Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

A Hitchhikers Guide to the ETH

Project thesis

by

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Abstract

This paper is based on a traffic and pedestrian simulation study for the GESS subject at the Swiss Federal Institution of Technology Zurich. Everyday, thousands of students travel from and to the said institution and therefore heavily strain the public transport system. This paper analyses the movements and the decision making of the students and simulates them with an agent-based, time-depending model. While mostly homogenous agents are regarded, one must also take into account special persons such as handicapped ones.

SHORT RESULT ABSTRACT

Contents

1. Introduction

1.1.

Nowadays, our everyday life becomes faster and more stressed, especially in big cities. We have to change locations quickly and therefore, an effective and reliable public transporation system is crucial.
In urban clusters, they are several places which particularly attract a large group of people. To come up to the transportation demand, there are often multiple routes which lead from a certain place to a specific other one. However, the paths might differ from each other in regard to the travel time, thus, one path will be favorized over another if the aim is to travel as fast as possible. Yet, a single path can have a limited capacity of individuals it can carry; e.g. a bus can transport maximally around 60 people from A to B every 10 minutes. If the number of individuals aiming to get to the same place exceeds the capacity of the shortest path, individuals will be forced to take the second fastest and therefore less favorable path, and so on.
There is only one path that has a nearly unlimited or rather rarely reached capacity: Walking, which was long neglected in urban-mobility research[1], can always be used as the last resort when all other means of transportation are overloaded or not available. Of course, there are certain situations, e.g. when small distances, where walking is the fastest way of locomotion. Nevertheless, in this study, we only consider situations when walking is the least desired option in terms of travel time.

Pedestrians are a well-documented and researched topic. However, most of the work groups concentrated on the actual trail formation of the pedestrians[2] or on their dynamics as a group[3]. However, those studies do not compare walking with other means of transportations such as public transport or private vehicles such as cars and bicycles.

This work is about the scenario, in which ETH students aim to get from the "Central" station to the ETH main building. We offer our agents three paths, which all lead to the desired destination but differ in both travel time and means of transportation. We assume that the agents prioritise time and therefore will take the shortest path. For this, they will have to distribute themselves and use the different possibilities to their advantage.

The aims of this thesis are:

- Simulating an abstracted version of the current situation in Zurich both quantitatively and visually.
- Developing a dynamic modell of the situation that shows how homogenous agents will disperse over paths with different characteristics.
- Study how improving capacity of the favorized paths influence the situation of the evasion path.

- Analysing how handicapped students that are limited to a single path change the dynamics of the entire system.

2. Materials and Methods

2.1. The three paths

We abstracted the situation and chose three entirely different means of transport to get from the "Central" station to the ETH main building.
The first path regarded is an agent taking the Polybahn. Corresponding strongly to reality, the time the Polybahn needs to get to the ETH was decided to be 2 minutes, while the interval between two consecutive polybahn has been set to 2 minutes. There is space for approximatelly 40 persons in one cab, and maximally another 80 persons waiting in front the station.
The second possibility is to take the tram from Central over Haldenegg to the ETH/Universitätsspital stop. For this distance, the tram needs 5 minutes. It was assumed that each tram has the capacity of taking 50 additional students; even though there are a total of 238 places in a typical "Cobra" tram, only a small amount is still unoccupied when arriving at the Central stop. The time between two consecutive trams has been set to 6 minutes, whereby two different tram lines were simplified to a single one.
The third and longest option is to walk from the Central to ETH main building. With a lenght of 8 minutes, this is the longest path. As the path is wide enough, no passage limitation can be observed in reality. Therefore, the capacity is unlimited and the waiting time for walking is obviously non-existing. The detailed trail can be see on the map in Figure 2.1.

