The identification of road modality and occupancy patterns by Wi-Fi monitoring sensors as a way to support the “Smart Cities” concept.

Application at the city centre of Dordrecht

P4 Presentation for MSc Geomatics: 13/03/2017

Dimitris Kyritsis

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- Data preparation & analysis
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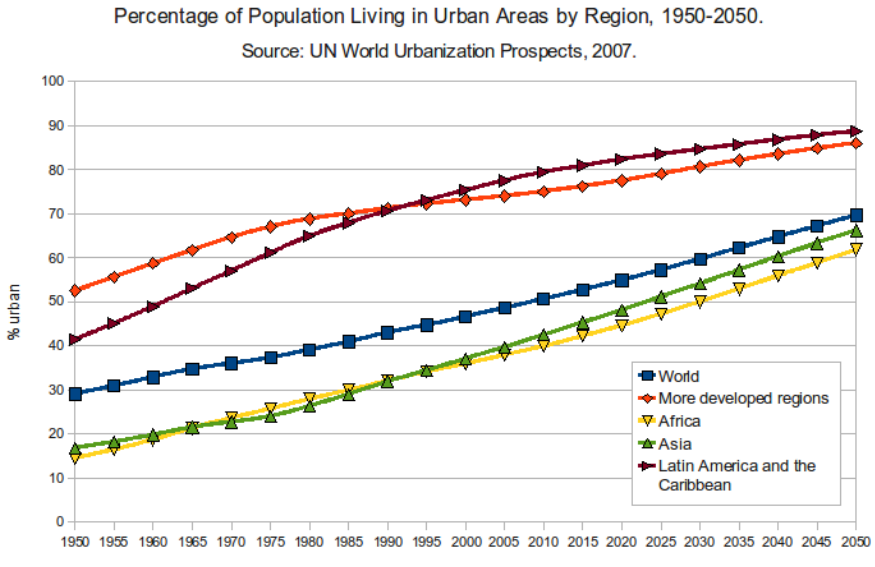
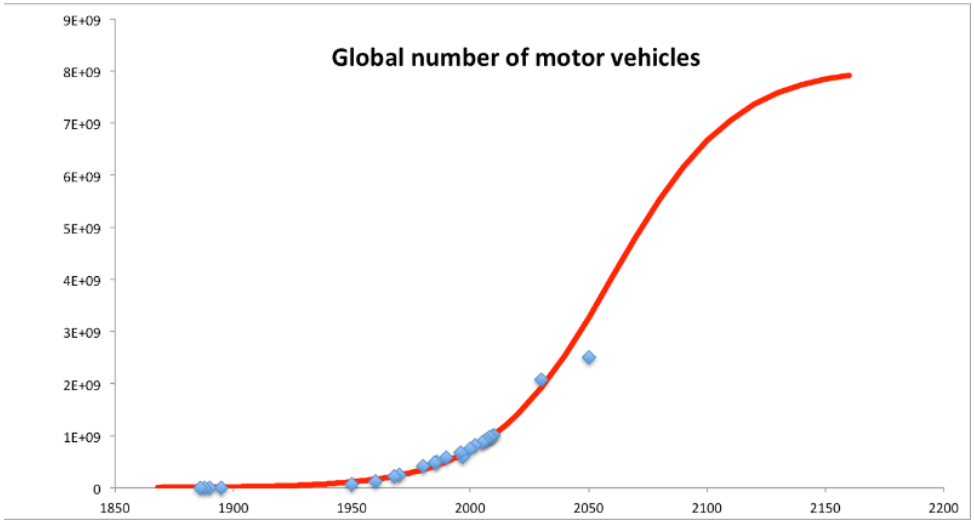
Motivation

- Today, half of the world population and the 80% of European citizens live in cities
- The total population expected to double by 2050





Smart Cities

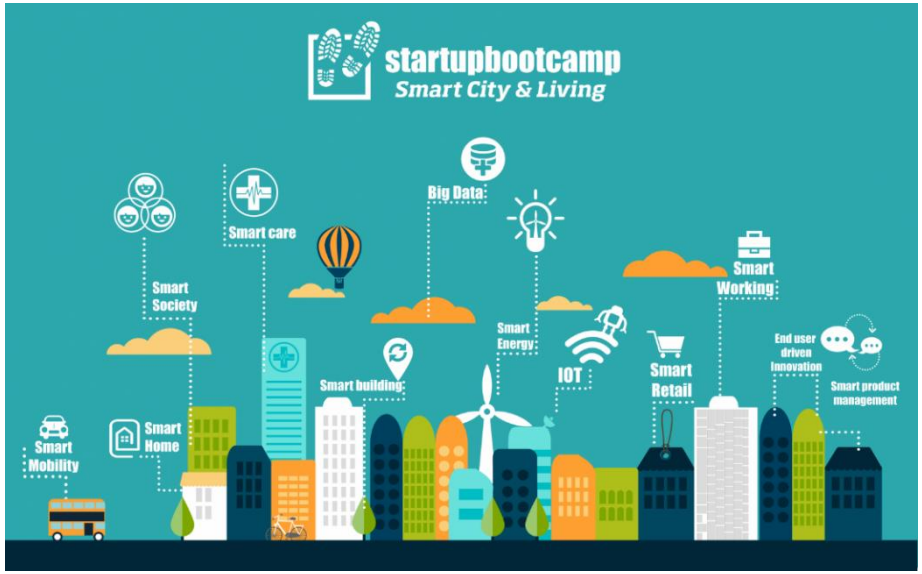
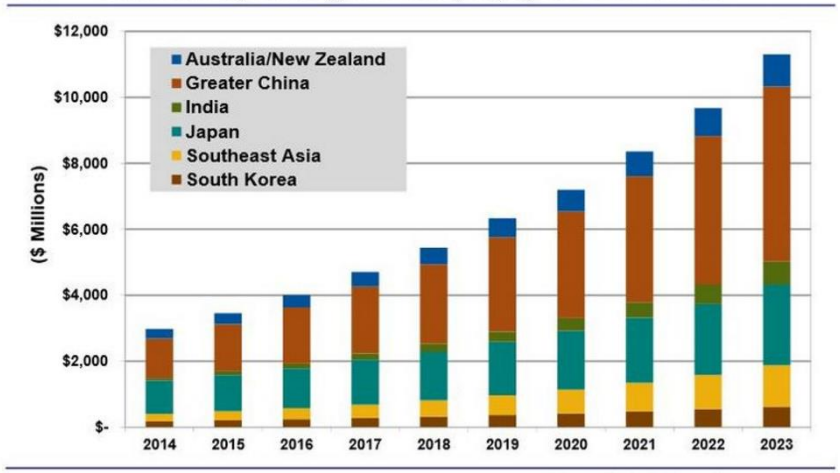
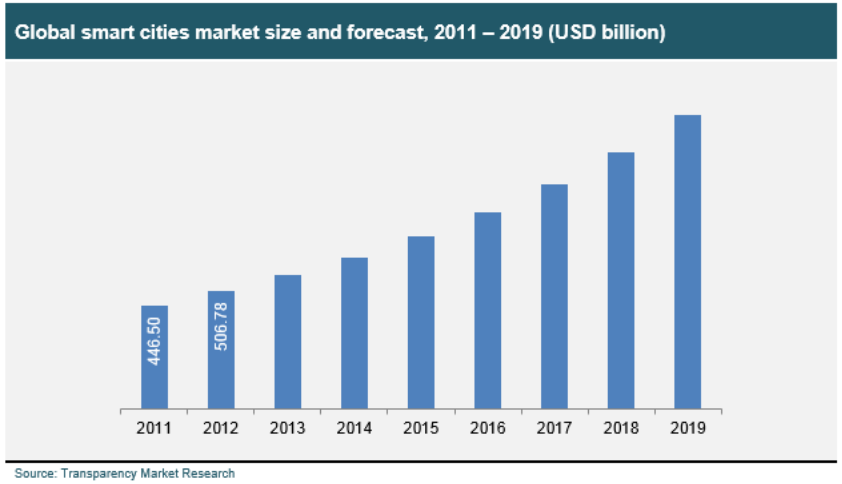
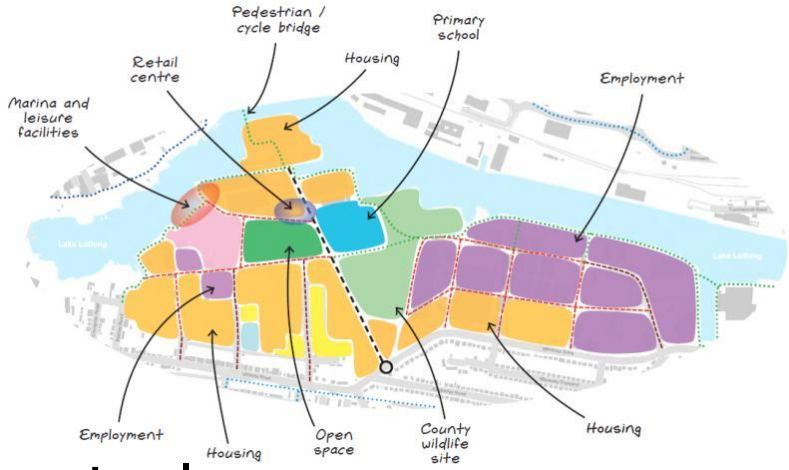


Chart 1.1 Annual Smart City Technology Investment by Region, Asia Pacific: 2014-2023





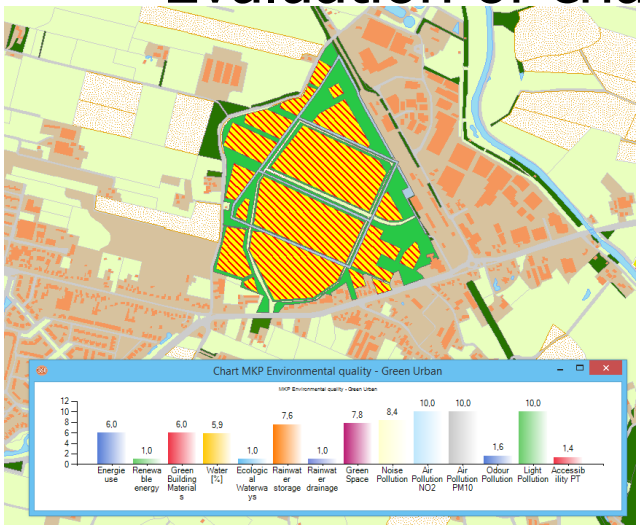
Urban Planning & Development



What do we need?

Pre & Post Processing tool
Evaluation of changes

How can we get it?

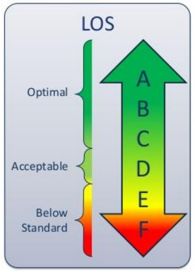


Problem Statement

- Road Modality
- Occupancy Patterns


choice
decisions
decision
making
dilemma
goal
why
strategy
answer
direction
planning
plan
problem
solution
where
process
smart
when
goals
what
how
analysis
question


SMARTRAFFIC


LOS
Optimal
Acceptable
Below Standard
A
B
C
D
E
F


FREE
ICE CREAM


PEDESTRIAN
SHOPS


THE BROADWAY
M&S

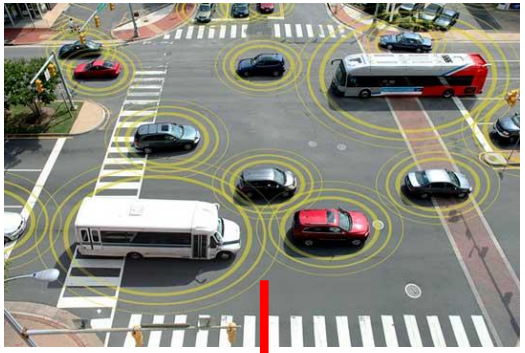

CLOSED

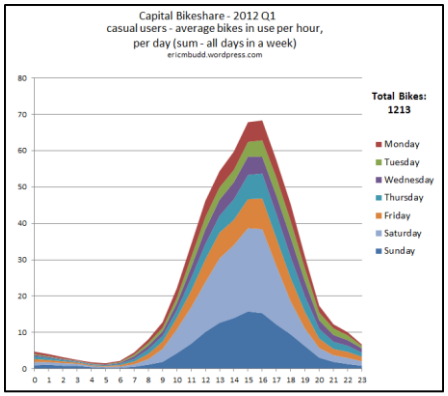
Problem Statement

- Road Modality
- Occupancy Patterns

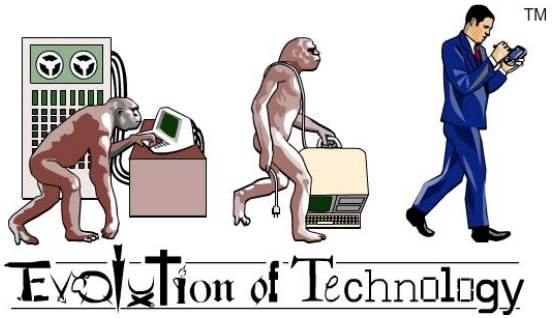
- Time consuming
- No real-time ability
- Many employees
- Difficult for big areas
- Difficult for 24/7
- Counting but not tracking

Internet of Things (IoT)

