Building Visual Overview of Potential Inefficiencies in Heterogeneous Mobility System

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Introduction – Motivation

- High car-usage exacerbates many problems

- Efficient solution : reduce private car use & increase public transport use (Goodwin, 1996).
- Improving public transport service quality can increase public transport use and lead to a large car use reduction (Eriksson et al., 2010).

Introduction – Motivation

- Heterogeneous mobility system: transport system with multiple transport modes, such as train, bus, subway, etc. has been applied widely (Habitat, 2013; Van Nes, 2002).
- Improving quality of heterogeneous mobility system

Introduction – Objective

- Helping experts, such as city planners, discover and understand potential inefficiencies in heterogeneous mobility system.

Introduction – Challenges

- Inefficiencies in heterogeneous mobility system are due to multiple reasons from different aspects.
- Inefficiency patterns are usually not well defined.

Introduction – Solution

- Using visual analytics techniques to explore the inefficiency patterns in heterogeneous transportation system.
  - Visualization: a technique to transform complex data to human-understandable graphical information.
  - Visual analytics: a science of analytical reasoning facilitated by interactive visual interface (Thomas & Cook, 2006).

Introduction – Workflow

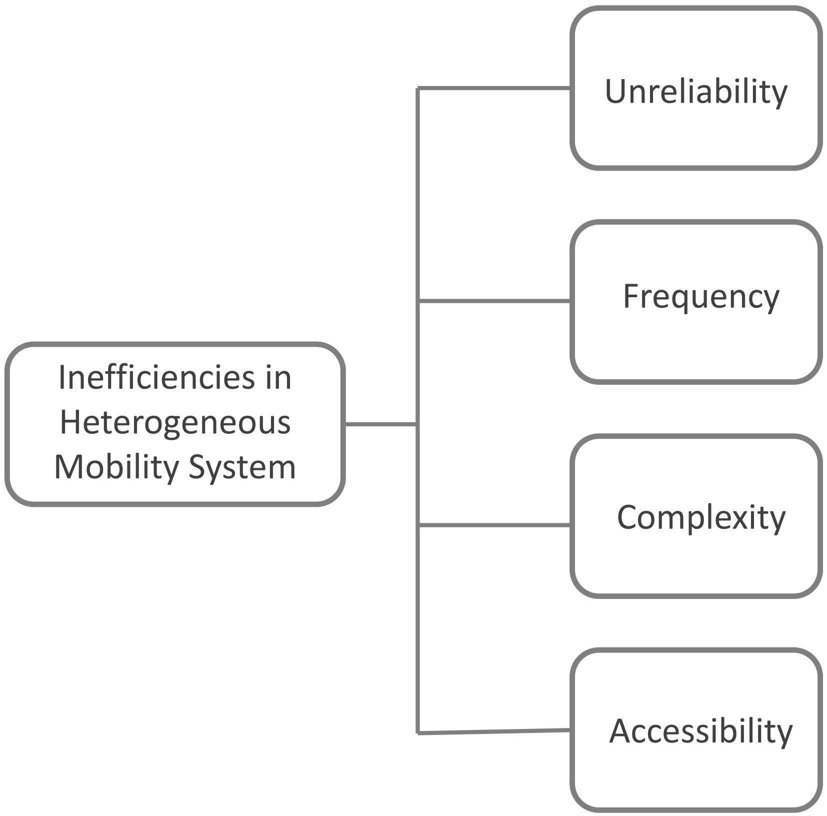
- Defining and finding factors contributing to inefficiencies of public transport service.
- Building proper visual analytics methods to explore spatiotemporal patterns of individual factor and their relations.
- Implementing proposed methods with real data.

Previous Work

- Review of public transport quality attributes (Redman et al., 2013)
- This thesis focuses on operational attributes

	Attribute	Definition
Physical	Reliability	How closely the actual service matches the route timetable
	Frequency	How often the service operates during a given period
	Speed	How time spend travelling between specified points
	Accessibility	The degree to which public transport is reasonable available to as many people as possible
	Price	The monetary cost of travel
	Information Provision	How much information is provided about routes and interchanges
	Ease of Transfers or Interchanges	How simple transport connections of vehicles, including time spent waiting
	Vehicle Condition	The physical and mechanical condition of vehicles, including frequency of breakdowns
Perceived	Comfort	How comfortable the journey is regarding access to seat, noise levels, driver handling, air condition
	Safety	How safety from traffic accidents passengers feel during the journey as well as personal safety
	Convenience	How simple the PT service is to use and how well it adds to one's ease of mobility
	Aesthetics	Appeal of vehicles, stations and waiting areas to users' senses

Methodology – Inefficiency factors overview



Previous work: focus on one aspect of inefficiency

This thesis: build an overview of inefficiency from four aspects with improved details as well as their relations

Unreliability

- Definition
  - The time difference between actual travel time for the trip and its official scheduled travel time.
- Importance:
  - The lack of reliability induces stress because of long waiting time (Cantwell et al., 2009).
  - Travel time reliability influence commuters travel mode decision because they attach high importance to the certainty of public transport (Bhat & Sardesai, 2006).

Unreliability

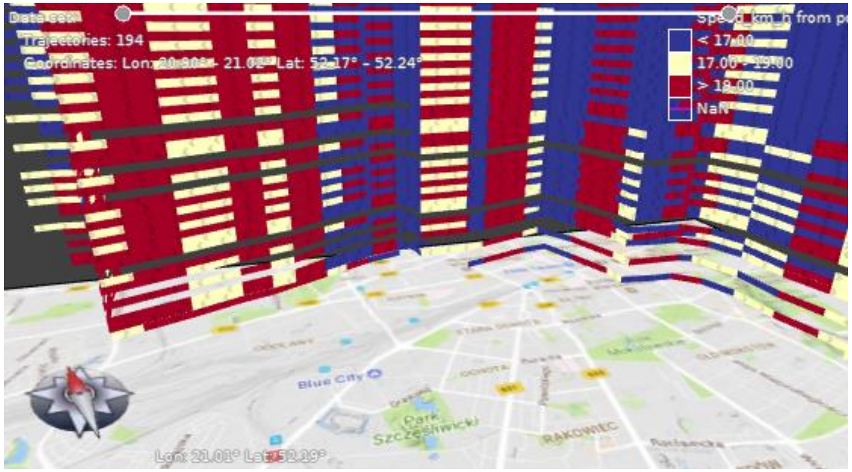
- Absolute unreliability: accumulative result of delay or advance at certain position
  - Advance: absolute time difference is negative
  - On time: absolute time difference is close to zero
  - Delay: absolute time difference is positive
- Relative unreliability: delay or advance change between two adjacent stations
  - Decrease of delay/advance: relative time difference is negative
  - No influence on delay /advance: relative time difference is close to zero
  - Increase of delay /advance: relative time difference is positive