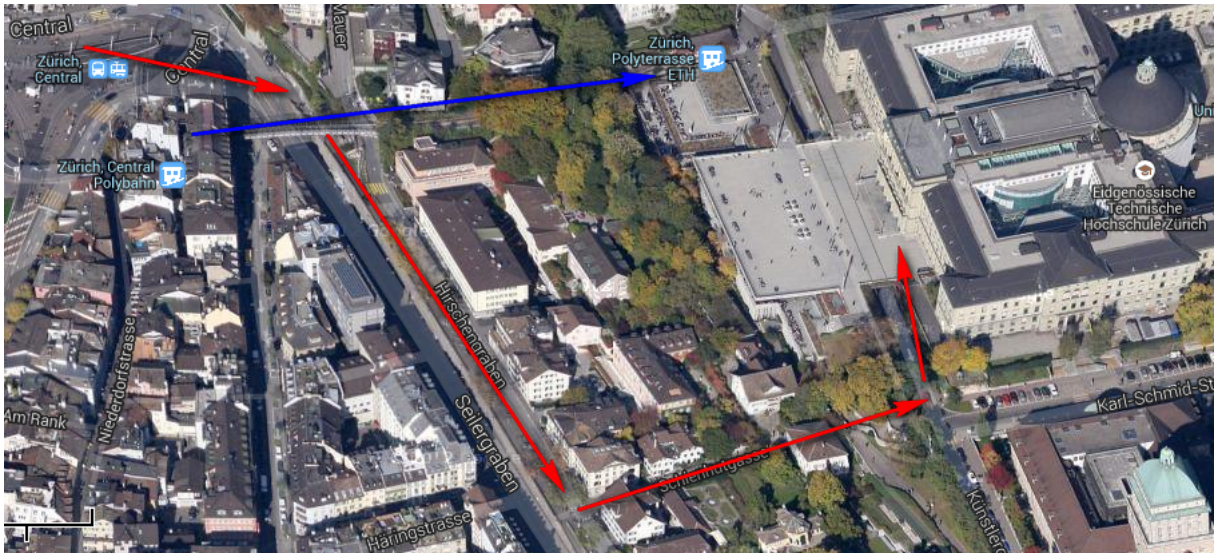

Figure 2.1.: Walking path in red, compared to the Polybahn in blue

2.2. Agents modelling

2.2.1. Homogeneous agents

The homogeneous agents represent students which are going to the ETH, whereby each agent has the exact same starting conditions. Each agent was programmed with three attributes. For reasons of efficiency, we chose to save the agents in a matrix, as object orientation is not implemented in an arithmetically preferable way in MATLAB. For this, we defined a function that creates a M x 3 matrix, with M being the number of agents and 3 the number of attributes.

Attribute 1 is an integer number storing the path chosen by the agent and can be -1, 1, 2, 3, 4 and 5. The numbers 1 to 3 stand for the three different paths an agent can chose from, i.e. taking the Polybahn, the tram or walking . The numbers 4 and 5 represent the actions of waiting for the Polybahn and waiting for the tram respectively. Once a homogeneous agent reaches the ETH, his first attribute becomes -1, indicating that he has finished his voyage and is no longer part of the active simulation. Latter is important, on one hand since we wanted to quantify the operating grade of each path over time and also since this allowes us to exclude all finished agents from further computations in the next time step.

Attributes 2 and 3 are double numbers representing time values. The first one indicates the time an agent has been on a certain path, while the latter saves the amount of time waited in a queue. This allows for statistical evaluation of the different paths and comparison of the time consumption of different paths.

2.2.2. Heterogeneous agents

While homogenous agents all evaluate the system and act correspondingly, there may be a certain percentage of the mass that is unable to walk. Sports accidents, serious illnesses, the increasing obesity and a general ageing of the population create a strain on public transport and increase transportation problems. As they are handicapped, those agents are not able to choose from all paths available and are required to use certain routes that may even be less favourable to others. In our simulation, the heterogenous agents try to simulate these circumstances. Even before the actual simulation starts, a fixed percentage of agents is being bound to use the Polybahn, as walking is no option and the trams are much less favourable in terms of sitting opportunities and entrance possibilities when it is crowded. As those agents do not respect the waiting capacity of the specific transportation medium (as they have no other option and cannot cancel their voyage), the ratio can reach a certain threshold, after which the waiting time constantly increases. This threshold can be located at the point, at which on average more handicapped agents arrive at the station per interval than the medium can carry in the same time slit. Therefore, this path is rendered useless and no more option for (general) public transport.

2.3. Simulation

The Simulation part of the modell is stuctured into three different subsections.

In the initialization, the agents are created by an external function described above and the global variables are specified. While crucial data, such as the number of agents per time interval (APTI) and the time step dT, are stored in a separate ”data” file and are accessible for all files,

simulation specific files such as the waiting time, capacities as well as frequencies are defined and initialized here.

The main part of the program is the simulation loop. As this model bases on a time-depending structure, the most outer loop implements time and increases once every iteration by a previously defined time step dT.
The inner loop iterates through all the agents that are currently in the system. To prevent redundant calculations of agents that already left the system, those agents are automatically excluded and the beginning and the ending of the loop are adjusted accordingly. The remaining agents in the system that were already treated before are checked again to see whether any change has occured; this is either because they arrived at the destination, or if a tram or Polybahn is departing and they can change from the queue to the actual moving vehicle. New agents are put into one of five categories: they can either catch a departing tram or Polybahn (if those are not full yet), start waiting for the next one or directly walk.
With an average of 200-300 agents in the system, the inner loop iterates the same amount per time interval. With a default of 6 * 60 * 4 = 1440 time steps, there are more than 1440 * 200 = 288'000 iterations through this inner decision loop in total. Whenever one time step has been entirely calculated, the "Visualisation" function draws the current situation into a figure and saves the image for further use in a video.

If the calculations are finished, the last phase of the simulation is initiated. Here, statistical data is calculated and data sets are getting prepared for saving. At the very end, a figure displaying the graphs of usage of the different paths and their waiting time is displayed and saved for further processing.

2.4. Visualisation

This function is used to display the calculated results visually on a map. This map shows the real paths from the "Central" station to the ETH as well as the buildings surrounding it. Each agent receives an x- and y-coordinate according to the time it has already spent traveling. The entire matrix is then displayed as a scatter plot and plotted over the background image.
In order to reduce the computation time, the paths are calculated in the first call of the function and afterwards stored for the next 1439 ones. A loop then reads each agent and gives it its coordinates corresponding to the way taken.

3. Results and Discussion

3.1. Modelling of the current situation

The model of the current situation has been run with only homogenous agent in the system, as handicapped agents appear to be a very small minority and can be omitted under normal circumstances. The Matlab model ouputed Figure 3.1, which graphically represents the amount of agents on the different paths as well as in the different waiting queues at each time step. Note that each time step equals 10 seconds or one sixth of a minute, which means that the plots with their 1440 time steps display the situation for four hours.