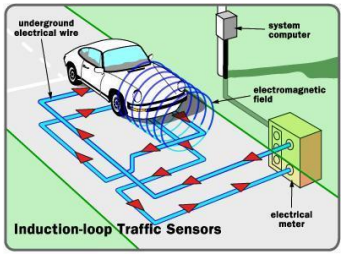


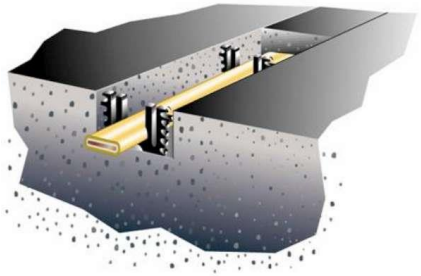


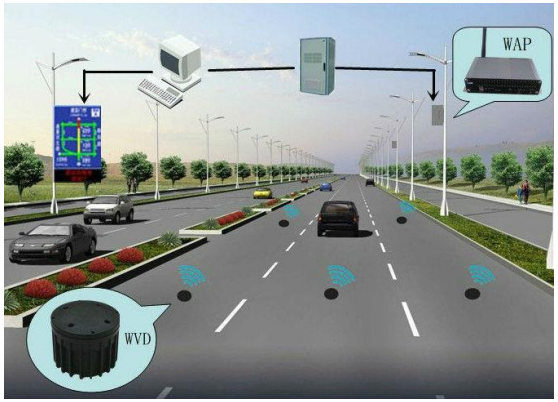
Solution(?): Technology

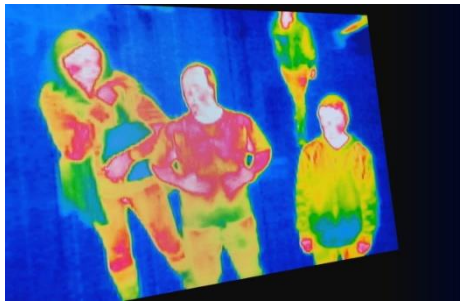


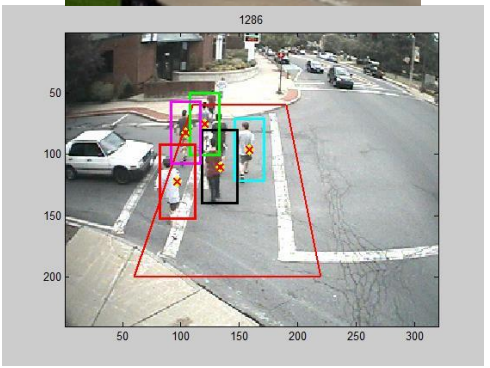
Overview of available Techniques







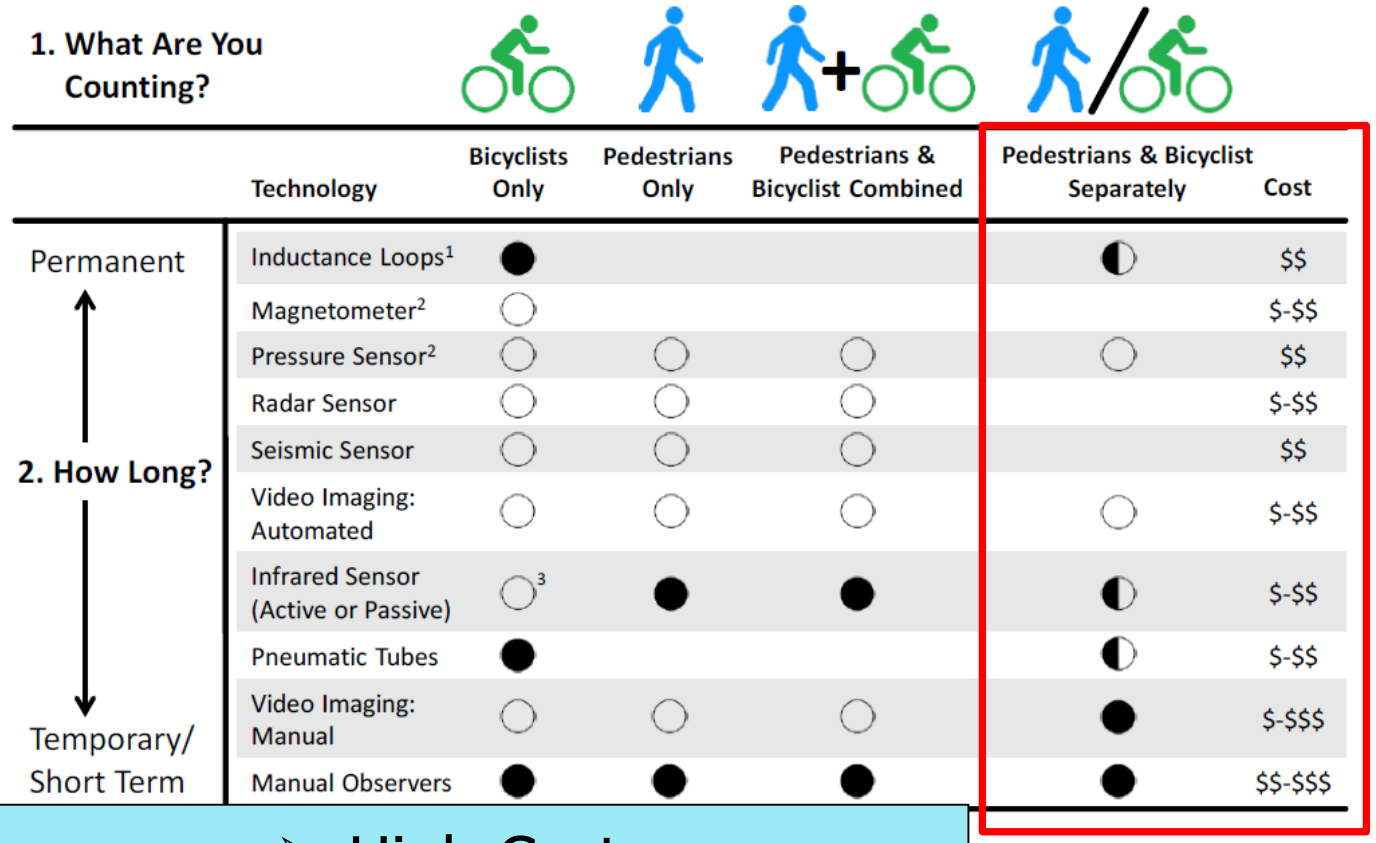




Overview of available Techniques

Technology	Typical Applications	Strengths	Weaknesses
Inductance Loop	Permanent counts Bicyclists only	Accurate when properly installed and configured Uses traditional motor vehicle counting technology	Capable of counting bicyclists only Requires saw cuts in existing pavement or pre-formed loops in new pavement construction May have higher error with groups
Magnetometer	Permanent counts Bicyclists only	May be possible to use existing motor vehicle sensors	Commercially-available, off-the-shelf products for counting bicyclists are limited May have higher error with groups
Pressure sensor/pressure mats	Permanent counts Typically unpaved trails or paths	Some equipment may be able to distinguish bicyclists and pedestrians	Expensive/disruptive for installation under asphalt or concrete pavement
Seismic sensor	Short-term counts on unpaved trails	Equipment is hidden from view	Commercially-available, off-the-shelf products for counting are limited
Radar sensor	Short-term or permanent counts Bicyclists and pedestrians combined	Capable of counting bicyclists in dedicated bike lanes or bikeways	Commercially-available off-the-shelf products for counting are limited
Video Imaging – Automated	Short-term or permanent counts Bicyclists and pedestrians separately	Potential accuracy in dense, high-traffic areas	Typically more expensive for exclusive installations Algorithm development still maturing
Infrared – Active	Short-term or permanent counts Bicyclists and pedestrians combined	Relatively portable Low profile, unobtrusive appearance	Cannot distinguish between bicyclists and pedestrians unless combined with another bicycle detection technology Very difficult to use for bike lanes and shared lanes May have higher error with groups

Overview of available Techniques



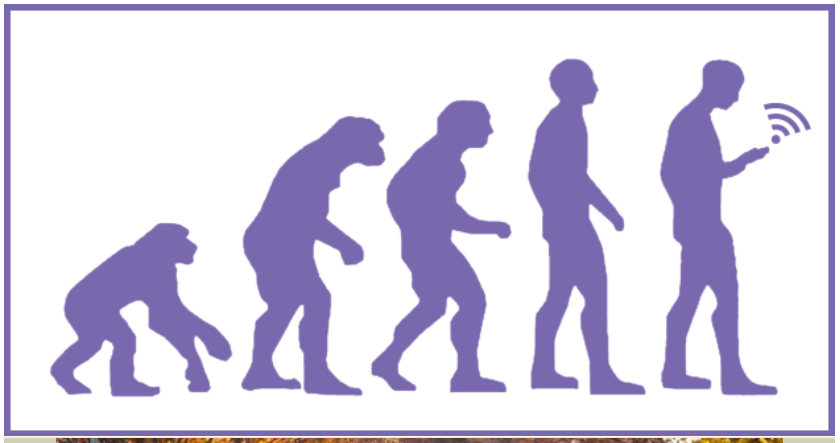
1. What Are You Counting?	Technology	Bicyclists Only	Pedestrians Only	Pedestrians & Bicyclist Combined	Pedestrians & Bicyclist Separately	Cost
Permanent	Inductance Loops[1]	●			◐	$$
	Magnetometer[2]	○				$-$$
	Pressure Sensor[2]	○	○	○	○	$$
	Radar Sensor	○	○	○		$-$$
	Seismic Sensor	○	○	○		$$
2. How Long?	Video Imaging: Automated	○	○	○	○	$-$$
	Infrared Sensor (Active or Passive)	○[3]	●	●	◐	$-$$
	Pneumatic Tubes	●			◐	$-$$
	Video Imaging: Manual	○	○	○	●	$-$$$
Temporary/ Short Term	Manual Observers	●	●	●	●	$$-$$$

- High Cost
- Counting
- Not Tracking

ists separately.

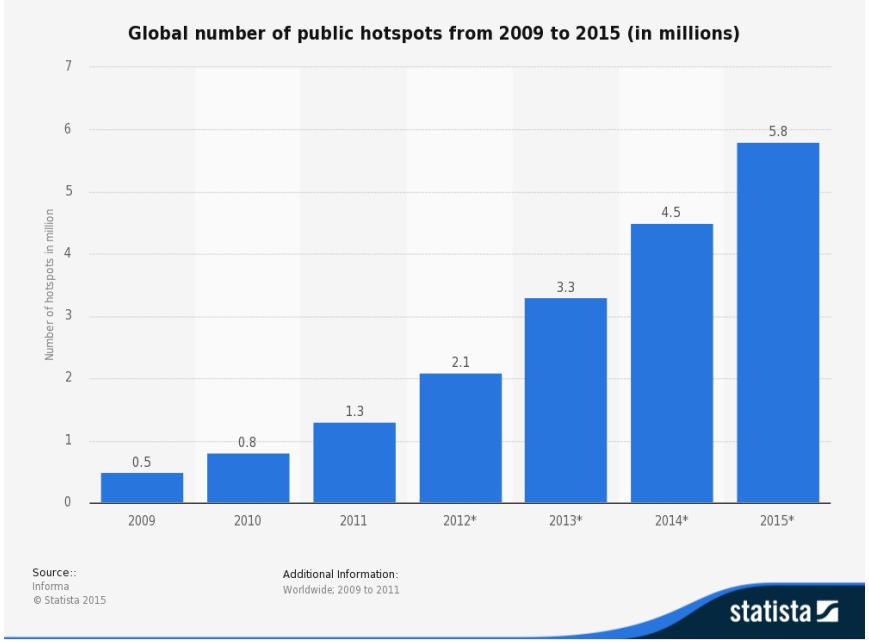
ed by bicyclists and motor vehicles.
ed, natural surface trails.
the sidewalk.

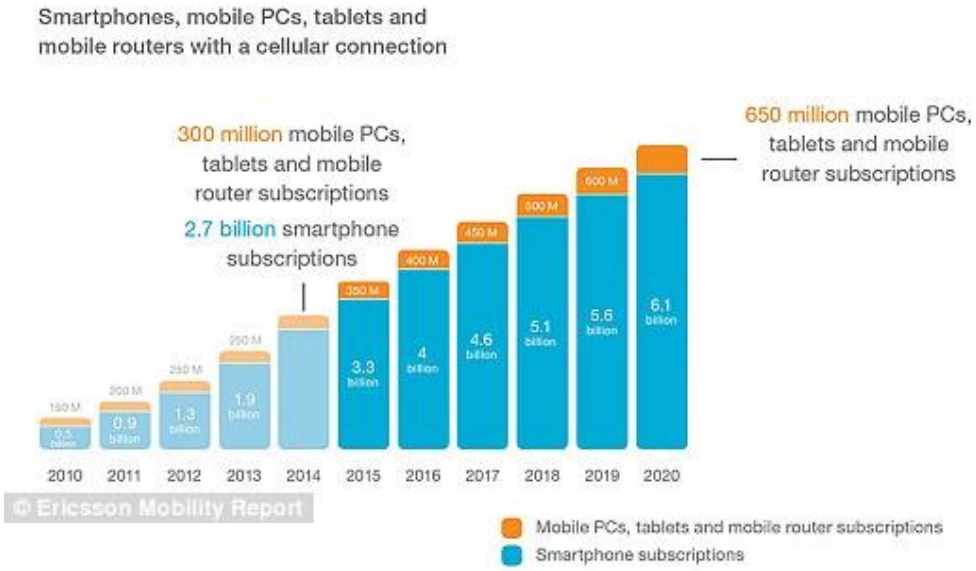
Solution(?): Technology (Wi-Fi monitoring)



Evolution of Technology

Why this method?