Unreliability – Methodology

- Objective: Where and when delay or advance incurs
  - Difficult to show spatial and temporal information at a large scale at the same time
- Solution from three aspects:
  - Trajectory-level: along a certain route over a long time period
  - Regional-level: over a large area during a short time period
  - Peak time distribution: detect significant time and position

Unreliability – Methodology

- Trajectory-level : trajectory wall
  - 2D map as spatial reference and stacking bands of trajectories ordered by time sequence. Colors indicates the behavior along trajectory.
  - Trajectory wall can show attributes attached to space and time by temporal ordering clearly



Blue: > average speed
Yellow: average speed
Red: < average speed

An example showing speed of vehicle along the trajectory

Unreliability – Methodology

- Regional-level : calculating and visualizing expected value of delay or advance
  - Step 1: Select a time period of interest T_m
  - Step 2: Calculate excepted value of delay of each position in an area over a selected time period. At position S, delay X_1 happens N_1 times… X_m happens N_m times. The total number of delay records is N. Excepted value of delay E_k at S during T_m is:

$$E_k = \sum_{m=0}^{N} X_m \frac{N_m}{N}$$

  - Step 3: Define influenced area of each position
  - Step 4: Visualize excepted value of delay on map

Unreliability – Methodology

- Peak time distribution : significant time period and position
  - Overview of unreliability
  - Significant time and position: when and where the expected value of delay or advance is higher than a threshold.

Frequency

- Definition
  - How often the service operates during a given period.
- Importance
  - Change of frequency may minimize the waiting time at the start of the trip or at transfer (Pratt et al., 2000).
  - Many studies reveal frequency optimization particularly impacts the efficiency and demand of public transport.

Frequency

- Frequency should meet the demand of passengers and minimize waiting time under certain conditions. Waiting time is related to headway.
- Headway: time interval of two sequential arrivals in one station of vehicles of same line
  - Short headway: passengers arrive at station randomly
  - Long headway: passengers arrive at station according to timetable

Frequency – Methodology

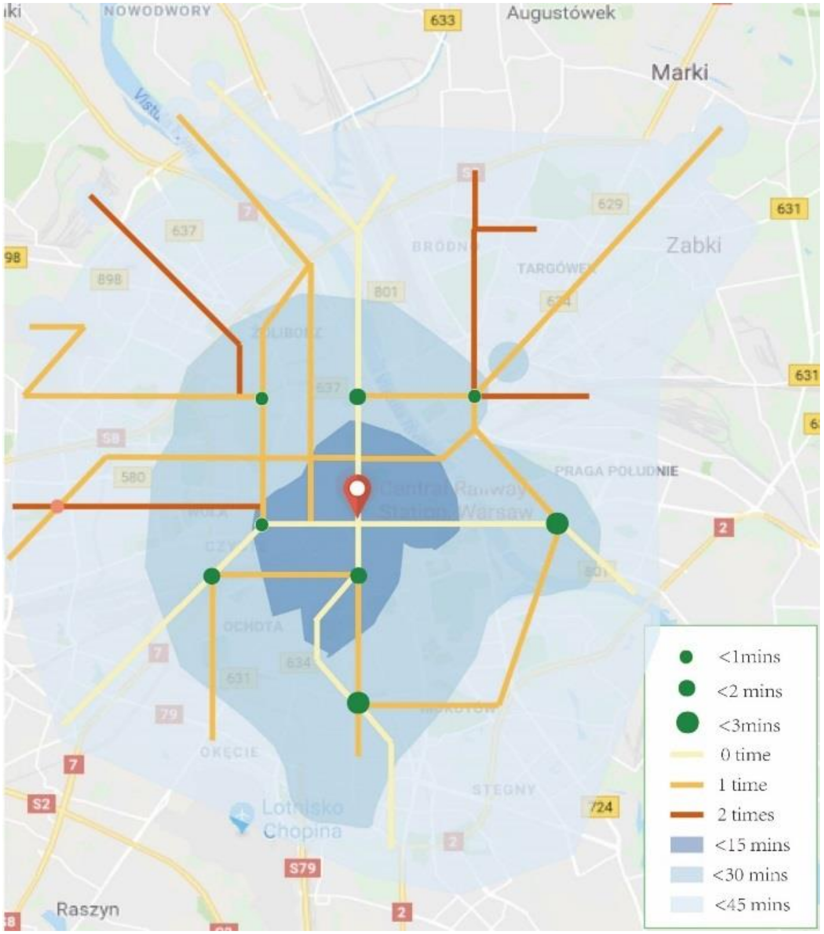
- In general: where and when service frequency meets the demand of passengers or not.
- Short headway: excepted passenger waiting time is related to headway, can be given by (Wilson et al., 1992):
  - $w = \frac{h}{2}(1 + c^2)$
  - w = mean waiting time. h = mean headway. c = coefficient of variation, which is the ratio of the standard deviation to the mean headway
- Long headway: unreliability is the key factor that increases waiting time. Where and when suffers unreliability and low frequency at same time should be pay attention by users.

Complexity and Accessibility

- Definition
  - Complexity: how many transfers are needed from origin to destination.
  - Accessibility: suitability for public transport taking individuals from origin to destination within a reasonable amount of time.
- Importance
  - Improved accessibility contributes to the increase of bus ridership. In some case it even leads to users selling their cars. (Loader & Stanley, 2009)
  - A study in Quito found that one third of daily trips are using transfers, and the number of passengers decreases as the number of transfer increases (Bastidas-Zelaya & Ruiz, 2016).