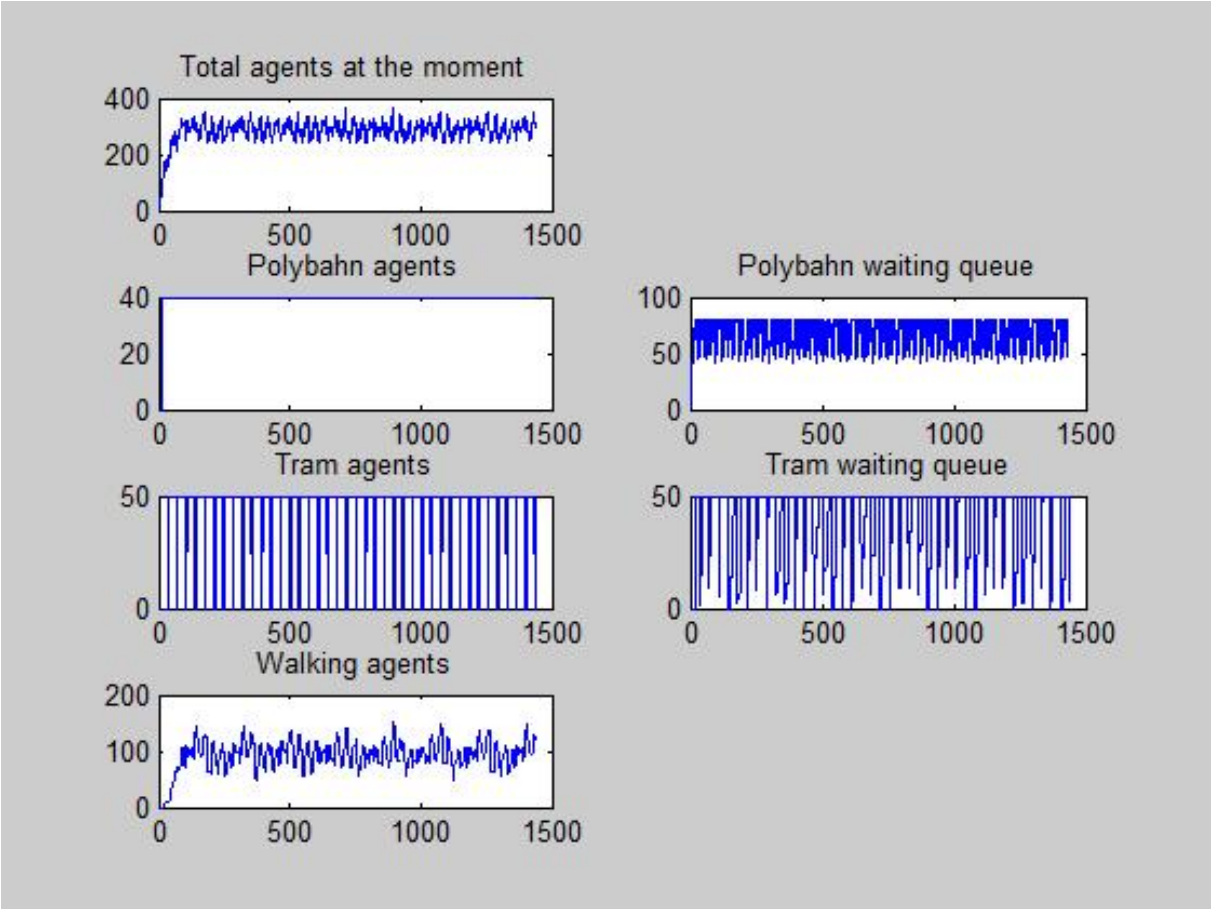

Figure 3.1.: Number of agents over time

Although the plots are hard to read, some important aspects can be derived. Approximately starting at time step 50, all curves, except for the one representing the number of agents in

the Polybahn, seem to exhibit a certain periodicity. Also by looking at the plot "Total agents at the moment" in the left top corner of Figure 3.1, one can see that the average number of agents simultanuously in the system is constantly around 300. The figure further shows, that the Polybahn is always filled maximally under the conditions of the current situation; with less agents per time, this degree of capacity utilization will decrease as less people will be traveling. However, as the Polybahn is mostly the preferred way due to its fast travel speed, those changes will only show after each the walking path and the tram path are completely drained.

When the simulation is run, the Matlab command window will show a result similar to the following:

```
   Average agents in Polybahn: 39.666667
Average waiting time at Polybahn: 3.795183
Average agents in Tram: 42.013889
Average waiting time at tram: 4.647436
Average agents walking: 92.734028
```

As can be seen, the calculated 93 average agents walking correlate well with the "walking agents" subplot. On the other hand the 42 average agents on the tram path can not intuitively be deduced from the "tram agent" subplot. This is due to the fact that while the average is the mean of the temporary numbers and therefore interpolates times with no agents on the path, the plot displayes the current data. Therefore, if no tram is in the system at the time, no agents are on the corresponding path and therefore the temporary number is equals to zero. This is temporary the case for one minute every period, as the time between departures is 6 mins, but the tram only needs 5 mins to reach the ETH station. In this minute, no agents are on the path; this minute is nevertheless considered in the calculation of the mean.
This fact can clearly be seen when analyzing the simulated data: If the tram is always full, it will be full in 5 out of every 6 minutes, which would correspond to a ratio of the average usage compared to the capacity of 84% (5/6 * 100%), which is exactly what can be observed in most of the simulations. As the tram departes every 2 minutes, and it reaches its end in just the same time, the capacity usage of the Polybahn is almost 99%.