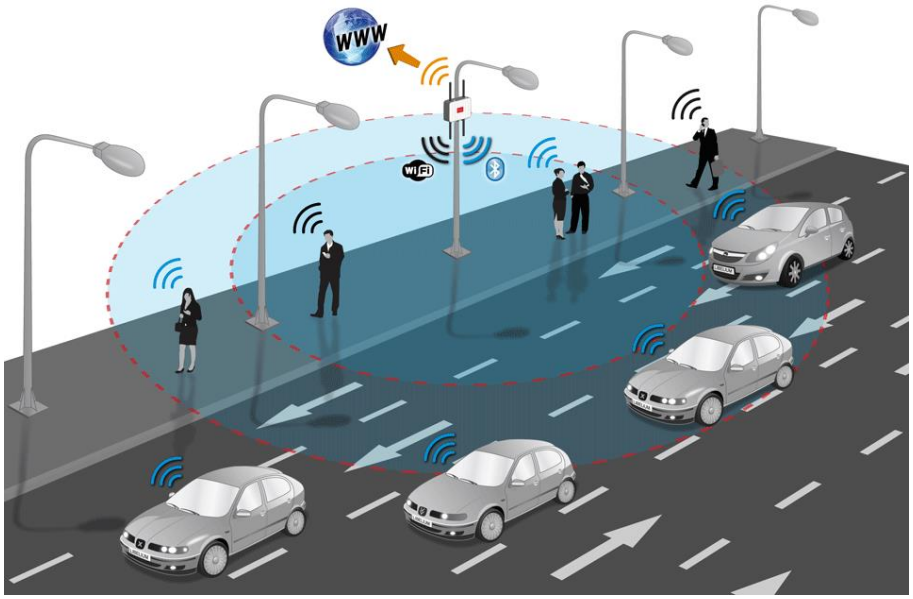


Why this method?

- More free Wi-Fi networks, more smartphones→ More reliable outcomes
- No need for extra system placement (extra cost)
- Ability to count but also to "follow" (use of MAC address)
- Ability to have real-time data and thus real-time system
- No need for data access request (like GPS providers)

Summary

- Increase of citizens and vehicles number
- Need for better monitoring and taking advance of space (Smart Cities)
- Need for information/meta-data: Road modality, occupancy patterns
- Old-fashioned ways of collection
- Rapid improve of technology



Research Question-Challenge

What kind of road modality and occupancy patterns can be recognized by Wi-Fi monitoring sensors in a city area in order to support the "Smart City" concept?

Sub-questions

- What is the influence of the Wi-Fi monitoring setup?
- What are the performance parameters of Wi-Fi monitoring and how we can measure them?

- What kind of movement patterns can be recognized by the Wi-Fi monitoring system?

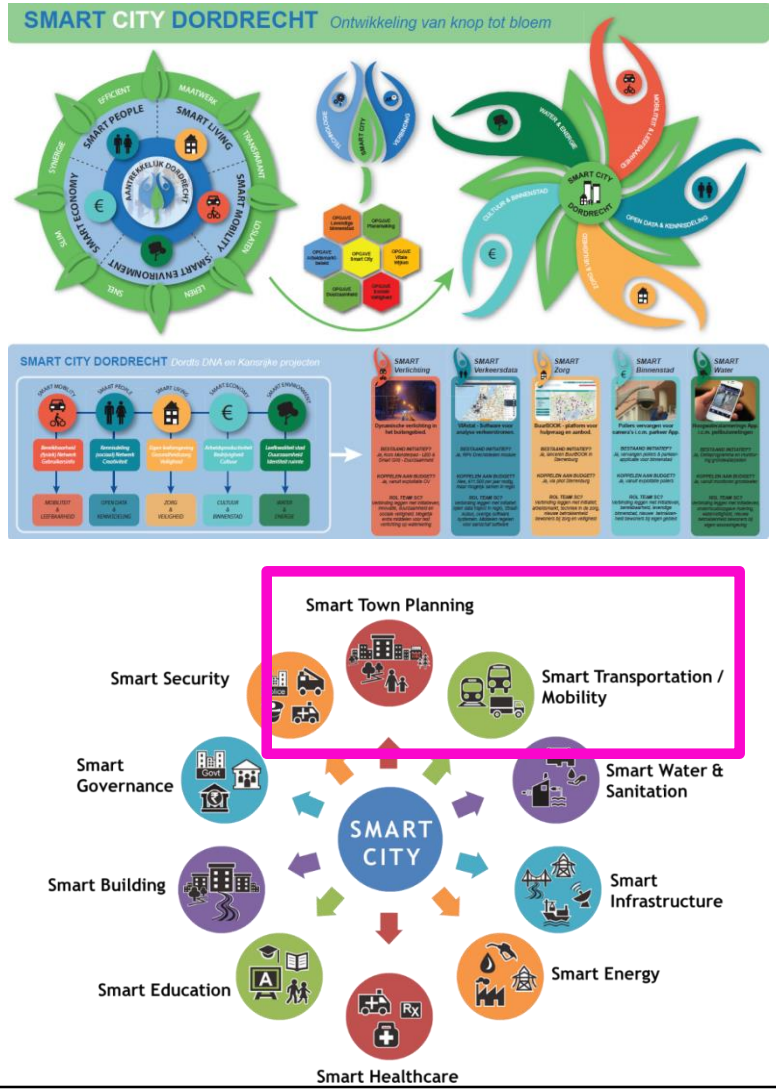
- What is the road modality in the researched area of Dordrecht during different times of day and month?
- What kind of road modality can be recognized by the Wi-Fi monitoring system?

- What is occupancy pattern in the researched area of Dordrecht during different times of day and month?
- Which occupancy patterns can be recognized by the Wi-Fi monitoring system?
- Is it possible to identify the effect of the weather to the road modality?

Applied Area

Municipality of Dordrecht

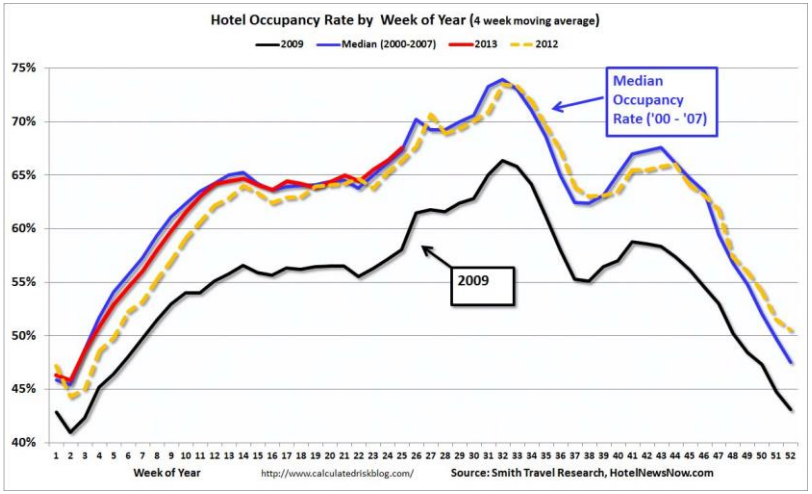
Why there?


SMART CITY DORDRECHT
Ontwikkeling van knop tot bloem
SMART CITY DORDRECHT
Dordts DNA en Kansrijke projecten
Smart Town Planning
Smart Security
Smart Transportation / Mobility
Smart Governance
Smart Water & Sanitation
SMART CITY
Smart Building
Smart Infrastructure
Smart Education
Smart Energy
Smart Healthcare


URBAN PLANNING
By 2050 the world will have undergone the largest and fastest period of urban expansion in human history: The urban population is estimated to double.
PROBLEMS
"London: 640 million litres water a day wasted"
"500 or more new cities by 2050"
Scarce Resources
"By 2050 total urban area is projected to TRIPLE"
"In East Asia alone, 500 million people will become urban residents over the next 25 years"
CHALLENGES
World Urban Population
2011
3.6 Billion
2050
6.3 Billion
How to plan better cities?
Real Time Data Harvesting
Increase Resource Efficiency
Sustainable Development
Find out more at http://www.
Published by the Documentation Committee, Universiti Teknologi MARA (UiTM) for GES2014, Kuala Lumpur, Malaysia

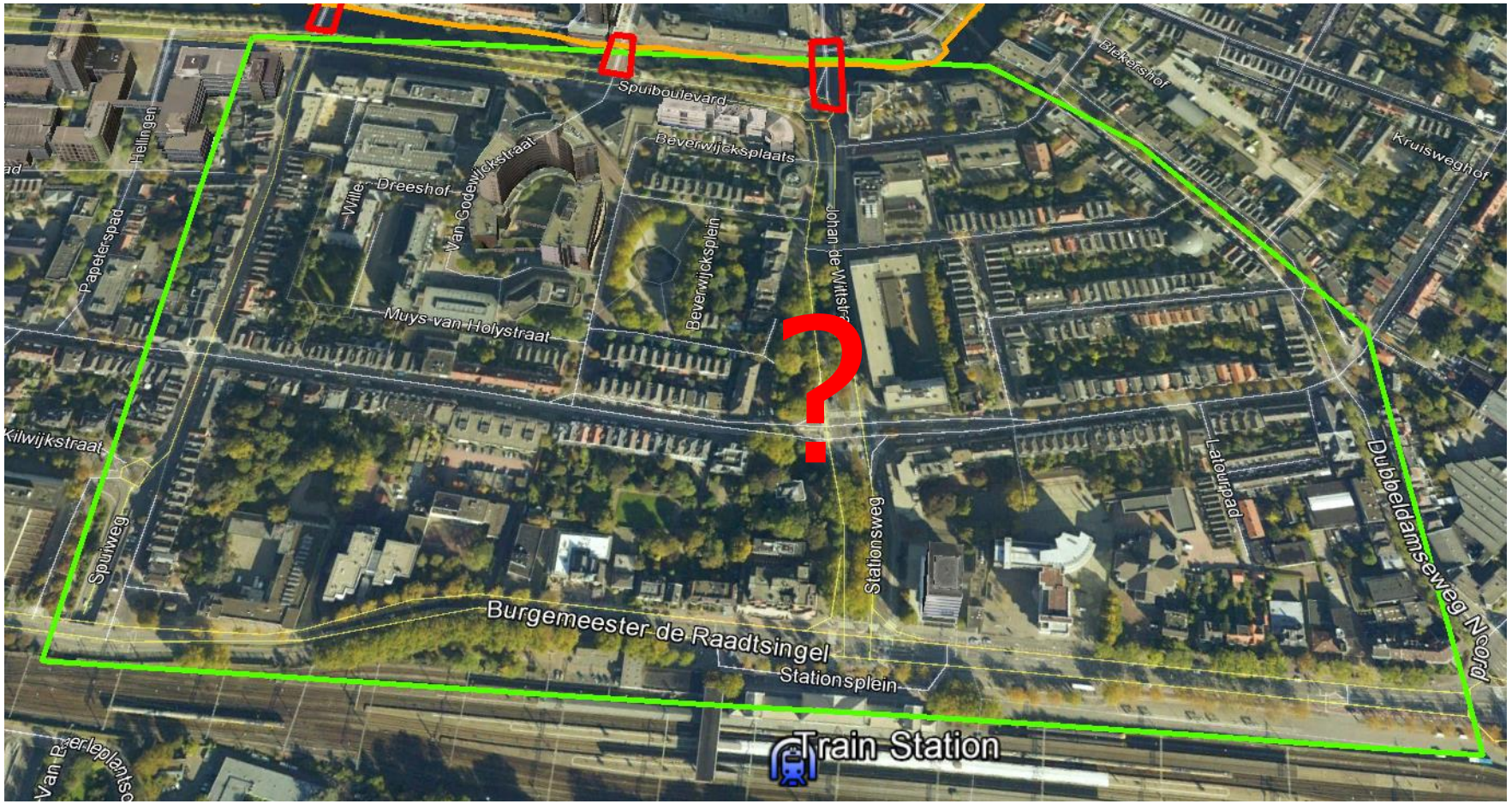
Why there?

