compared to the green wave time (with all green lights as they are approached).

2.2 Walking strategies

There are different strategies pertaining to analysis of when to cross the street. The two main strategies I focused on in this investigation are the following:

1. Crossing to the other side only when it is not possible to continue going straight;

2. Crossing to the other side as soon as a green light is available to do so.

There is also the question of whether and how block length affects travel time. It is often possible to choose predominantly longer or shorter blocks when planning a walking route. I investigated this question by varying the parameter W discussed in Section 2.1 to simulate how different block lengths affect the time delay R.

3 Simulation procedure

Random traffic light switching was used to simulate real-life situations. This is a common simulation approach that is widely used in various scientific and engineering fields [2]. Specifically, I generated a uniformly distributed random number in the interval between 0 and 1 for each traffic light; those lights assigned random numbers over 1/2 are considered red.

I restrict the values of W to take integer values only, which simplifies the simulation dramatically. This restriction is not expected to limit the applicability of the results since I vary W in a wide range and can study the effect of this variable for multiple integer values.

The computer simulation code was written in Julia language, which provides clean and expressive syntax and fast speed for technical computing needs [3]. The most complex function that determines walking actions at each simulation time-step is depicted in Listing 3.1. The function takes current simulation step coordinates of the pedestrian and computes the next coordinates after one time unit is passed.

```julia
function coordstep(x::Int64, y::Int64, Nx::Int64, W::Int64,
    L::BitVector, strategy::Int64)
    xnew = x
    ynew = y

    # determine portion of the block for the current x
    blockpart = x % (W + 1)
    if (x < 1) || (0 < blockpart < W)
        xnew = x + 1
    else
        if (x == Nx*(1 + W)) && (y < 1)
            # reached the last x-block: need to cross y
            return x, y + 1
        end

        # possibly y-movement: light state index
        iL = fld(x, W + 1)
        if blockpart == 0
            if (strategy == 2) && (y < 1) && (!L[iL])
                # crossing along y
                ynew = y + 1
            else
                xnew = x + 1
            end
        end
        if blockpart == W
            # end of block x-wise before crosswalk
            if L[iL+1]
                xnew = x + 1
            elseif y < 1
                # crossing along y regardless of strategy
                ynew = y + 1
            end
        end
    end

    return xnew, ynew
end
```

Listing 3.1: The core function of the simulation code written in Julia language [3] specifying the walking decision logic dependent on the street crossing strategy choice.

Figures based on the simulation output presented in this work were produced with the Julia language package Makie [4].

The final output of a walking simulation is the numerical value of the relative delay R defined by (2).

3.1 Multiple runs and reproducible outcomes

Each walking simulation has been repeated on the computer 100000 times to make sure the results are reproducible. Average values and standard deviations of the computed R values were used to compare the effect of strategies and block length on the total walking time. This comparison is shown in Table 1.

Table 1: Average values and standard deviations of the relative walking delay computed for the Strategy 1 and Strategy 2 ($R_{av}^{(1)}$ and $R_{std}^{(1)}$, $R_{av}^{(2)}$ and $R_{std}^{(2)}$, respectively), for different combinations of block length parameter W and the number of blocks N. The total route distance $N(1+W)$ is kept constant. 100000 simulations were performed for each combination of parameters to compute the averages and standard deviations.

W	N	$N(1+W)$	$R_{av}^{(1)}$	$R_{std}^{(1)}$	$R_{av}^{(2)}$	$R_{std}^{(2)}$
2	40	120	1.17	0.03	1.17	0.03
3	30	120	1.12	0.02	1.13	0.02
4	24	120	1.10	0.02	1.10	0.02
5	20	120	1.08	0.02	1.09	0.02
7	15	120	1.06	0.02	1.07	0.02

4 Results and discussion

4.1 Long or short blocks?

In order to check my hypothesis about the effect of block length on the overall travel time, which was outlined in Section 1.3, I performed repeated computer simulations to compare different combinations of block length and total number of blocks. In order to keep the total route distance constant, the quantity $N(1+W)$ representing the product of the block length and the number of blocks was kept constant. The results of this comparison are presented in Table 1 and Figure 4.1.

Table 1 shows the difference in average and standard deviation for each strategy with different block lengths. It is evident from these results that the longer the blocks (for the same route length), the less time delay there is. It also shows that the shorter the blocks, the less difference there is between the two strategies.

It is interesting to also study the effect of the total distance traveled, through the number of blocks N, on the relative walking time delay (2). Simulation results of this study are presented in Figure 4.2. The time delay decreases with the number of blocks because the less traffic lights there are, the less opportunity there is to get stuck at a red light.