Another interesting observation is that the average waiting time at the Polybahn (3.8 minutes) is almost twice as long as the travel time with the Polybahn (2 minutes). If considering the average tram waiting time though (4.6 minutes), one can see that latter is inferior to the travel time with the tram (5 minutes).
The reason behind this fact can be found in the corresponding capacities and frequencies: While someone waiting for the Polybahn waits up to two departures until he himself can use it, a tram user only waits for the next tram. Therefore, the maximal waiting time of a tram agent is equals the time interval between two departures (6 min), whereas a Polybahn agent waits up to 4 min (2 * 2min) for his turn.

3.2. Handicapped agents

By running the model several times with different percentages of handicapped agents, we tried to simulate how an increasing "walking disability" may impact the waiting time at the Polybahn as well as the usage of the walking path. As previously described in the "Method" part, the handicapped agents rely exclusively on the Polybahn and therefore also do not consider taking the tram.
According to those assumptions, Figure 3.2 shows the variations of the number of agents walking and the waiting time at the Polybahn as a function of the percentage of handicapped agents.

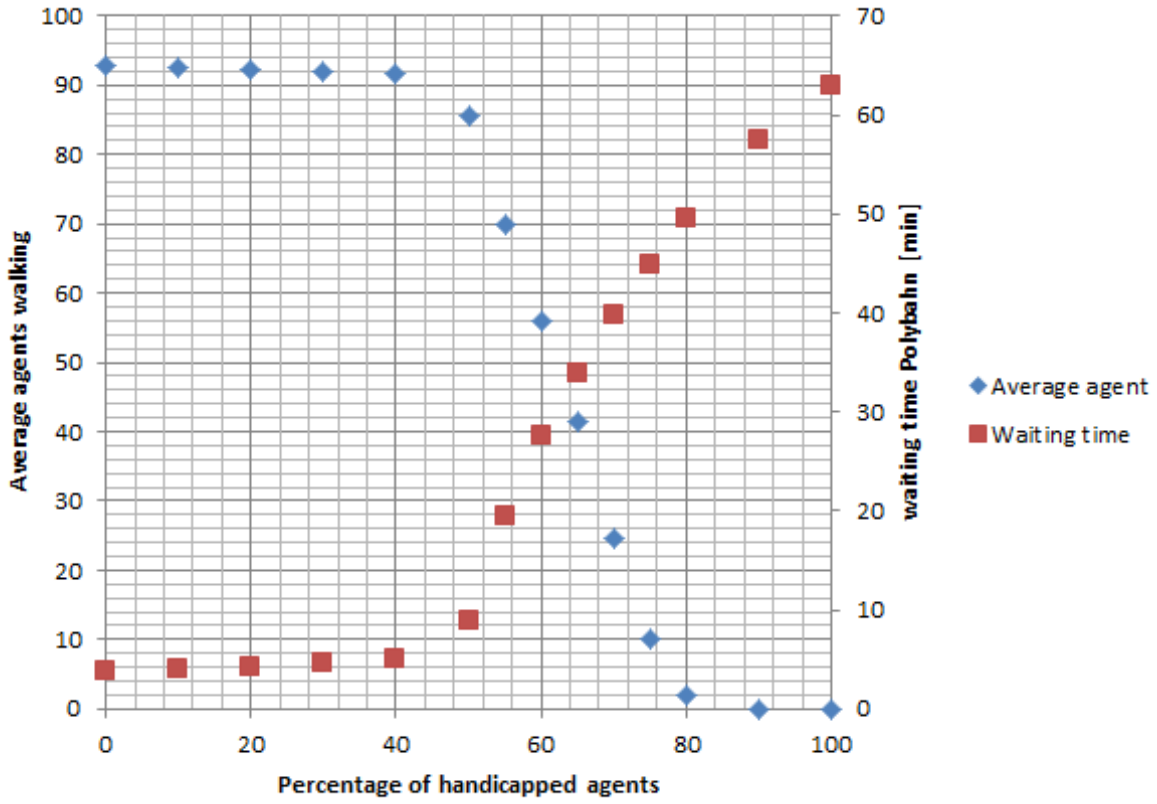

Figure 3.2.: Influence of handicapped agents, Polybahn waiting time and number of walking agents

As can be seen, a handicapped agent fraction of up to 40 % has almost neither an effect on the Polybahn waiting time nor on the average number of agents walking. However, this changes when the percentage of the agents, which imperatively take the Polybahn, exceeds this mark. Between 40% and 80%, the average number of agents walking drops from 82 to 2. Correspondingly, the waiting time at the Polybahn explodes from 5 minutes to 50 minutes. Thus, we can conclude that the critical percentage of handicapped agents the transportation system can handle lies between 40% and 45%. Otherwise, the waiting time at the Polybahn will exceed the travel time on the walking path and the preferences of the paths change accordingly.

3.3. Frequency and capacity adaptations

The other main goal this project has targeted was to determine whether the current conditions can be improved by increasing the departure frequencies of the public transport and by increasing its transport capacity.
As the Polybahn is a fixed installation and its cabins cannot be replaced by larger cabins due to the space available in the depots and the width of the path, the Polybahn capacity has been considered unchanged. The same counts for its frequency: As there can be maximally two cable cars on the tracks at the same time due to its technology, more vehicles are not a possible option. Furthermore, faster travel speed is hardly possible due to the steep terrain.
Therefore, only the tram parameters were considered when evaluationg possible improvements.

3.3.1. Improving the tram capacity

Figure 3.3 describes the influence of an enlarged tram capacity on both the waiting time at the tram and the average number of agents which are simulataneously on the walking path.