Rebuild the area - Smart Planning

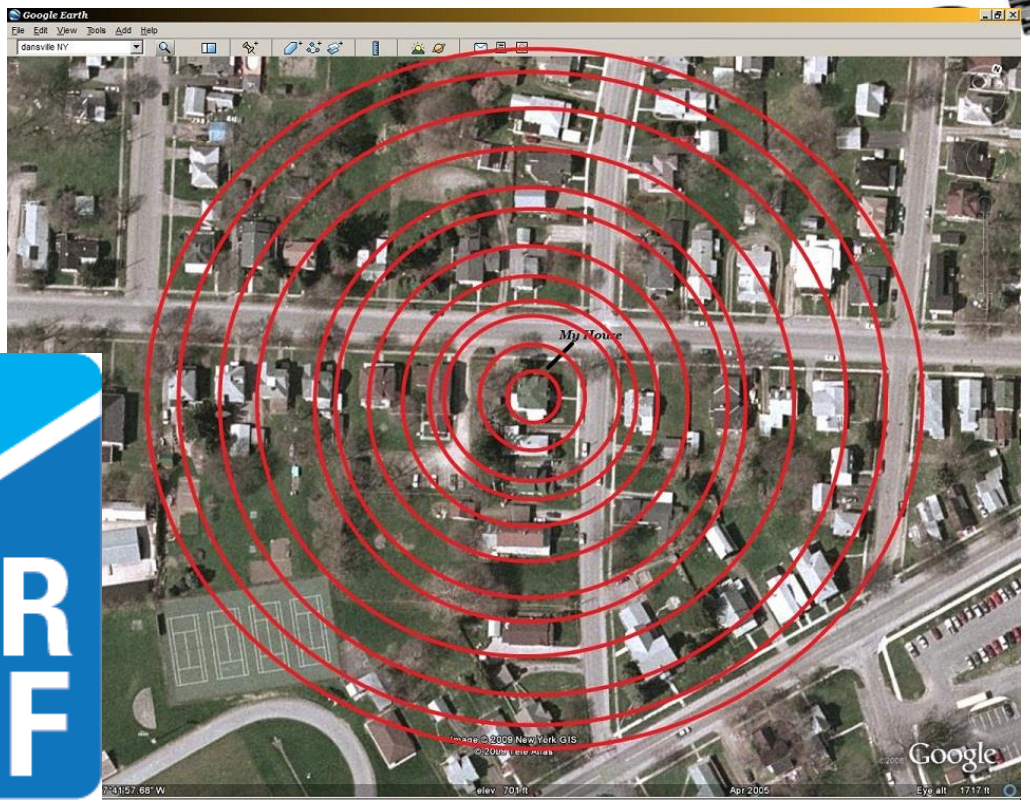


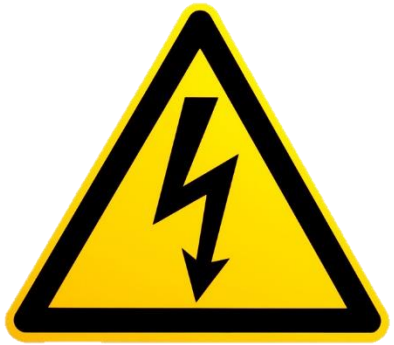
Pre & Post- Processing Tool
Evaluation of Planning

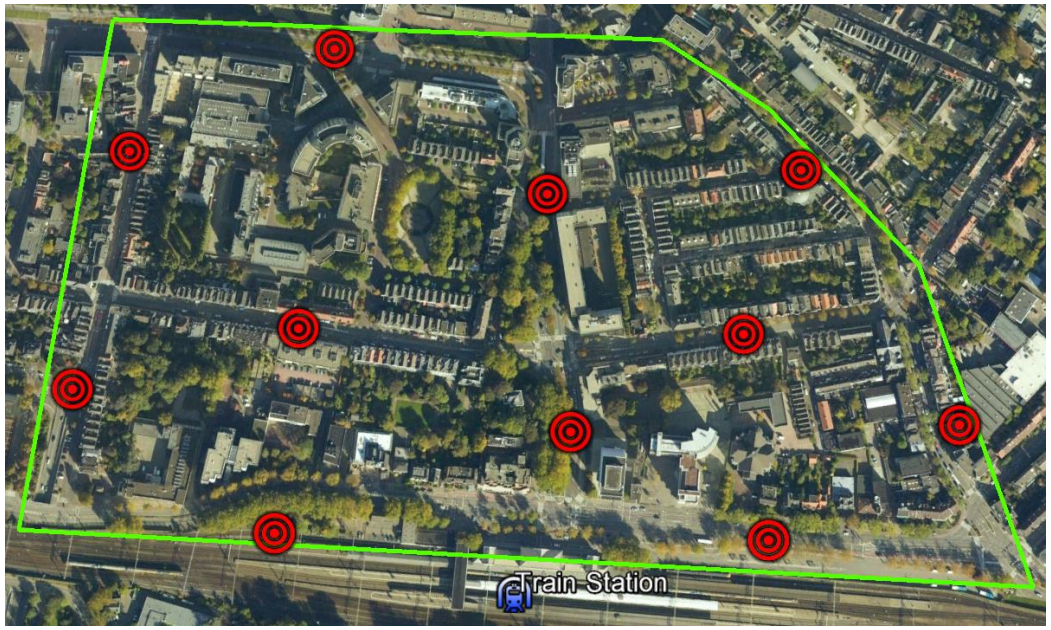
Observation network



Observation network

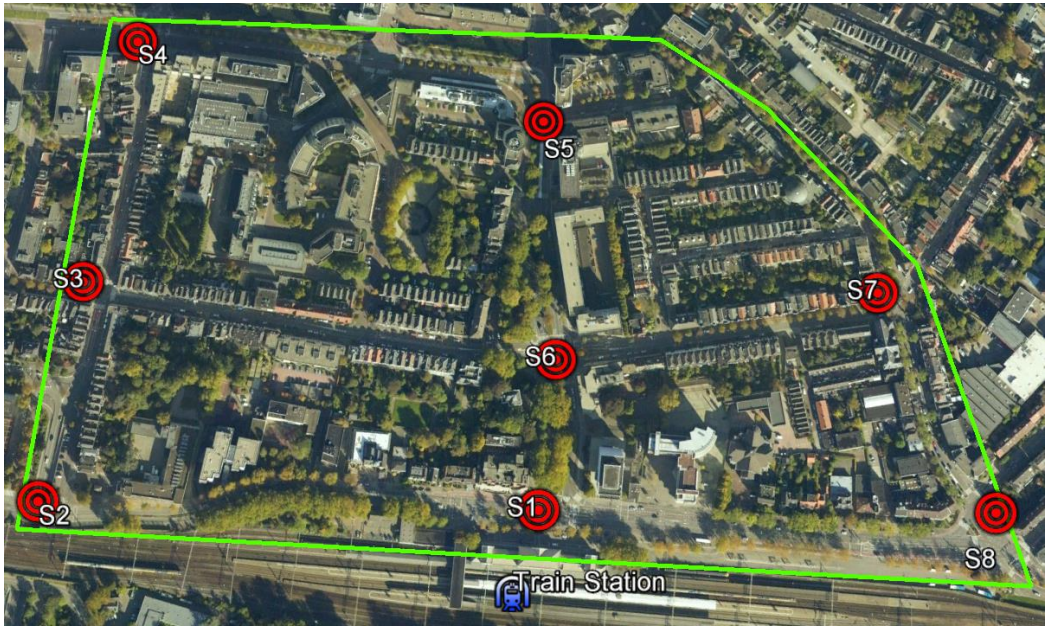






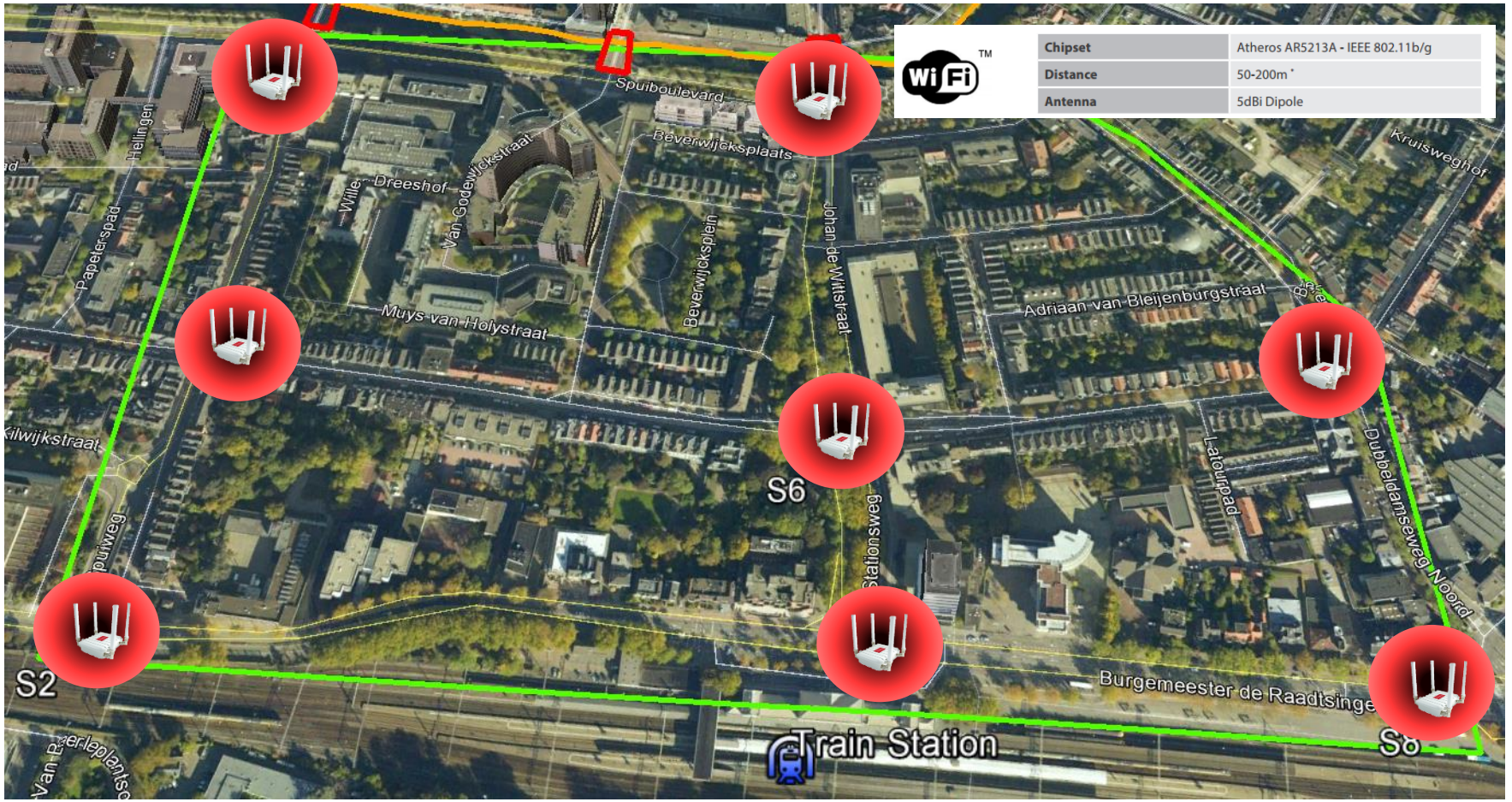
- Location of scanned device
- Fewer sensors in case of most crowded streets study