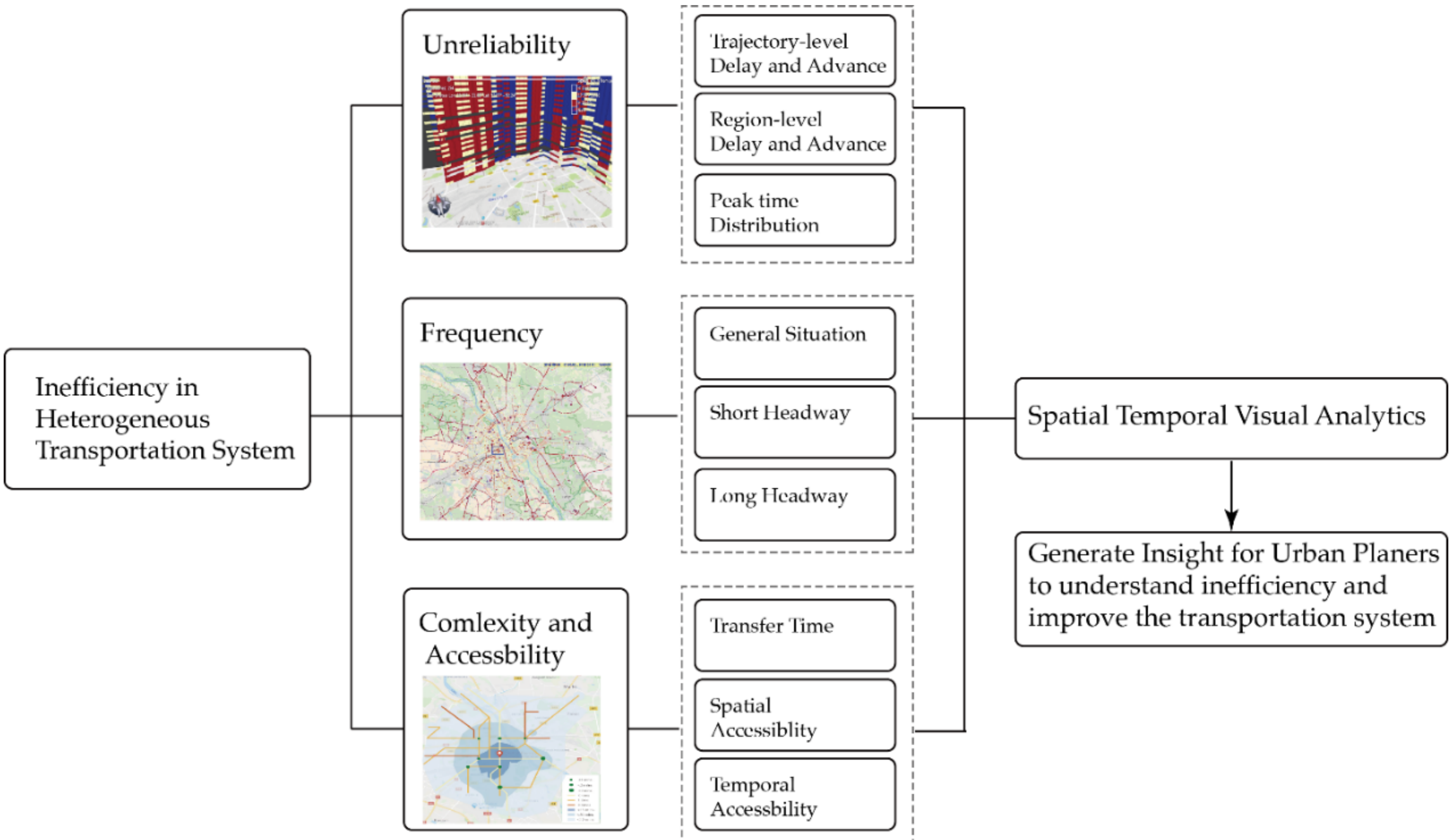
Complexity and Accessibility – Methodology

- In heterogeneous mobility system, multiple transport modes offer better accessibility to passengers.
- It is inevitable to make transfer in heterogeneous mobility system.
- In heterogeneous mobility system, passengers want maximizing accessibility and minimizing transfer times.
- Combination of flow map and isochrone map



visualization of complexity and accessibility

Methodology – Summary



Case study: City of Warsaw

- Data : 2016-09-01

  Timetable: General Transit Feed Specification (GTFS)

  GPS: VaVeL project

- Software

  V-analytics

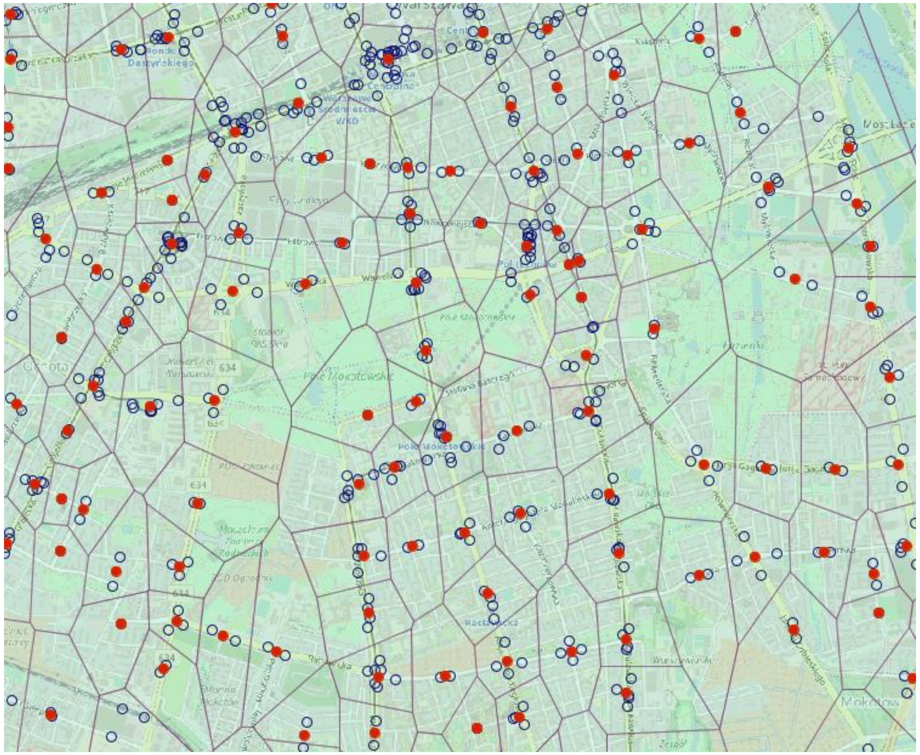
http://geoanalytics.net/V-Analytics/

(Andrienko et al., 2007)