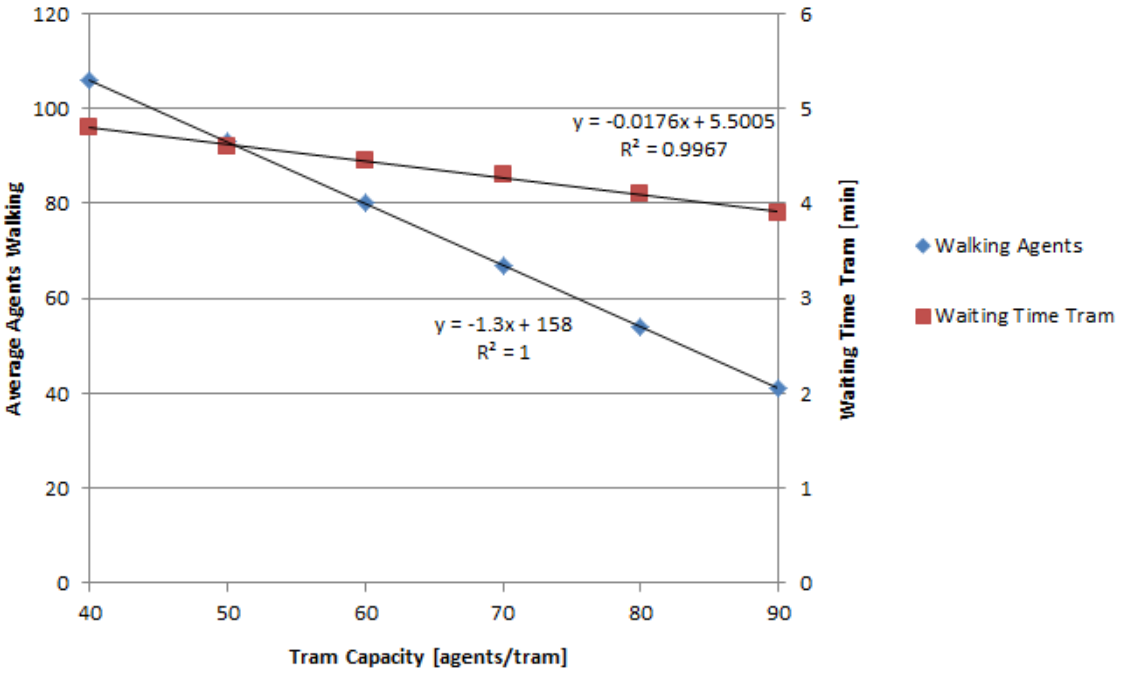

Figure 3.3.: Influence of enlarged capacity on the waiting time and number of walking agents

As one can see, the average agents walking can be expressed precisely as a function of the tram capacity, since the correlation coefficient of the linear approximation is 1. A correlation coefficient of 0.9967 between tram capacity and waiting time at the tram allows us likewise to assume a linear relationship between those two parameters. Both linear equations are also given in Figure 3.3. The comparison of both slopes leads to the conclusion that the average number of walking agents is approximatively one hundred times more sensitive in regard to the tram capacity then the waiting time at the tram. RESENTENCE THIS PHRASE

3.3.2. Improving The tram frequency

The influence of an increased tram frequency on the average number of walking agents as well as the waiting time for the tram can be contemplated in Figure 3.5.

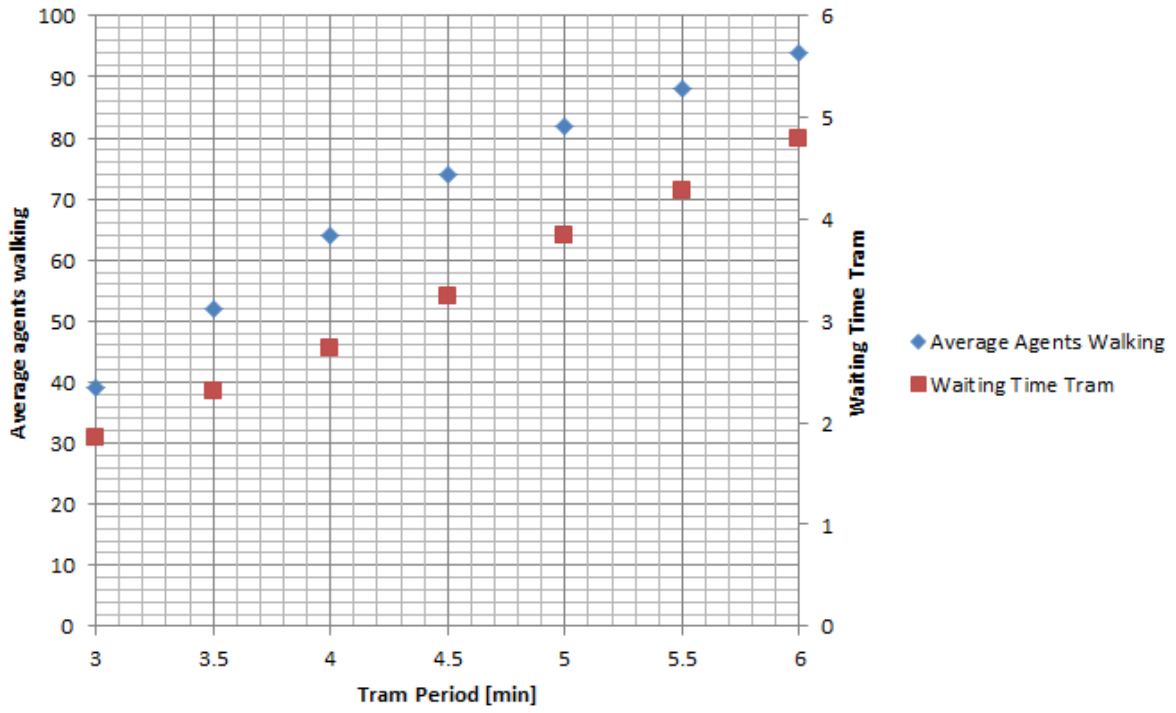

Figure 3.4.: Influence of an increased frequency on the waiting time and the number of walking agents

It is eyecatching that both parameters react similarly to the frequency. An increase of the tram frequency, respectivly decrease of the tram period, leads to a similar lowering of the average number of walking agents as well as of the waiting time for the tram.