- Less sensors
- Separate study of each street



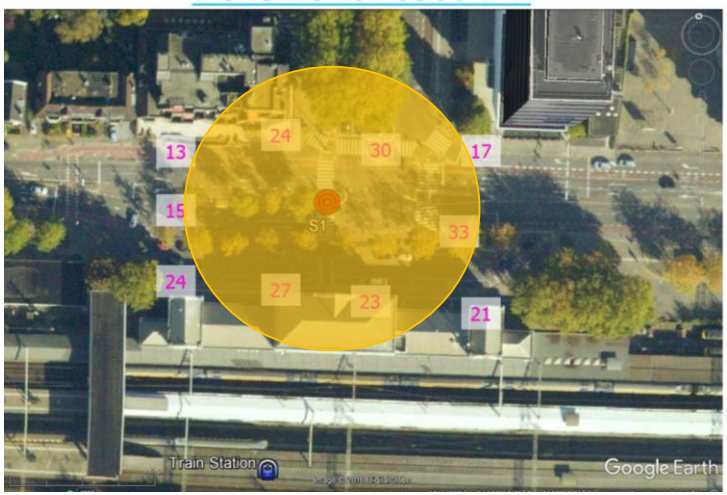
Observation network

Zero-level test

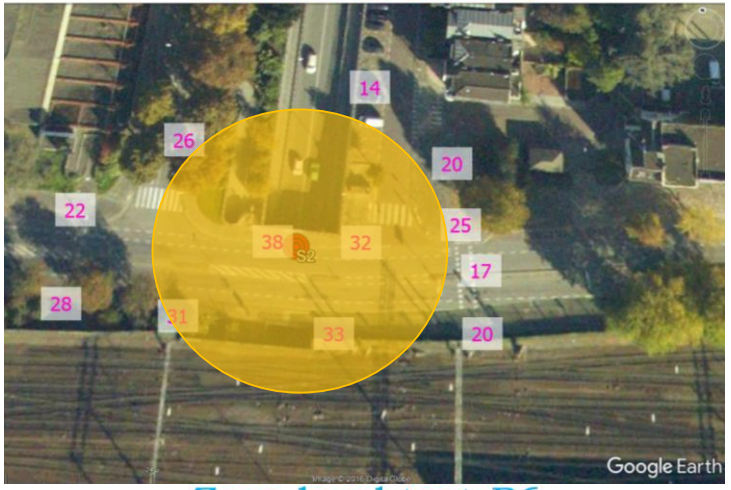


Zero-level test

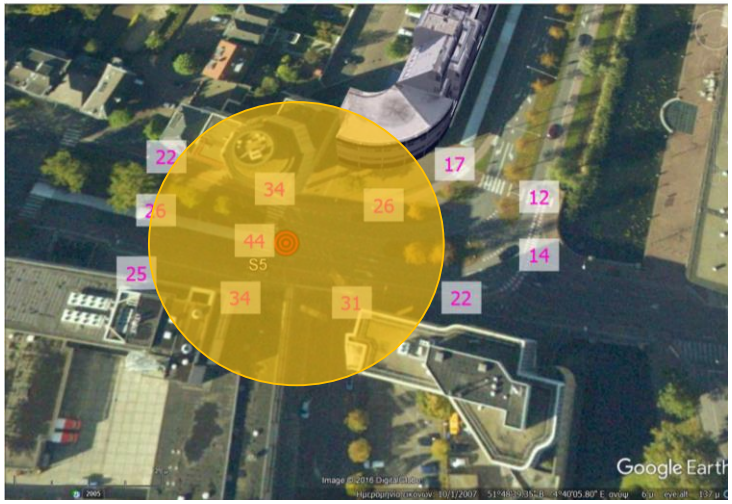
Zero-level test-P1



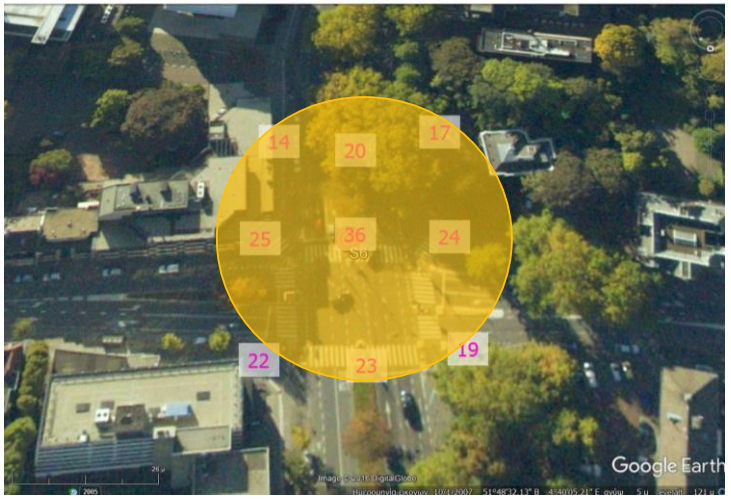
Zero-level test-P2



Zero-level test-P5

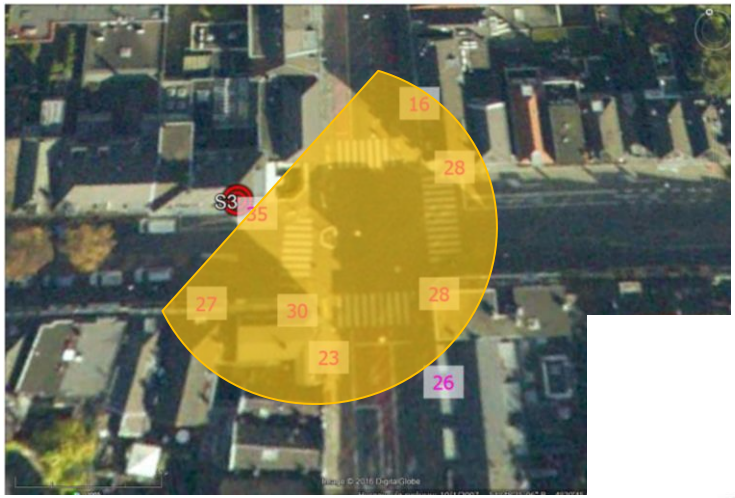


Zero-level test-P6



Zero-level test

Zero-level test-P3

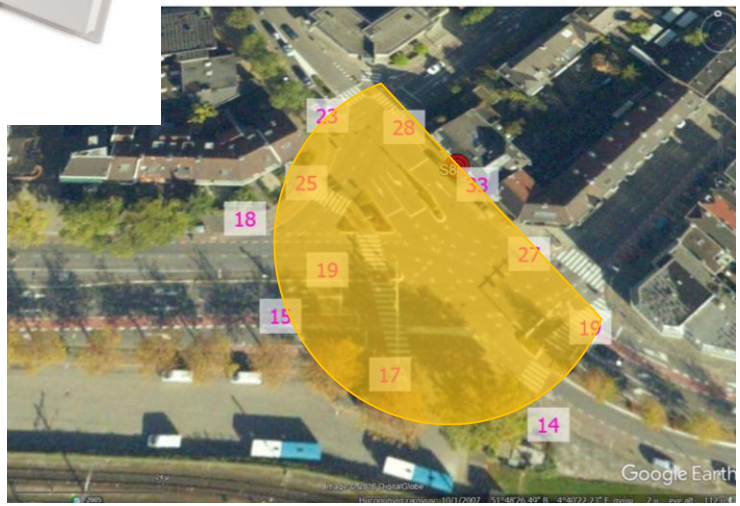


Zero-level test-P4

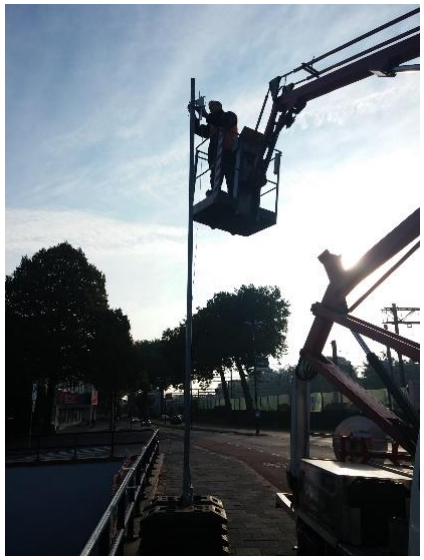
Figure : Directional antenna for Meshlium Scanner

Zero-level test-P7

Zero-level test-P8



Overview



Data collection

Date	S1	S2	S3	S4	S5	S6	S7	S8	Weather
13/9/2016			Installation				Installation		Download
14/9/2016	Installation	Installation		Installation	Installation	Installation		Installation	Download
15/9/2016			Download-Update	Download-Update			Download-Update	Download-Update	Download
16/9/2016	Download-Update	Download-Update	Download-Update	Download-Update	Download-Update	Download-Update	Download-Update	Download-Update	Download
17/9/2016									Download
18/9/2016									Download
19/9/2016	Download-Update	Download-Update	Download-Update	Download-Update	Download-Update	Download-Update	Download-Update	Download-Update	Download
20/9/2016									Download
21/9									Download
22/9									Download
23/9									Download
24/9									Download
25/9									Download
26/9									Download
27/9									Download
28/9									Download
29/9/2016									Download
30/9/2016	Download-Update	Download-Update	Download-Update	Download-Update	Download-Update	Download-Update	Download-Update	Download-Update	Download
1/10/2016									Download
2/10/2016									Download
3/10/2016	Download-Update	Download-Update	Download-Update	Download-Update	Download-Update	Download-Update	Download-Update		Download
4/10/2016								Download-Update	Download
5/10/2016									Download
6/10/2016	Download-Update	Download-Update	Download-Update	Download-Update	Download-Update	Download-Update	Download-Update	Download-Update	Download
7/10/2016									Download
8/10/2016	Download-Update	Download-Update	Download-Update	Download-Update	Download-Update	Download-Update	Download-Update	Download-Update	Download
9/10/2016									Download
10/10/2016	Download-Update	Download-Update	Download-Update	Download-Update	Download-Update	Download-Update	Download-Update	Download-Update	Download
11/10/2016									Download
12/10/2016									Download
13/10/2016	Download-Update	Download-Update	Download-Update	Download-Update	Download-Update	Download-Update	Download-Update	Download-Update	Download
14/10/2016	Download-Update	Download-Update	Download-Update	Download-Update	Download-Update	Download-Update	Download-Update	Download-Update	Download

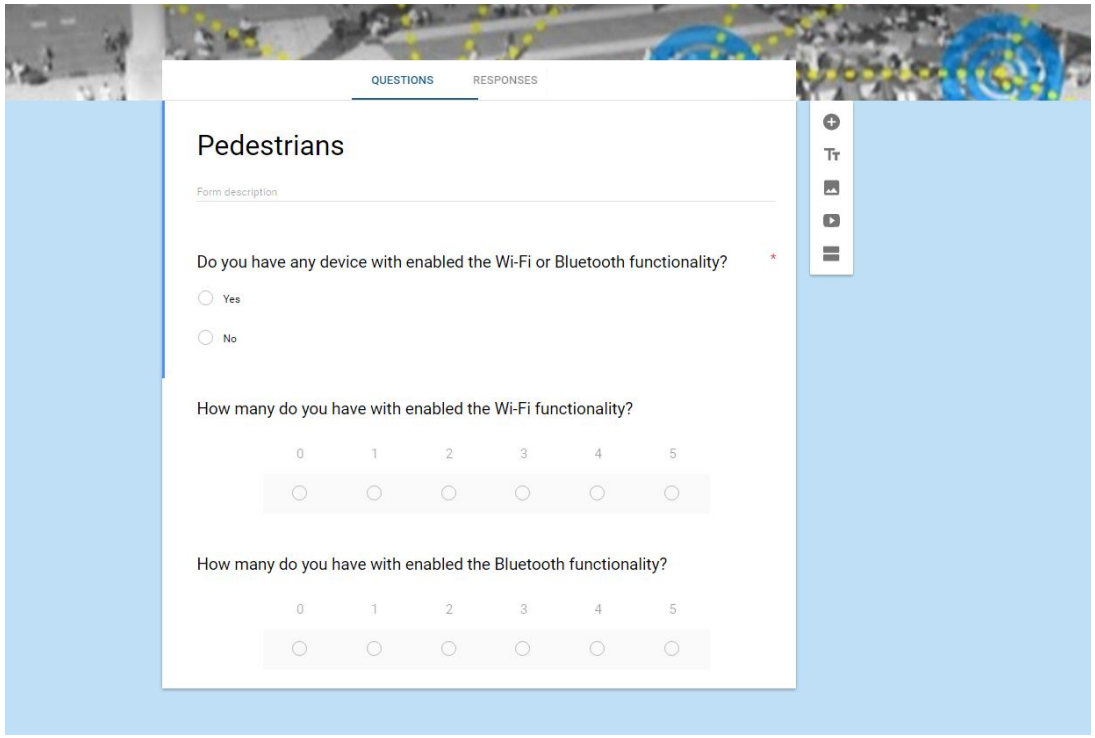
Data Output | Explain | Messages | History

	id_frame integer	timestamp timestamp without time zone	mac character varying(17)	ssid character varying(32)	rssi character varying(3)
1	18498390	2016-10-12 23:59:42	A0:EC:80:47:6D:FC	H368N476DFC	3
2	18498380	2016-10-12 23:59:42	00:1D:68:70:EC:47	SpeedTouchvanBram	7
3	18498476	2016-10-12 23:59:42	88:03:55:C2:6C:01	KPN Fon	33
4	18498471	2016-10-12 23:59:42	00:1D:AA:E2:8F:68	VFNL-E28F68	25

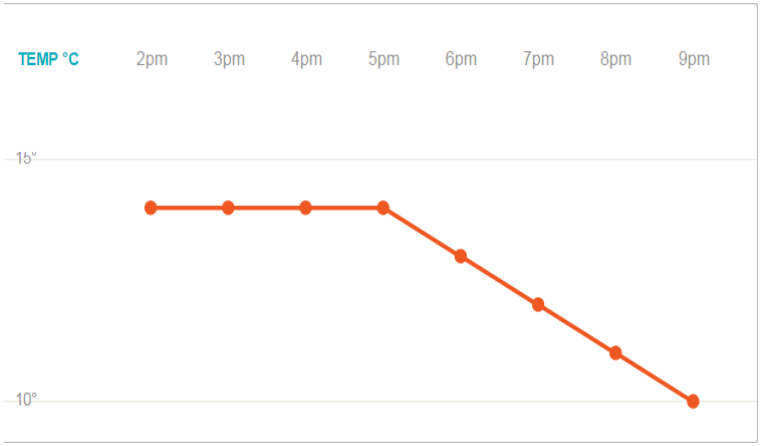
Dordrecht Cameras & RMC Data

Dordrecht Cameras & RMC Data

Questionnaire & Weather

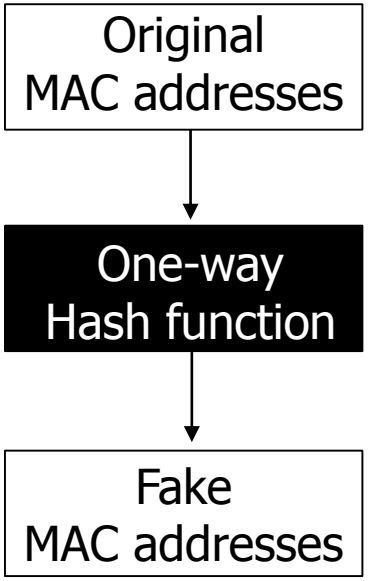


SATURDAY	2pm	3pm	4pm	5pm	6pm	7pm	8pm	9pm
Forecast	Showers	Partly Cloudy	Showers	Partly Cloudy	Partly Cloudy	Partly Cloudy	Cloudy	Cloudy
Temp (°C)	14°	14°	14°	14°	13°	12°	11°	10°
RealFeel®	12°	13°	12°	12°	11°	10°	10°	10°
Wind (km/h)	13 NE	13 NE	13 NE	13 NNE	11 NNE	11 NNE	7 NNE	7 NNE