Name	Example	Description
Id	1_@_101_1_TO-NWD_1	Identify a segment along a trajectory.
Trajectory_id	101_1_TO-NWD_1	Identify a trajectory
Line	10	Identify line
Tripmode	tram	Information of vehicle, bus or tram
Start_ID	1462	Identify start point of a segment
End_ID	1122	Identify end point of a segment
Start_time	20160901 00:00:00	Starting time of the segment
End_time	20160901 00:02:00	Ending time of the segment
Segment N	1	The sequence number of the segment along the trajectory
Start_X	20.96036911	Longitude of start point
Start_Y	52.31063843	Latitude of start point
End_X	20.96449089	Longitude of end point
End_Y	52.3132515	Latitude if end point

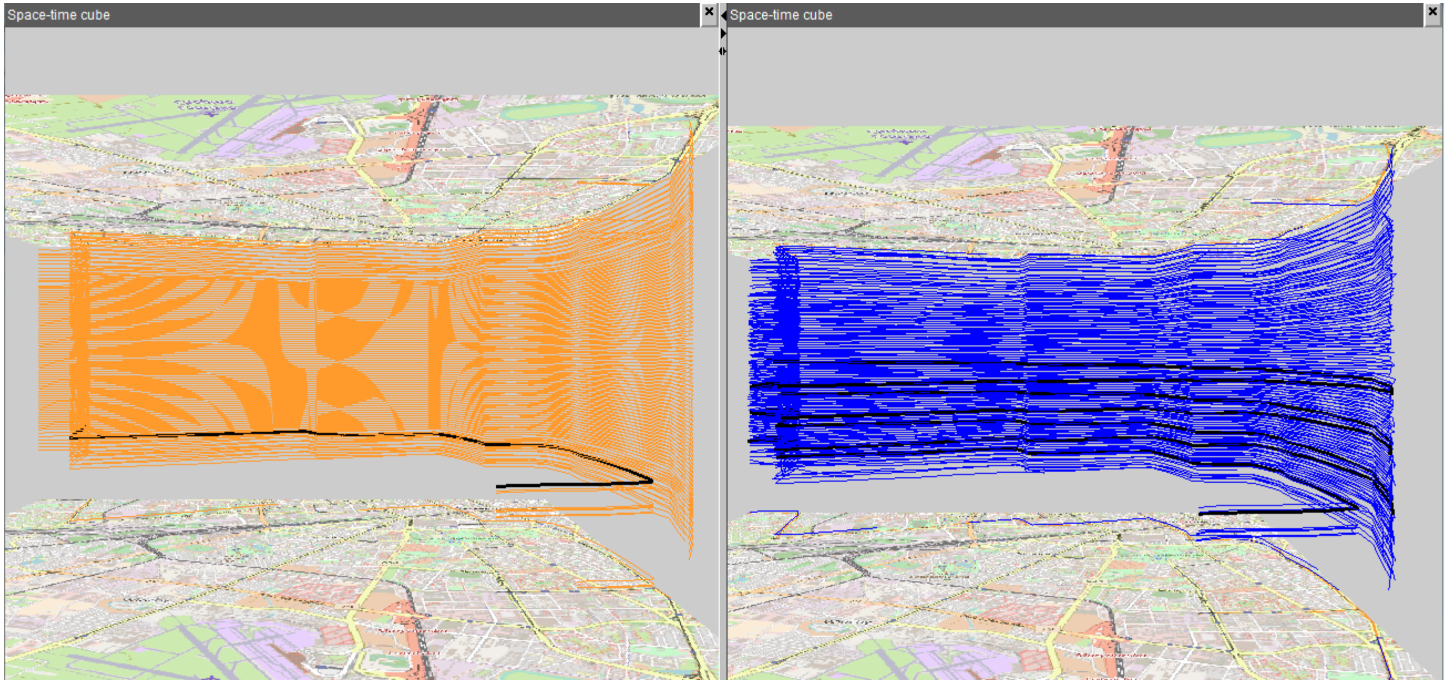
Case study: City of Warsaw

- Data
  - Blue points are real stops in Warsaw and red points are centroids of a group of points inside an voronoi polygon.



Case study: Data process

- Date process: trajectory matching (example of tram line 10)
- Difficulty: one trajectory of GPS data contains many trips.



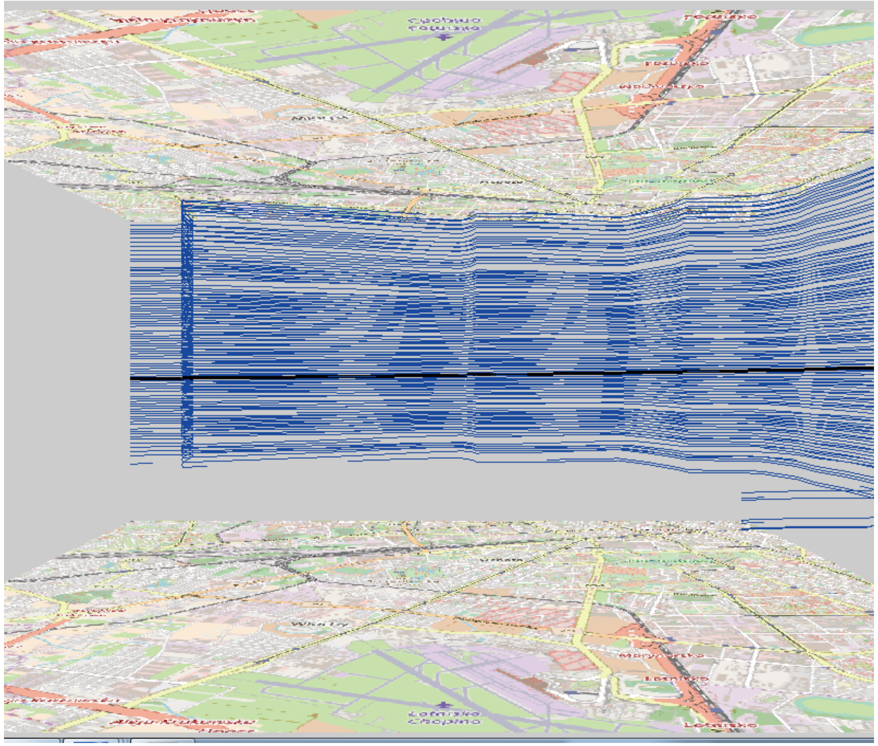
Left: timetable trajectories. Right: GPS trajectories. One selected trajectory is shown in black.