By comparing Figure 3.3 and Figure 3.5, it can be seen that increasing the tram capacity up to 90 agents/tram leads to the same results in terms of average number of walking agents as decreasing the tram period to 3 minutes. However, an increased tram capacity of 90 entails a waiting time of nearly 4 minutes while a shortened tram period of 3 minutes results in an only 2 minutes waiting time.
It can thus be conluded, that increasing the tram capacity is a less effective way of shortening the waiting time for the tram than by decreasing the tram period. MAYBY BIRI CAN SAY WHY INCREASING FREQUENCY IS MORE EFFECTIVE TO DECREASE WAITING TIME;)

3.4. Visualisation of the model

The visualisation aspect of the simulation was mainly important for debugging and enables the user to interpret the data in an easier way.

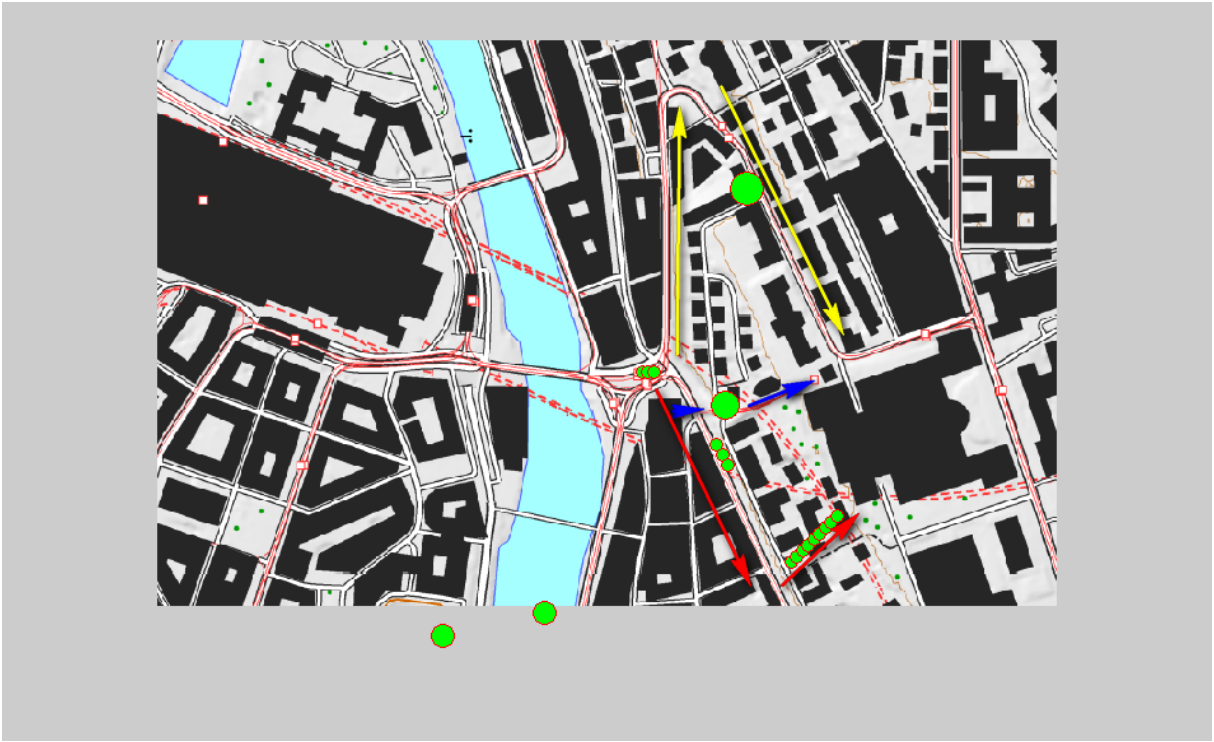

Figure 3.5.: The three paths: Polybahn (blue), Tram (yellow) and walking (red)

The full video of the process can be found in the GitHub folder.

4. Conclusion and Perspective

We used a multi-agent approach with predetermined paths which are not altered by external factors during the simulation. In contrast to other proposed methods such as 'deviation analysis'[1], the agents stay on their path once they decided and will continue until they reached their target. With the simulation, we developed a tool that enables us to better understand how the system reacts to changes in the parameters. While other groups used cellular automata to achieve this[4], we chose a time-descrete, but spacial unlimited modell which enables detailed time measurement.

WE SHOWED THAT ...