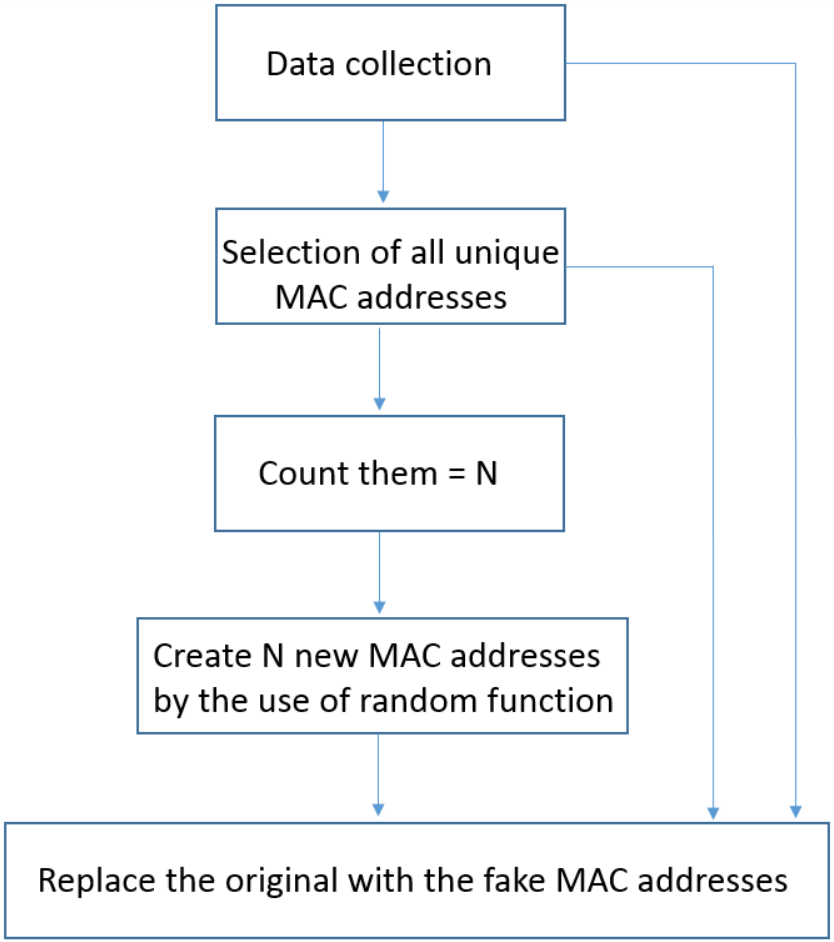


Data preparation & analysis

-Hashing of MAC addresses



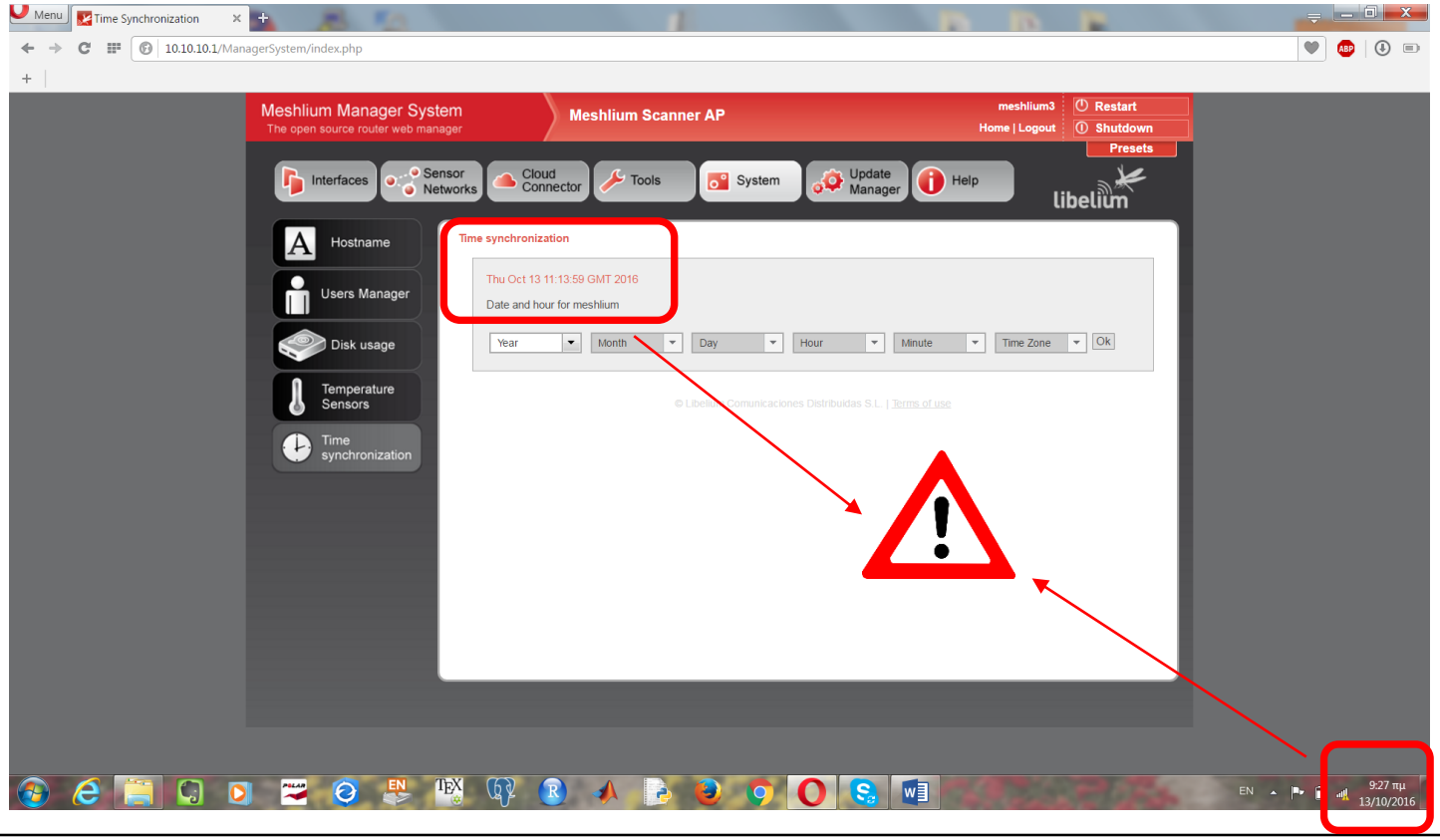
One-way hash function



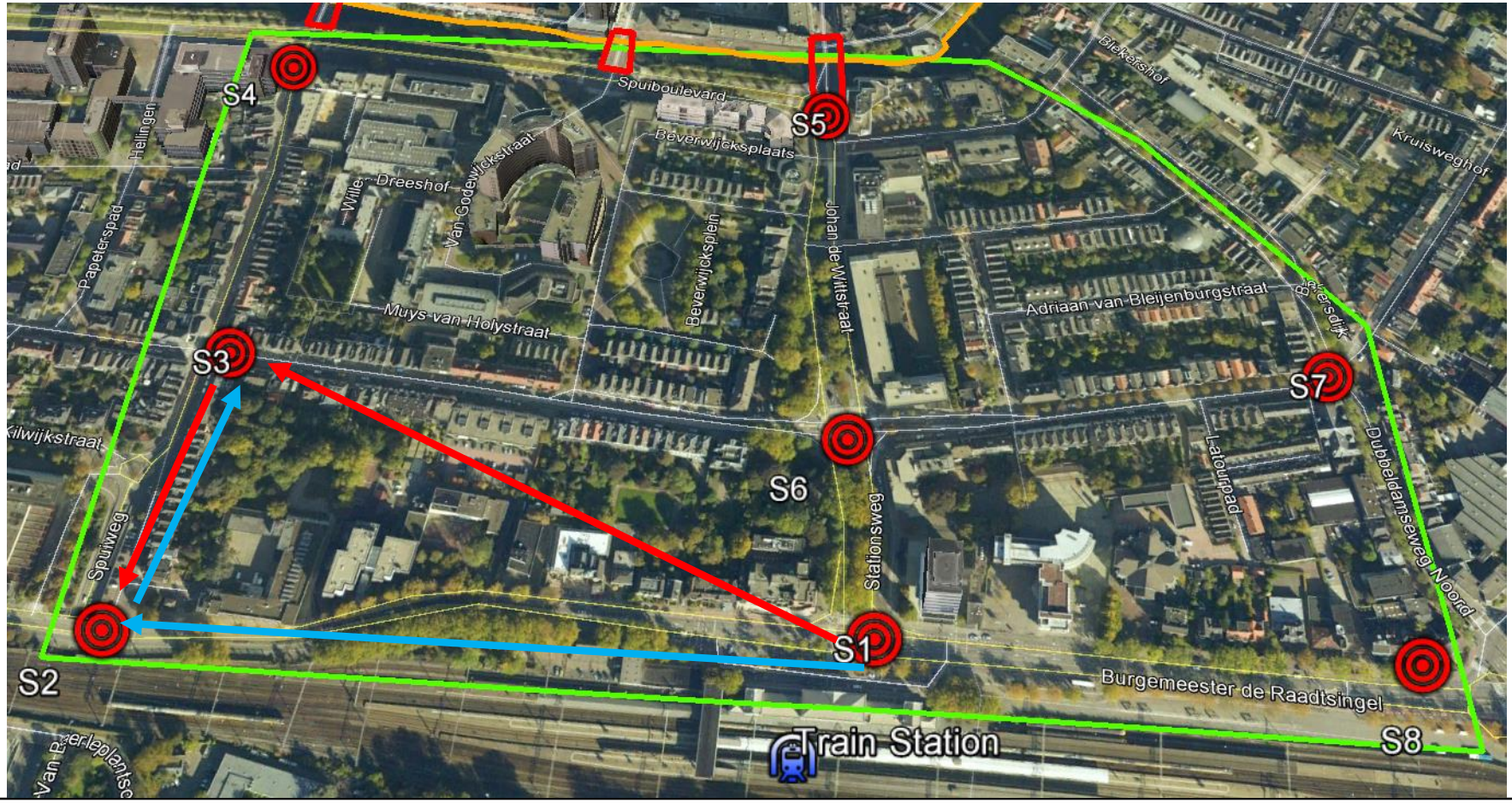
Correction of record time

Data Output | Explain | Messages | History

	id_frame integer	timestamp timestamp without time zone	mac character varying(17)	ssid character varying(32)	rssi character varying(3)
1	18498390	2016-10-12 23:59:42	A0:EC:80:47:6D:FC	H368N476DFC	3
2	18498380	2016-10-12 23:59:42	00:1D:68:70:EC:47	SpeedTouchvanBram	7
3	18498476	2016-10-12 23:59:42	88:03:55:C2:6C:01	KPN Fon	33
4	18498471	2016-10-12 23:59:42	00:1D:AA:E2:8F:68	VFNL-E28F68	25