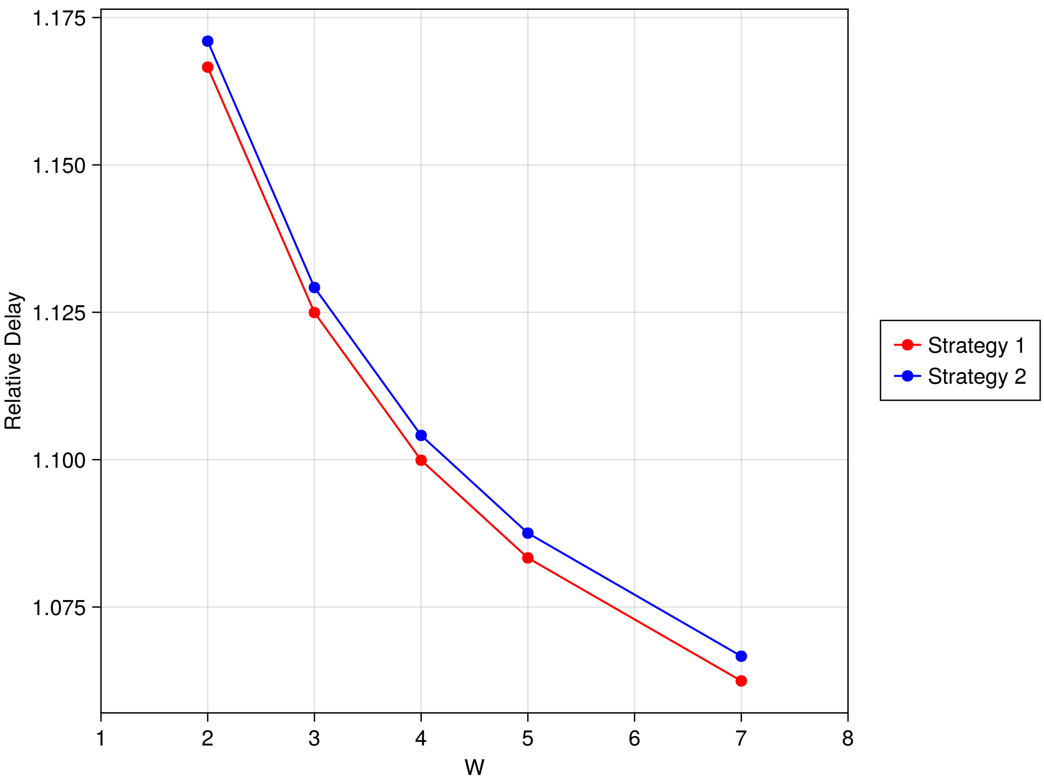


Figure 4.1: Average values of the relative walking delay computed for different values of the block length parameter W, using walking strategies 1 and 2.

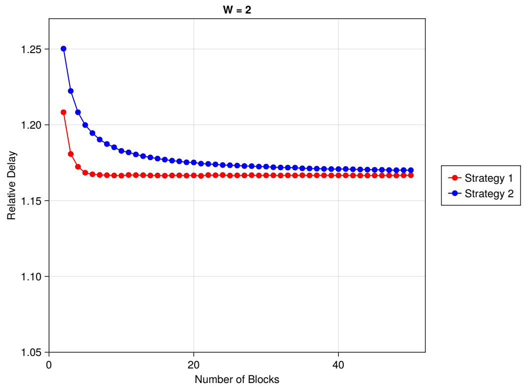
Through the simulations I discovered that as the number of blocks N grows, the relative delay R tends to approach a constant value, dependent on the block length parameter W, as evident from Figure 4.2. After further analysis of the model, I realized that this observation could be rationalized considering that for a large number of blocks, a traveler is going to encounter red lights on about half of the crosswalks due to the random light switching. This would add $N/2$ time units to the total walk time, resulting in the large-N limiting value for the relative delay from (2) being:

$$R_{lim} = \frac{N(1+W) + N/2}{N(1+W)} \tag{3}$$

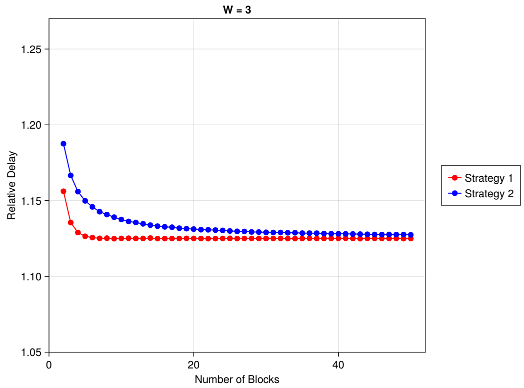
This algebraically simplifies to

$$R_{lim} = 1 + \frac{1}{2N(1+W)} \tag{4}$$

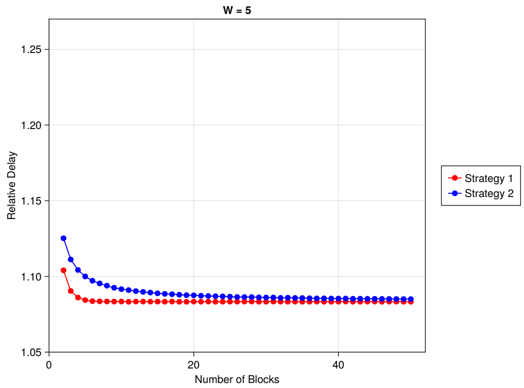
Numerically, the values of R_{lim} for different block length W indeed agree with the results of computer simulations presented in Figure 4.2 For example, for the shortest block considered, $W = 2$, $R_{lim} = 1/6 \approx 0.17$, which agrees with the chart. For the longest block considered, $W = 7$, $R_{lim} = 1/16 \approx 0.06$, which again agrees with the results of the simulations. Thus, after running the simulations, a simple result for the large number of blocks was discovered and verified numerically.



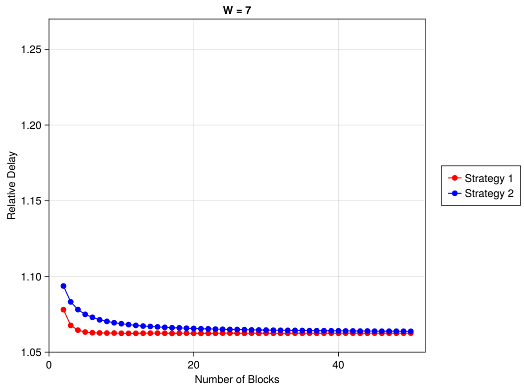
(a) Block length parameter $W = 2$



(b) Block length parameter $W = 3$



(c) Block length parameter $W = 5$



(d) Block length parameter $W = 7$

Figure 4.2: The variation of the average relative walking delay with the number of blocks for progressively longer routes. Note the prominent differences between walking strategies 1 and 2 for smaller number of blocks. I discovered that as the number of blocks increases, the relative delay approaches a constant limiting value (4) dependent on the block length W only.

4.2 Optimizing street crossing strategy

The total time delay is generally lower for the Strategy 1 as compared to Strategy 2. This is particularly evident for a smaller block length, see Figure 4.2a.

As you finish crossing the street, you may have the urge to cross to the other side, since a green light is available to do so. However , this corresponds to Strategy 2 in my model. Doing so will most likely increase the overall time delay of your route. The optimal strategy dictates continuing to go straight until you encounter a red light.

5 Summary and conclusions

In this work I have investigated the question of optimal walking route selection and several variables relevant to the total route time delay. My hypothesis about the preference for a smaller number of longer blocks was confirmed by computer simulations corresponding to a simplified model of the route and crosswalks.

As far as the timing of crossing streets in different directions, the most favorable strategy in terms of the overall time involves not crossing to the other side of the street if a green light is available to continue going straight but rather continue walking until you meet a red light or you reach the end of your destination with one crosswalk left.

After running computer simulations, I noticed that the values of the relative delay approach specific limits that depend on the block length. I used basic probability reasoning to explain this observation and was able to find a formula for that limit that is in agreement with the simulations.

In summary, choosing longer blocks is more time effective. The less blocks, the better. Using some thought as to when to cross the street and in what direction can help to additionally reduce overall time delay.

While this work involved a model with a number of simplifications, it captures the core of the problem and can be used to extend the study for biking and other types of transportation.

6 Limitations and further research

No model is perfect. Each model studies some aspects more than others. One of the limitations of my model is related to traffic light patterns along walking routes. It is quite possible that the timing of traffic lights along certain streets allows "green waves" for biking and/or walking under certain conditions (which is actually beginning to happen in some San Francisco neighborhoods thanks to City planning efforts). My model assumes random traffic light states along the route and therefore does not take into account such possibilities. Incorporating different light patterns into the model is a doable addition that could be undertaken in future research.

Another limitation is associated with the assumption that the walking speed stays constant along each block. In reality, I know that I myself oftentimes speed up if I know the light ahead is likely to switch soon, or slow down if the light is red already at the end of a block. This limitation is more challenging to address using the simplified model I used and would require continuous simulations incorporating variable walking speed.

Yet another limitation of the model is that I assumed that all blocks are the same length. At the same time, I posed a question as to whether block length affects travel time. However, while this model may be applicable to some areas, it could be useful to extend my simulation in order to consider a combination of of different block lengths along the route.

Furthermore, the core of the model I developed can be used to address more challenging urban planning tasks such as slow street organization, planning "green waves" for pedestrians and bicyclists, and route planning for disabled pedestrians [5], all of which the City and County of San Francisco is vigorously expanding upon.

7 Acknowledgments

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8 Bibliography

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