Bibliography

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[3] Itami, R.M. ; Gimblett, H.R. Intelligent recreation agents in a virtual GIS world. University of Melbourne, 2000

[4] Dijkstra, J. ; Jessurun, A.J. ; Timmermans, H.J.P A Multi-Agent Cellular Automata Model of Pedestrian Movement. Springer-Verlag, 2001

A. Code Appendix

A.1. Simulation

```
% Evaluation / Simulation

load data;  % loads time_poly, time_tram and time_walk

M = Handicapped(0); % in percent -> Handicapped(1) = 1 % of the agents who will

agents =  length( M(:,1) );

% Way -1: already done
% Way 1: Polybahn
% Way 2: Tram (Haldenegg)
% Way 3: Walking (Stairs ETH/University)

% Way 4: Waiting for Polybahn
% Way 5: Waiting for Tram

% initialize variables and preallocate memory (for maximized speed)
total_temp = zeros(time_span/dt,1);
poly_temp  = zeros(time_span/dt,1);
tram_temp  = zeros(time_span/dt,1);
walk_temp  = zeros(time_span/dt,1);
poly_tempw = zeros(time_span/dt,1);
tram_tempw = zeros(time_span/dt,1);

previous = 1; % index of maximal block of agents that has already been progressed
old_top = 0;
new_top = 0;

poly_capacity = 40;
tram_capacity = 50;
walk_capacity = 10000; % atm infinite

poly_frequency = (2 *6 + 1)*dt;  % Time interval between Polybahn departures in
tram_frequency = (6 *6 + 1)*dt;

poly_wait = 80;
tram_wait = tram_capacity; % people wait exactly for the next tram, and not more
```

```
waiting_poly = 0;
driving_poly = 0;
waiting_tram = 0;
driving_tram = 0;

% Preparing Visualisation
calc = 0; % for preventing multiple calculations
%[A,map] = imread('https://github.com/abiri/A_Hitchhikers_Guide_to_the_ETH/blob/
fid = figure;

video = VideoWriter('Video_1.avi');
% video.FrameRate = 60; % change framerate if required
open(video);

for i = 1:(time_span/dt); % loops through all time intervals

    old_top = new_top;
    new_top = new_top + 1 + ceil( apti*abs(sin(2*pi/60 * i)) );    % periodically

    while ( M(previous,1) < 0)  % skips agents that already progressed through t
Path "-1" == done
        previous = previous + 1;
    end

    for k = previous:old_top  % loops through "old" agents (skips previous ones)

        if (M(k,1) > 0)
            if (M(k,1) > 3)
                M(k,3) = M(k,3) + dt; % increase waiting time
            else
                M(k,2) = M(k,2) + dt; % increase way time
            end
        end

        switch M(k,1)
            case 0
                % nothing happens, just to short-circuit evaluation
            case -1
                % nothing happens, just to short-circuit evaluation
            case 1
                if ( M(k,2) > time_poly )
                    M(k,1) = -1;
                    driving_poly = driving_poly + 1;
                    waiting_poly = waiting_poly + M(k,3);
                else
                    poly_temp(i) = poly_temp(i) + 1;
                end
```

```
            case 2
                if ( M(k,2) > time_tram )
                    M(k,1) = -1;
                    driving_tram = driving_tram + 1;
                    waiting_tram = waiting_tram + M(k,3);
                else
                    tram_temp(i) = tram_temp(i) + 1;
                end
            case 3
                if ( M(k,2) > time_walk )
                    M(k,1) = -1;
                else
                    walk_temp(i) = walk_temp(i) + 1;
                end
            case 4
                if ( ( mod(i*dt,poly_frequency) == 0) && (poly_temp(i) < poly_ca
                    poly_temp(i) = poly_temp(i) + 1;
                    M(k,1) = 1;
                else
                    poly_tempw(i) = poly_tempw(i) + 1;
                end
            case 5
                if ( ( mod(i*dt,tram_frequency) == 0) && (tram_temp(i) < tram_ca
                    tram_temp(i) = tram_temp(i) + 1;
                    M(k,1) = 2;
                else
                    tram_tempw(i) = tram_tempw(i) + 1;
                end
            otherwise
                X = fprintf('Something went wrong with the path %d at timestep %
        end
    end


    for j = (old_top+1):new_top % loops through new agents at the end of stack

        switch M(j,1)
            case 0
                if (( poly_temp(i) < poly_capacity) && ( mod(i*dt,poly_frequency
% Polybahn is just departing
                    M(j,1) = 1;
                    poly_temp(i) = poly_temp(i) + 1;
                elseif (( tram_temp(i) < tram_capacity) && ( mod(i*dt,tram_frequ
                    M(j,1) = 2;
                    tram_temp(i) = tram_temp(i) + 1;
                elseif ( poly_tempw(i) < poly_wait)
                    M(j,1) = 4;
```

```
                    poly_tempw(i) = poly_tempw(i) + 1;
                elseif ( tram_tempw(i) < tram_wait)
                    M(j,1) = 5;
                    tram_tempw(i) = tram_tempw(i) + 1;
                else
                   M(j,1) = 3;
                   walk_temp(i) = walk_temp(i) + 1;
                end

            case 4
                poly_tempw(i) = poly_tempw(i) + 1;
            case 5
                tram_tempw(i) = tram_tempw(i) + 1;
        end
    end


    % statistic data and visualisation

    total_temp(i) = new_top - sum( M(:,1) == (-1)*ones(agents,1));

    current = i; % for stacked display of waiting agents in Visualisation

    %Visualisation

end

%close(video);

mean_poly = waiting_poly/driving_poly;
mean_tram = waiting_tram/driving_tram;

X = fprintf('Average agents in Polybahn: %f \n', mean(poly_temp) );
X = fprintf('Average waiting time at Polybahn: %f \n', mean_poly);
X = fprintf('Average agents in Tram: %f \n', mean(tram_temp) );
X = fprintf('Average waiting time at tram: %f \n', mean_tram);
X = fprintf('Average agents walking: %f \n', mean(walk_temp) );


fid2 = figure;
figure (fid2);

subplot(4,2,1), plot(total_temp);
title('Total agents at the moment');
subplot(4,2,3), plot(poly_temp);
title('Polybahn agents');
subplot(4,2,4), plot(poly_tempw);
```

```
title('Polybahn waiting queue');
subplot(4,2,5), plot(tram_temp);
title('Tram agents');
subplot(4,2,6), plot(tram_tempw);
title('Tram waiting queue');
subplot(4,2,7), plot(walk_temp);
title('Walking agents');

frame = getframe(fid2);
[X,map] = frame2im(frame);
imwrite(X,'Subplot_1.jpg','jpg');

X = fprintf('Finished video and picture and saved into GitHub-Folder..\n');
```