Case study: Data process

- Looking for corresponding trajectory of timetable in GPS data
  - Identifying corresponding trajectories by attributes of starting time and direction.
- Result:

  Original data records: 6794

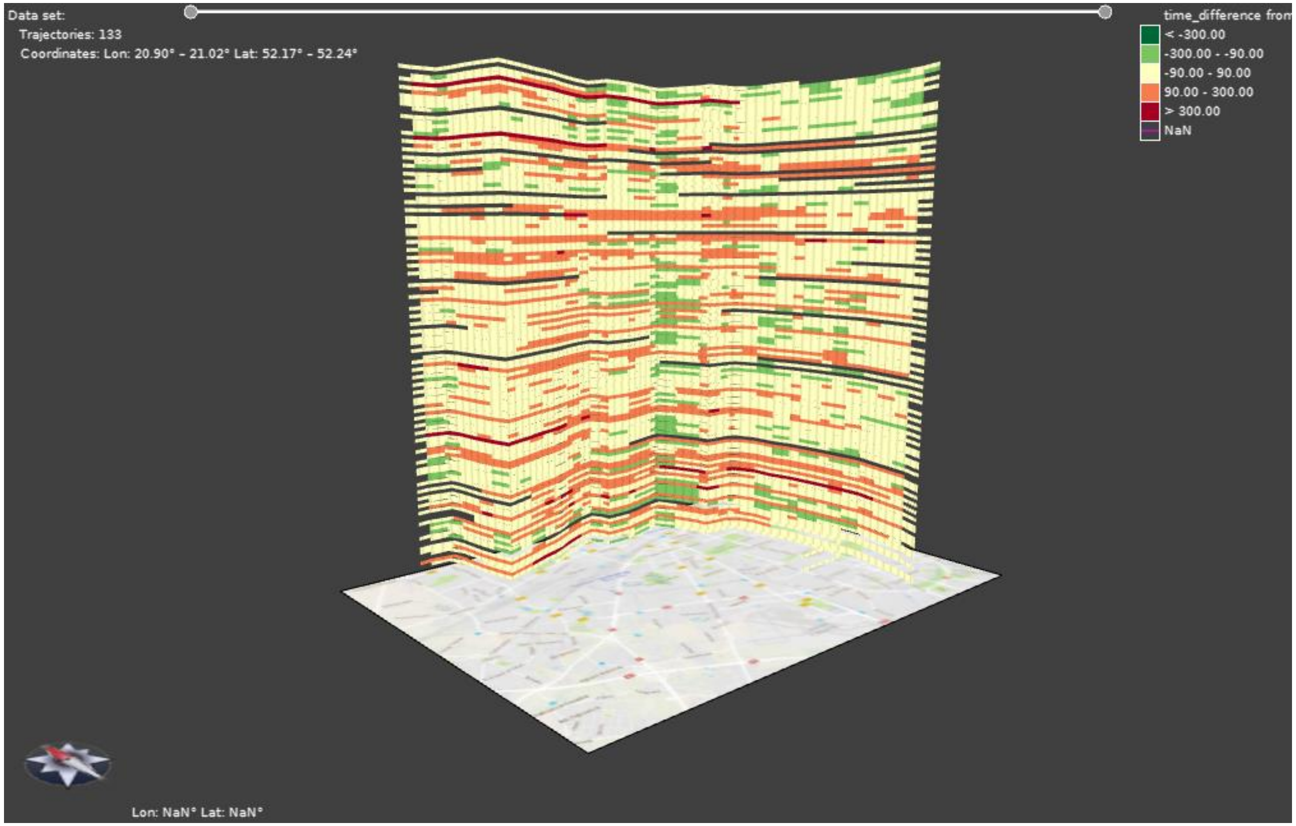
  Matching result records: 4765



Result of matching trajectories of tram line 10

Case study: Unreliability – Trajectory Level

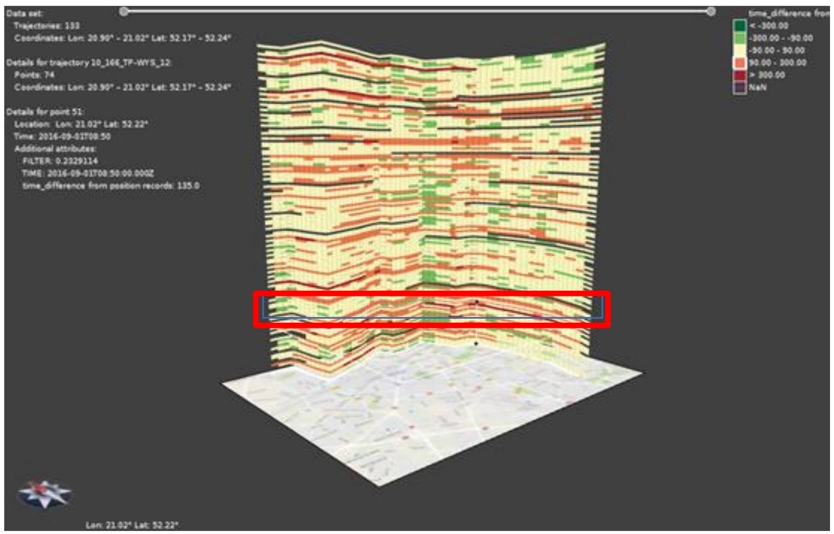
- Trajectory wall of absolute time difference of tram 10