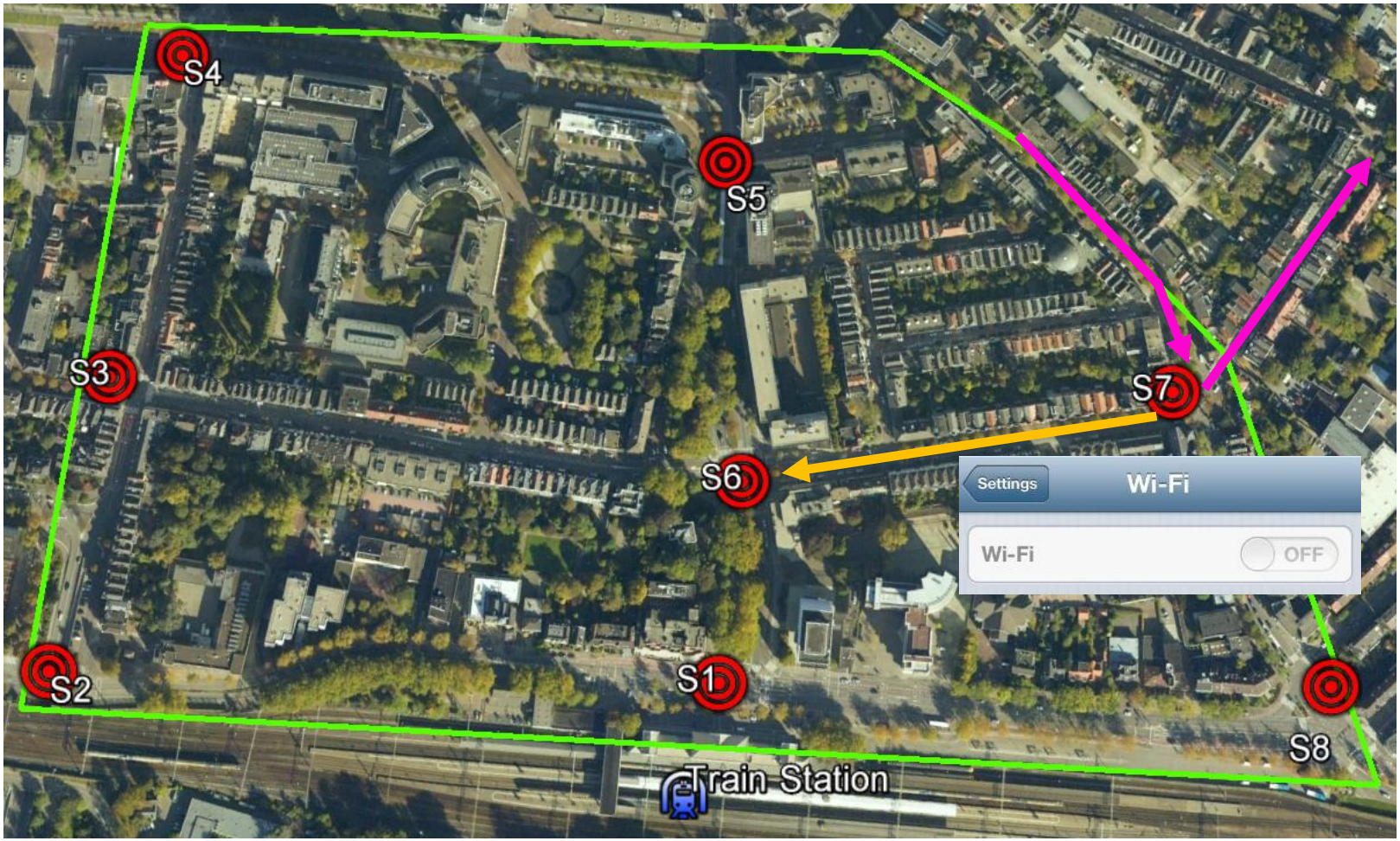


Correction of record time

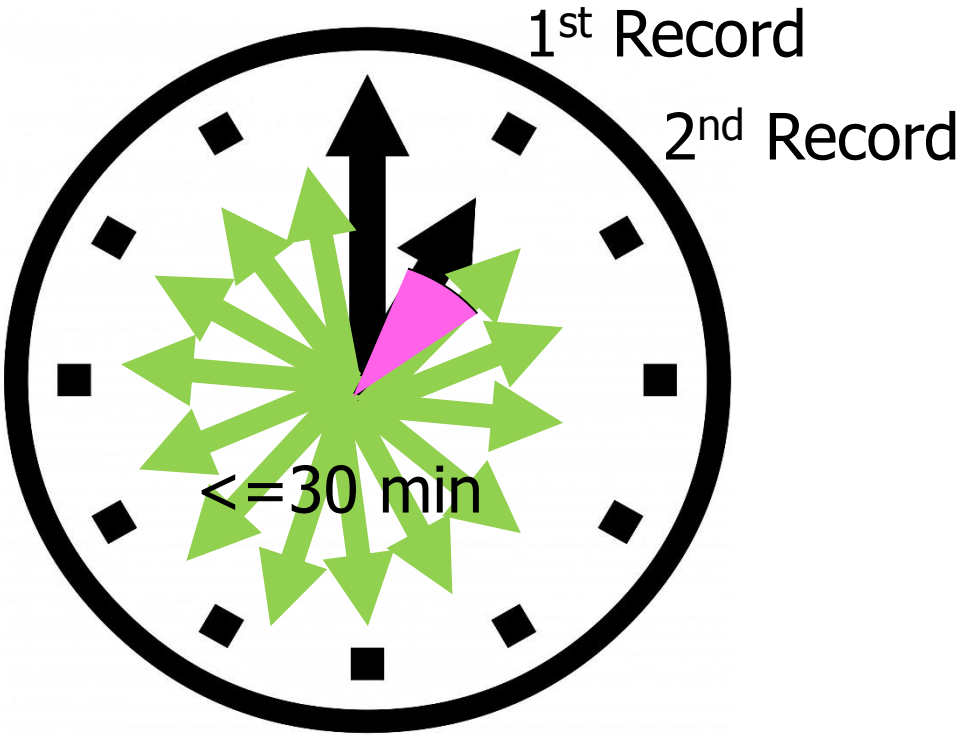


Filtering

-Devices which were scanned by only one sensor


S4
S5
S3
S7
S6
Settings
Wi-Fi
Wi-Fi
OFF
S2
S1
S8
Train Station

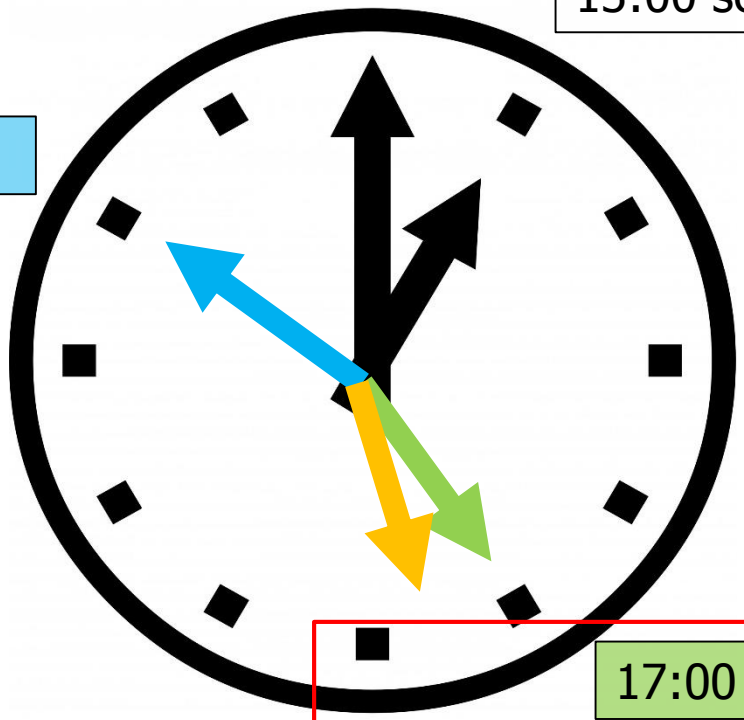
-Devices which were continuously scanned for a period longer than twelve hours



-Records whose time difference is longer than two hours

13:00 scanned by sensor1

22:00 scanned by sensor3



17:00 scanned by sensor2

17:30 scanned by sensor4

-Records with negative signal strength indicator (RSSI)

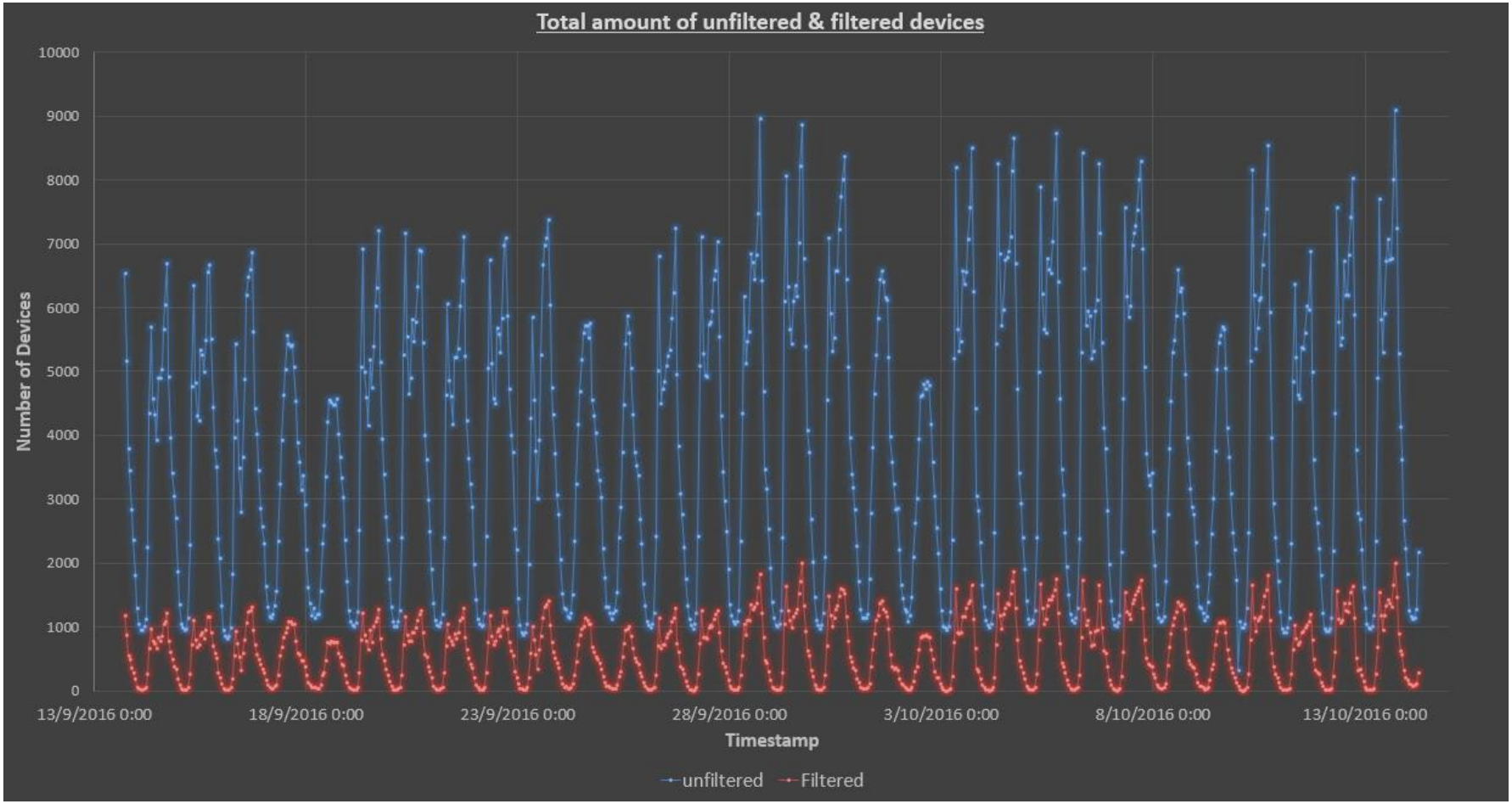
IEEE 802.11

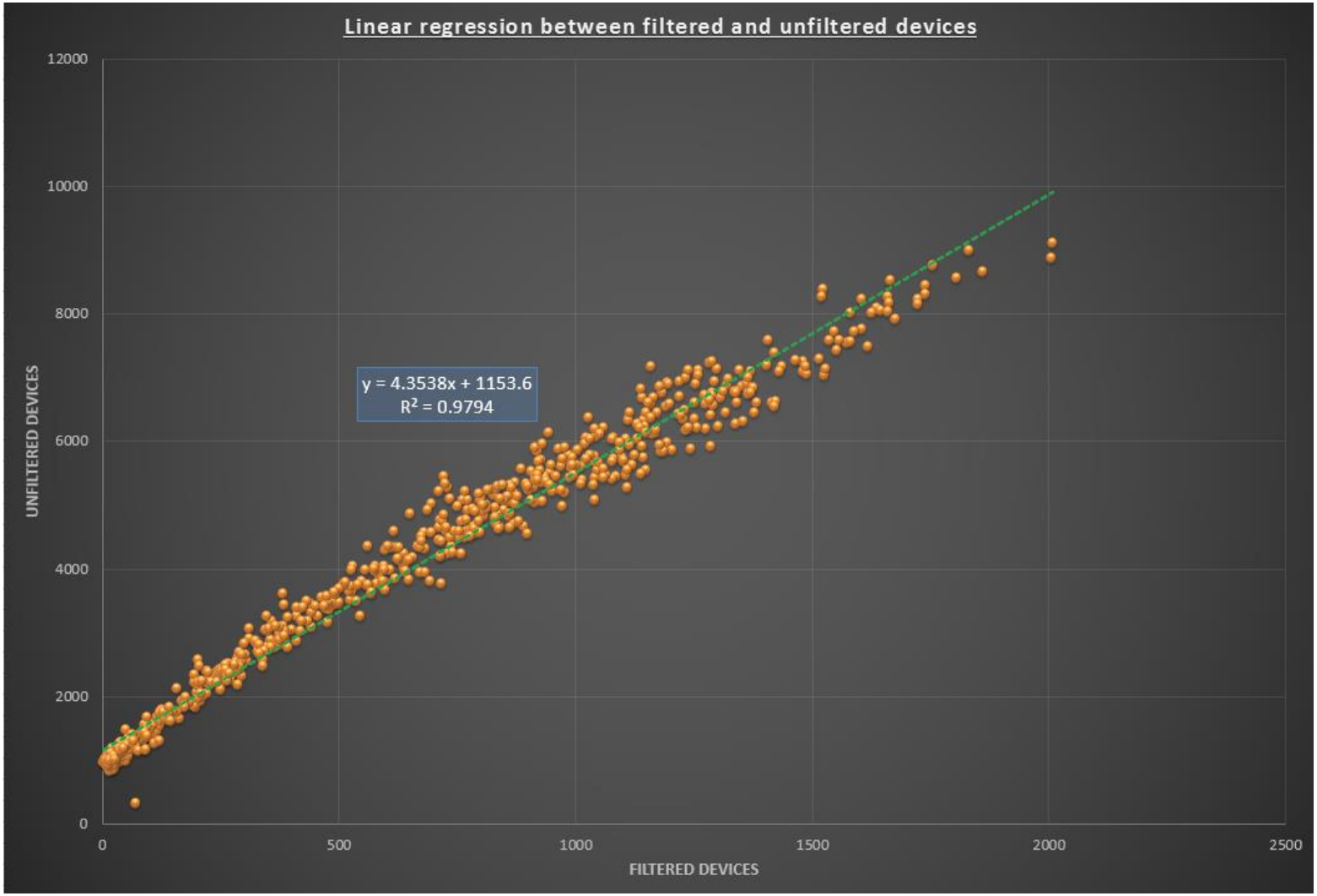
Signal strength of the wireless network:[-100,-10] dBm