A.2. Visualisation

```
% Draws the agents on the map

load data;

if (calc == 0)

    % Polybahn
    y_p = zeros(time_poly/dt,1);
    x_p = 1:(time_poly/dt);
    time1 = round(time_poly/dt *0.1);
    time2 = round(time_poly/dt *0.35);

     for i = 1:length(y_p)

         if (i <= time1)

             y_p(i)= 290;

         elseif ( i <= time2 )

             y_p(i) = 13*( x_p(i) - time1 ) + y_p(time1);

         else

             y_p(i) = -5*(  x_p(i) - time2 ) + y_p(time2);

         end
     end

    % Tram
```

```
    y_t = zeros(time_tram/dt,1);
    x_t = 1:(time_tram/dt);
    time1 = round(time_walk/dt *0.15);
    time2 = round(time_walk/dt *0.25);

     for i = 1:length(y_t)

         if (i <= time1)

             y_t(i)= 290;

         elseif ( i <= time2)

             y_t(i) = -50*( x_t(i) - time1 ) + y_t(time1);

         else

             y_t(i) = 15*( x_t(i) - time2 ) + y_t(time2);

         end
     end

    % Walking
    y_w = zeros(time_walk/dt,1);
    x_w = 1:(time_walk/dt);
    time1 = round(time_walk/dt *0.27);
    time2 = round(time_walk/dt *0.67);

     for i = 1:length(y_w)

         if (i <= time1)

             y_w(i)= 290;

         elseif ( i <= time2)

             y_w(i) = 9*( x_w(i) - time1 ) + y_w(time1) ;

         else

             y_w(i) = -5*( x_w(i) - time2 ) + y_w(time2) ;

         end
     end


end
```

```
calc = 1; % prevents multiple plottings


% Plots the agents at their corresponding position
agent_y = zeros(old_top - previous,1);
agent_x = zeros( old_top - previous,1);
plot_size = ones( old_top - previous,1);

plot_poly = 300;
plot_tram = 400;
plot_walk = 80;
plot_wait = 200;

until = old_top - previous;

 for i = 1:(until+1)

    time = M(i+(previous-1),2);
    agent_x(i) = round(time/dt);

    if (time > 0)
        switch M(i+(previous-1),1)
            case 1
                agent_y(i) = y_p(agent_x(i));      % Polybahn
                agent_x(i) = 18*agent_x(i) + 390;
                plot_size(i) = plot_poly;
            case 2
                agent_y(i) = y_t(agent_x(i));      % Tram
                agent_x(i) = 7*agent_x(i) + 390;
                plot_size(i) = plot_tram;
            case 3
                agent_y(i) =  y_w(agent_x(i));     % Walking
                agent_x(i) = 5*agent_x(i) + 390;
                plot_size(i) = plot_walk;
        end
    elseif ( M(i+(previous-1),1) > 3 )
        switch M(i+(previous-1),1)
            case 4
                agent_y(i) = 500;                   % Waiting for Polybahn
                agent_x(i) = 5 * poly_tempw(current);
                plot_size(i) = plot_wait;
            case 5
                agent_y(i) = 520;                   % Waiting for tram
                agent_x(i) = 5 * tram_tempw(current);
                plot_size(i) = plot_wait;
            case -1
                agent_y(i) = 347;                   % finished
```

```
                agent_x(i) = 625;
                plot_size(i) = plot_wait;
            otherwise
                X = fprintf('There was an agent with path %d and waiting time %d
                agent_y(i) = 200;
                agent_x(i) = 200;
                plot_size(i) = plot_wait;
        end
    else
        agent_y(i) = 0;
        plot_size(i) = 1;
    end

end

figure (fid);

imshow(A,map);
hold on;

ylim([0 550]); % so that waiting lines are printed correctly

scatter(agent_x,agent_y, plot_size, 'fill', 'MarkerEdgeColor','r', 'MarkerFaceC

frame = getframe(fid);
writeVideo(video,frame);

hold off;
%pause(0.1);
```

A.3. Heterogenous agents

The homogenous agents can be calculated by setting the handicapped percentage to zero.

```
function M = Handicapped(percent_poly)
%Initializes heterogenous agents

load data;

%Calculate sum of all agents
agents = 0;
for i = 1:(time_span/dt)
    agents = agents + 1 + ceil( apti*abs(sin(2*pi/60 * i)) );
end

attributes = 3;
```

```
M = zeros(agents,attributes);

chance = rand(1,agents) < (percent_poly / 100); % percentage of agents that will
M(:,1) = 4*chance;


% Attribute 1: Path chosen

% Attribute 2: Time on the way

% Attributes 3: Time waiting
```