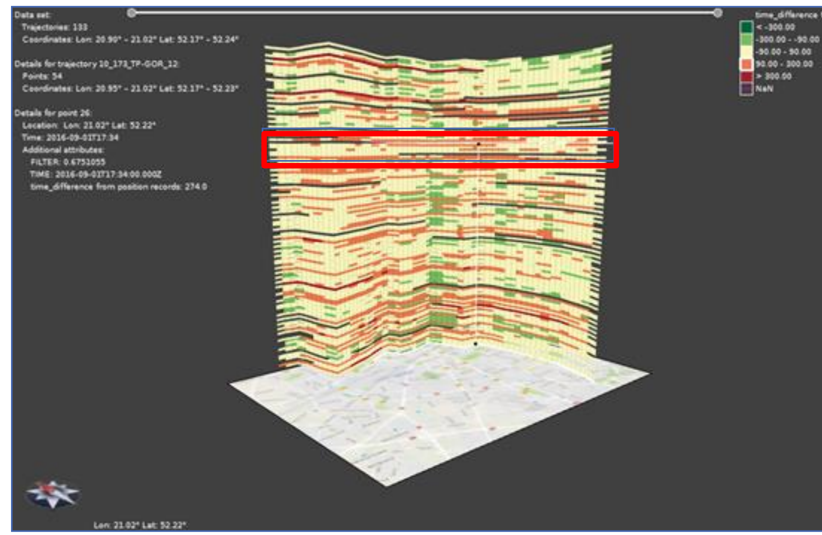
Red: delay Yellow: on time Green: advance

Case study: Unreliability – Trajectory Level

- Significant delay time is marked in red square



08:30-09:30

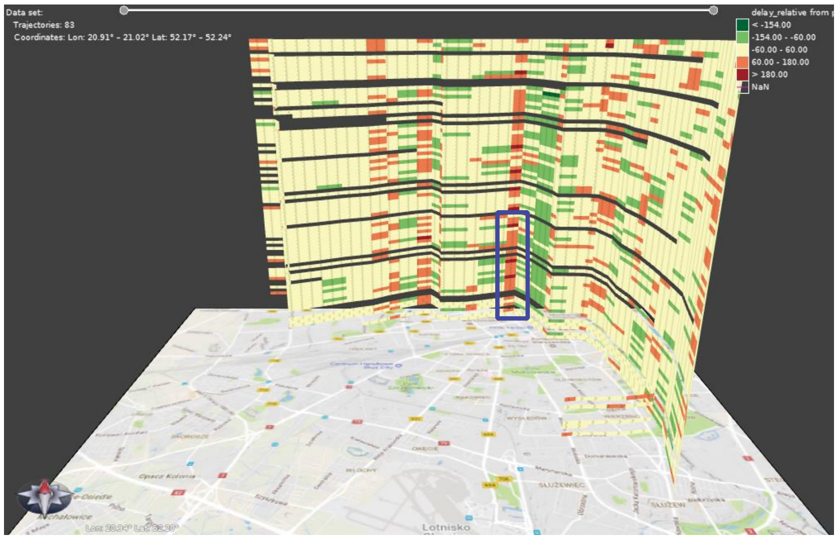


17:00-18:00

Red: delay Yellow: on time Green: advance

Case study: Unreliability – Trajectory Level

- Relative unreliability with two opposite directions



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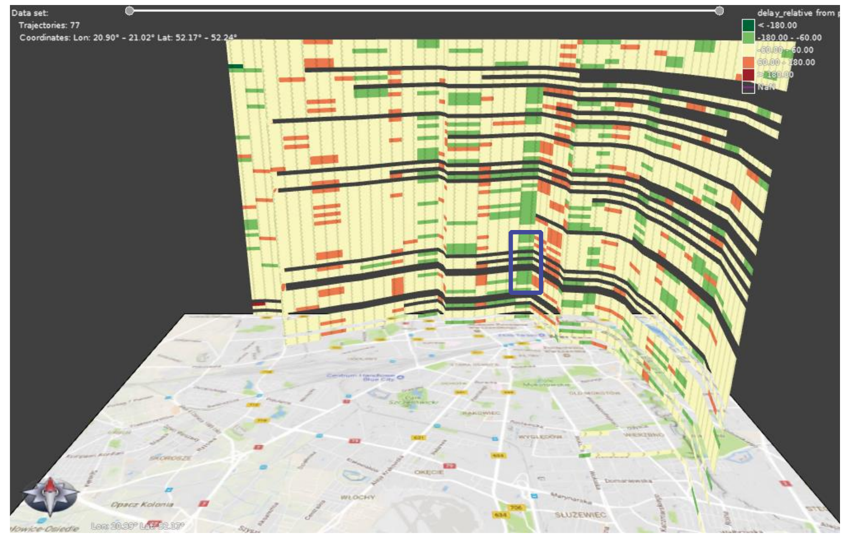

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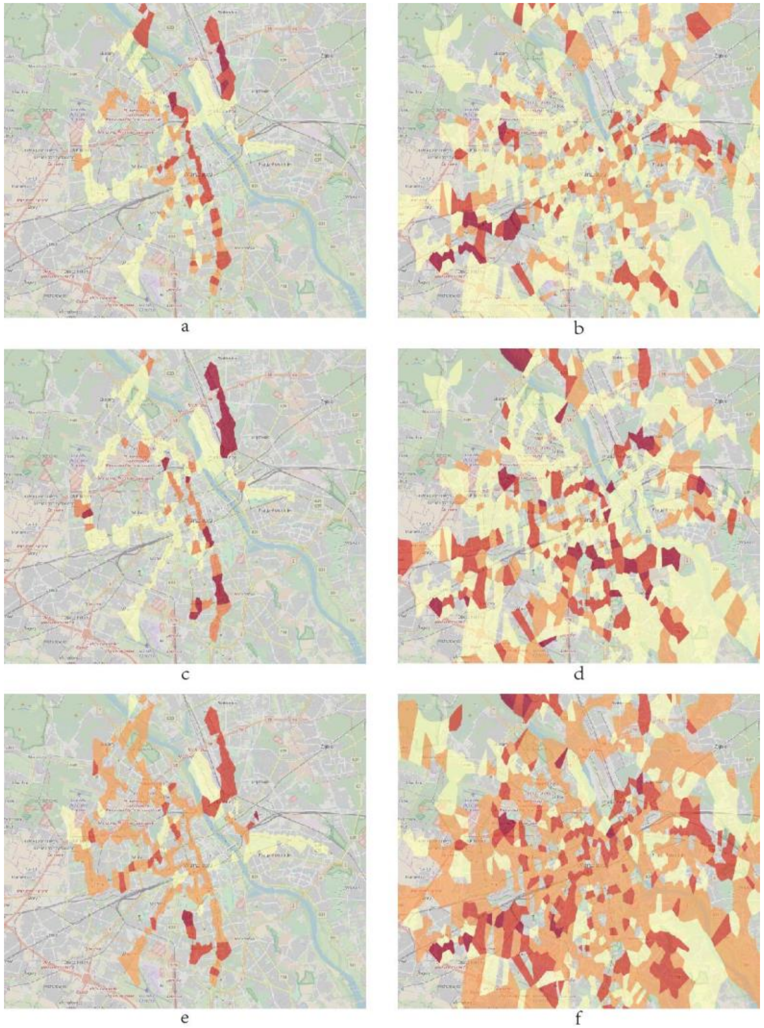
Red: delay increase Yellow: no influence Green: delay decrease

Case study: Unreliability – Regional Level

- Delay comparison of different time periods and transport modes

tram | bus



a b c d e f

8:30-9:30

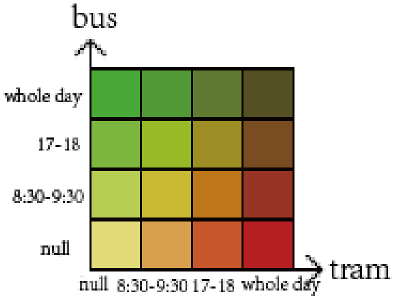
17:00-18:00

whole day

Red: delay

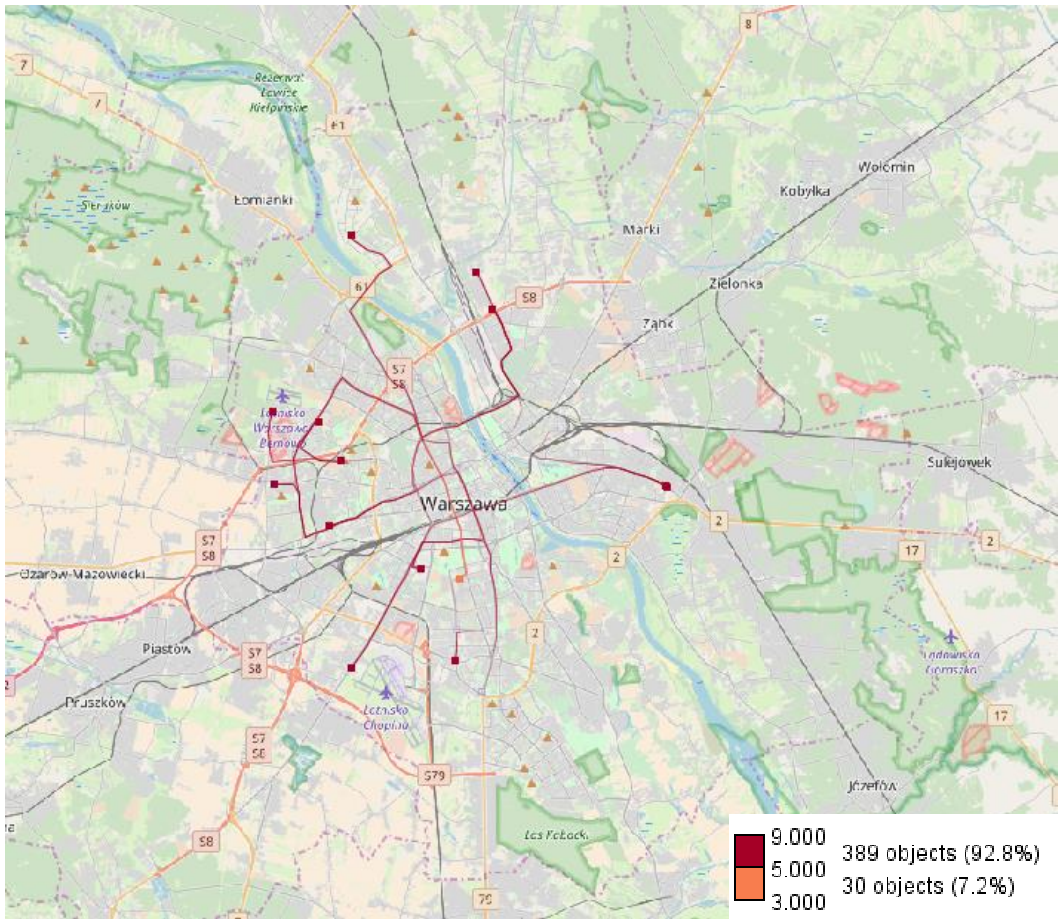
Case study: Unreliability – Peak Time Distribution

Left: Summary result of delay
Right: Summary result of delay increase



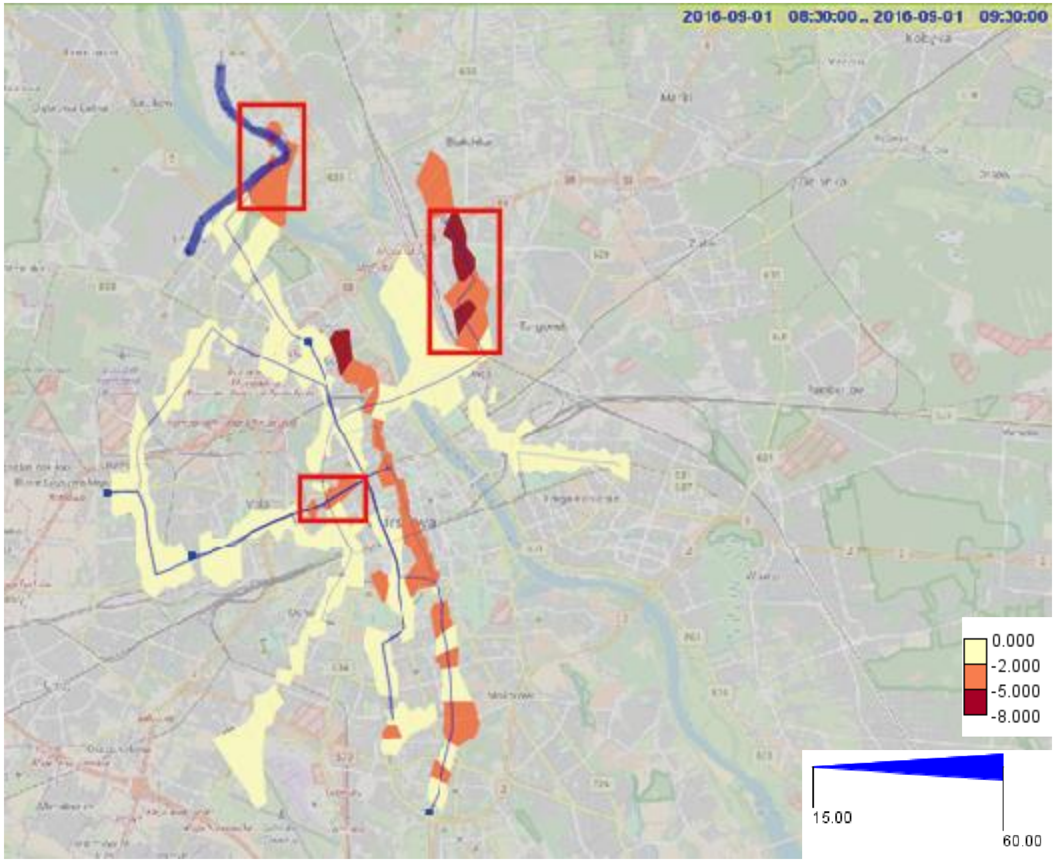
Case study: Frequency – Short Headway

- Mean waiting time of high frequency trams during 13:30-14:30



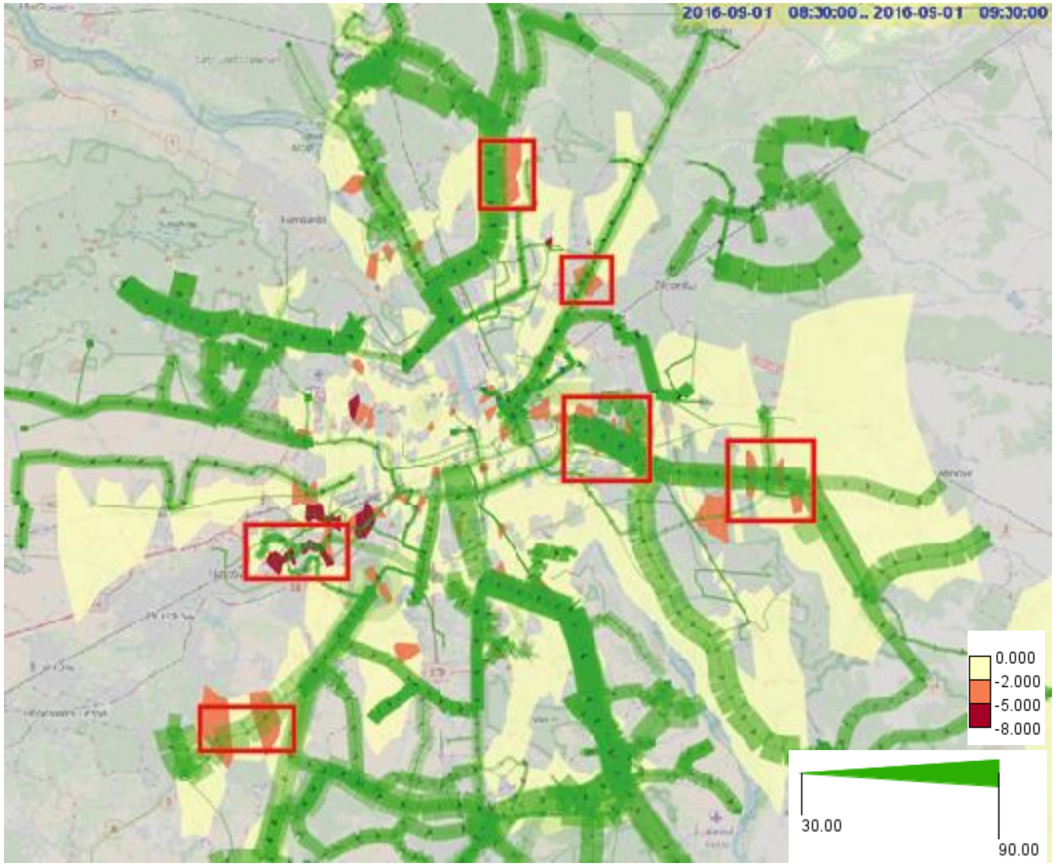
Case study: Relation of Frequency and Unreliability

- Combination of tram frequency and delay



Case study: Relation of Frequency and Unreliability

- Combination of bus frequency and delay



Case study: Results

- Temporal patterns
  - Delay peak time were detected in morning 08:30-09:30 and evening 17:00-18:00 in the workday
- Spatial patterns
  - Trams experience more delay in north and south in city while buses experience more in east and north
  - Places where have low frequency and high unreliability
- Spatiotemporal patterns
  - Buses show more delay patterns in suburban areas in the morning and more delay patterns in the city center in the evening
  - The mean waiting time of traffic lines with high frequency

Discussion

- In case study, visual analytics method of complexity and accessibility was not implemented due to the restriction of data availability.
- Only two transportation modes, which are trams and buses, were considered in this thesis. Future work could extend to multiple transport modes.

Conclusion

- Identifying and finding inefficiencies in heterogeneous mobility system
  - Four attributes affecting inefficiencies were summarized: unreliability, frequency, complexity and accessibility.
  - Visual analytics methods for individual attribute and their relations were proposed based on its own feature.
  - Case study was implemented with Warsaw city data. From results, patterns of inefficiencies can be detected.

Thank you for your attention.

Unreliability – Methodology

- Peak time distribution : significant time period and position
  - Overview of unreliability
  - Significant time and position: when and where the expected value of delay or advance is higher than a threshold.
  - Time period of interest are set as T_1, $T_{2.}$ E_1, E_2 are respective excepted value of targeted attribute of transport mode M during T_1, T_2 at position $S_.$ E_p is the threshold set by users. At each significant position S, we define with significant time C as:
    - IF E1 >= Ep AND E2 < Ep THEN C = M&T1
    - ELSEIF E2 >= Ep AND E1 < Ep THEN C = M&T2
    - ELSEIF E1 >= Ep AND E2 >= Ep THEN C = M&T1 + M&T2
    - ELSE C = NULL