RSSI: [0,255] arbitrary units

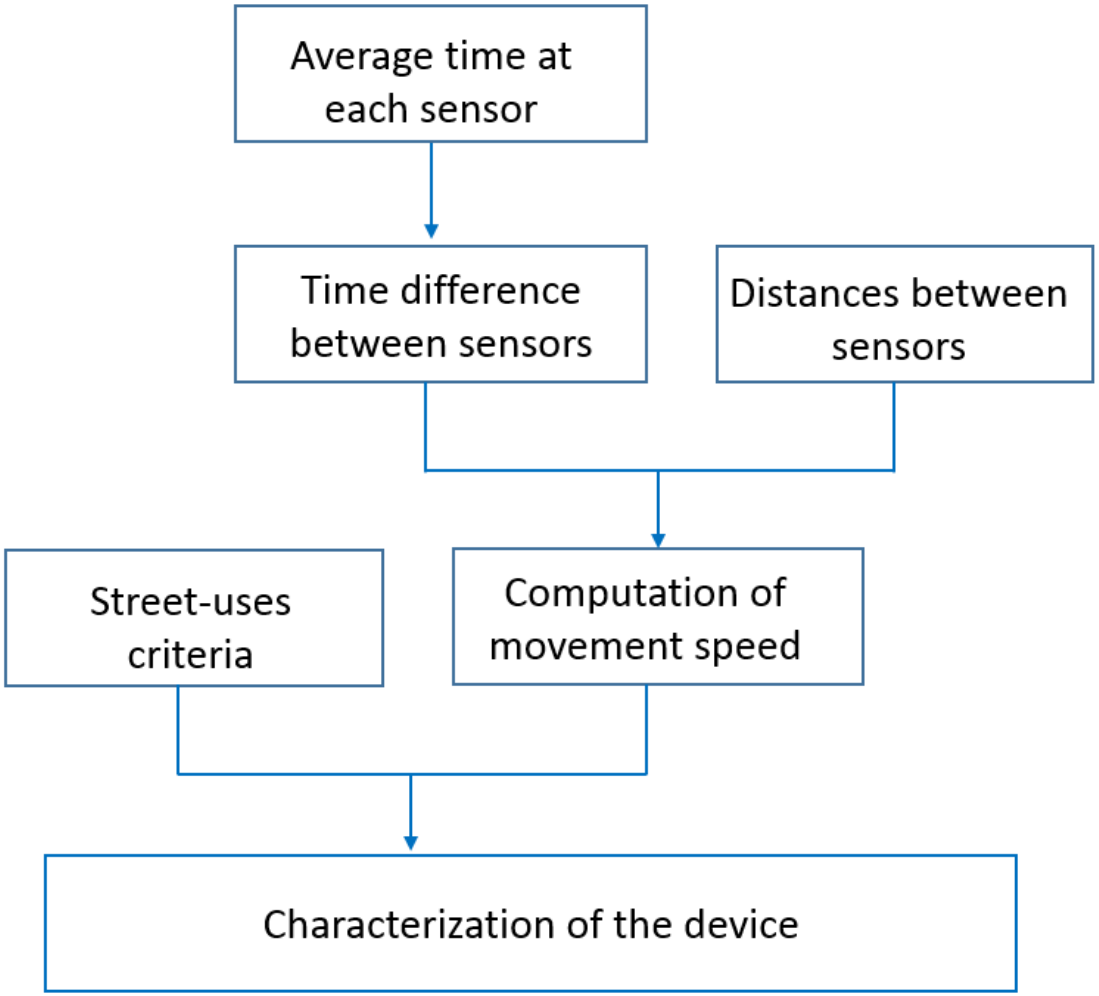
Cisco systems: [0,100]

Atheros: [0,127]
128= invalid value

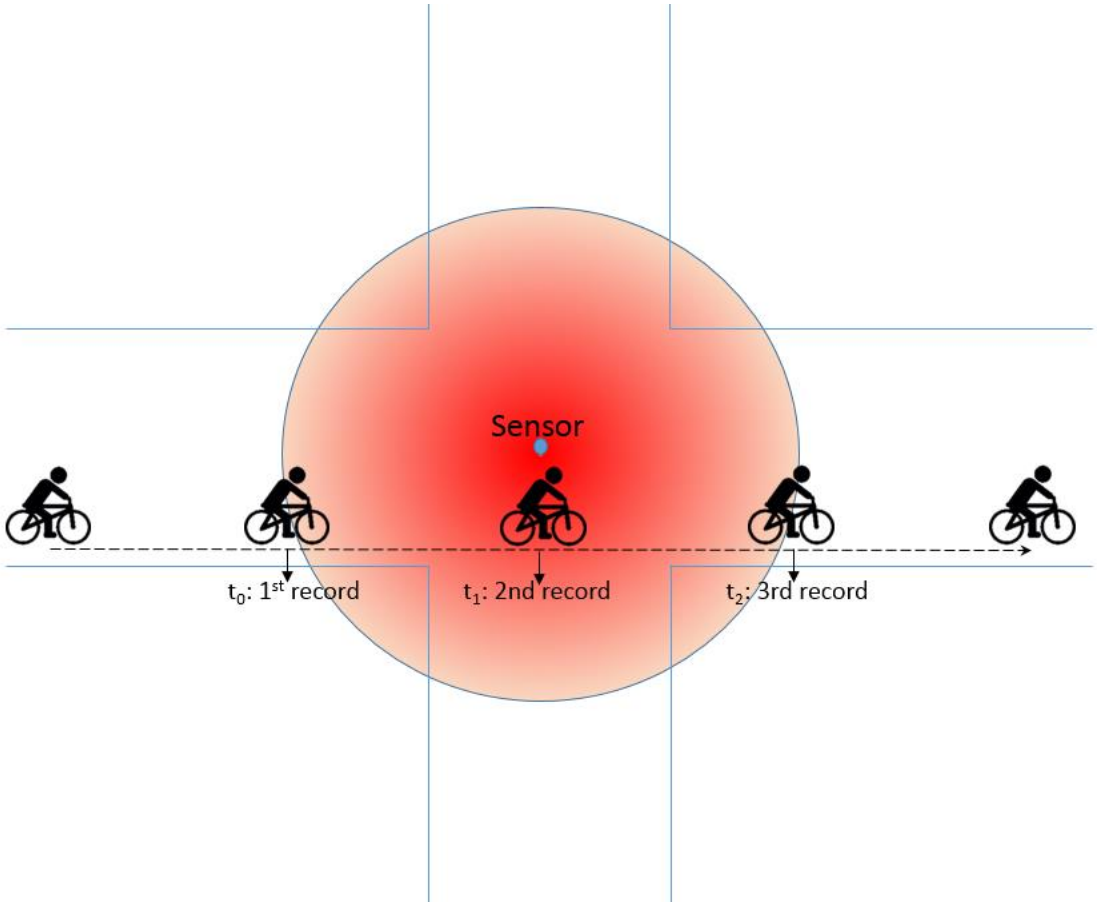

Total amount of unfiltered & filtered devices
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Number of Devices
13/9/2016 0:00
18/9/2016 0:00
23/9/2016 0:00
28/9/2016 0:00
3/10/2016 0:00
8/10/2016 0:00
13/10/2016 0:00
Timestamp
unfiltered
Filtered


Linear regression between filtered and unfiltered devices
12000
10000
8000
6000
4000
2000
0
UNFILTERED DEVICES
y = 4.3538x + 1153.6
R² = 0.9794
0
500
1000
1500
2000
2500
FILTERED DEVICES

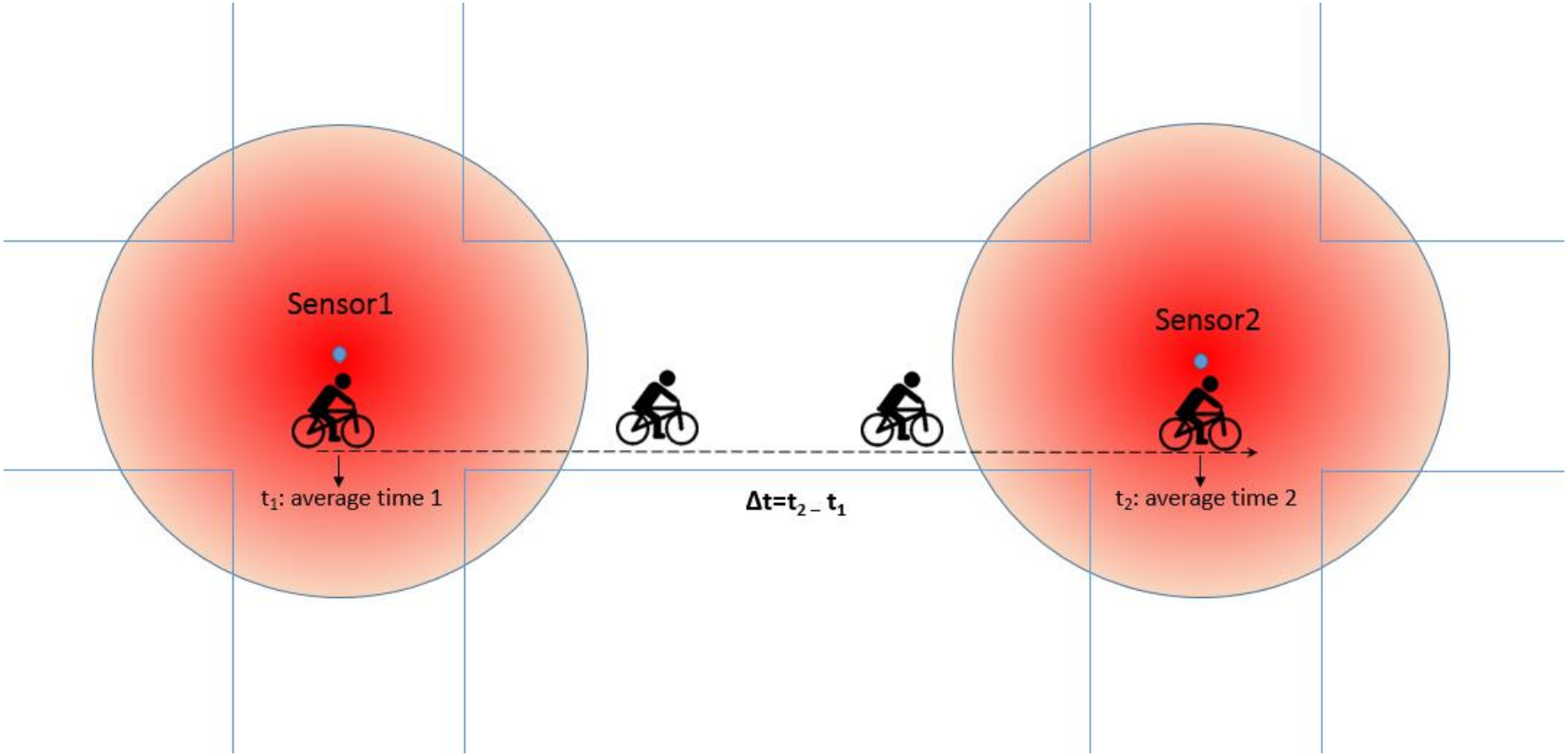
Computation of road modality



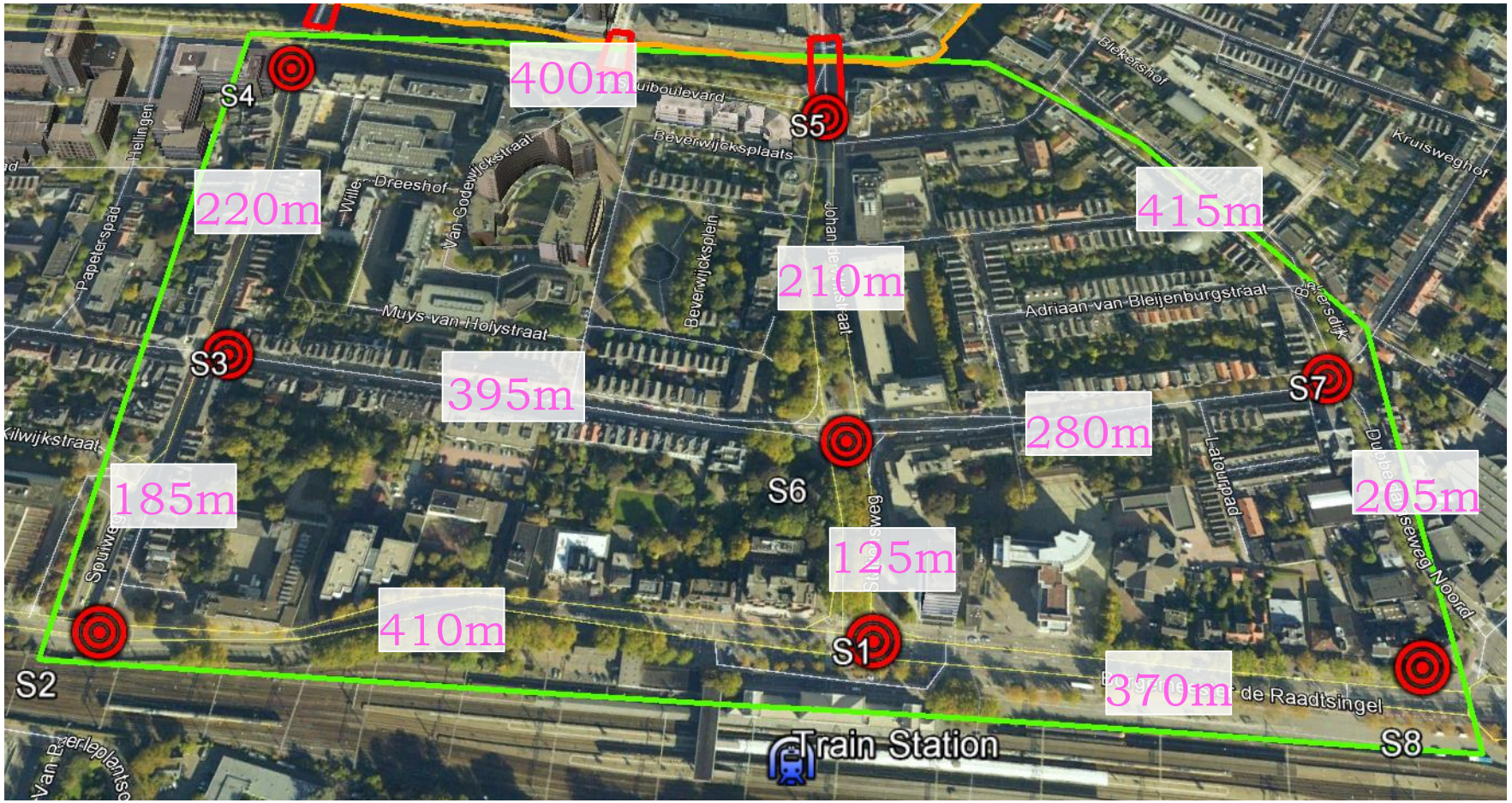
-Computation of average time at each sensor



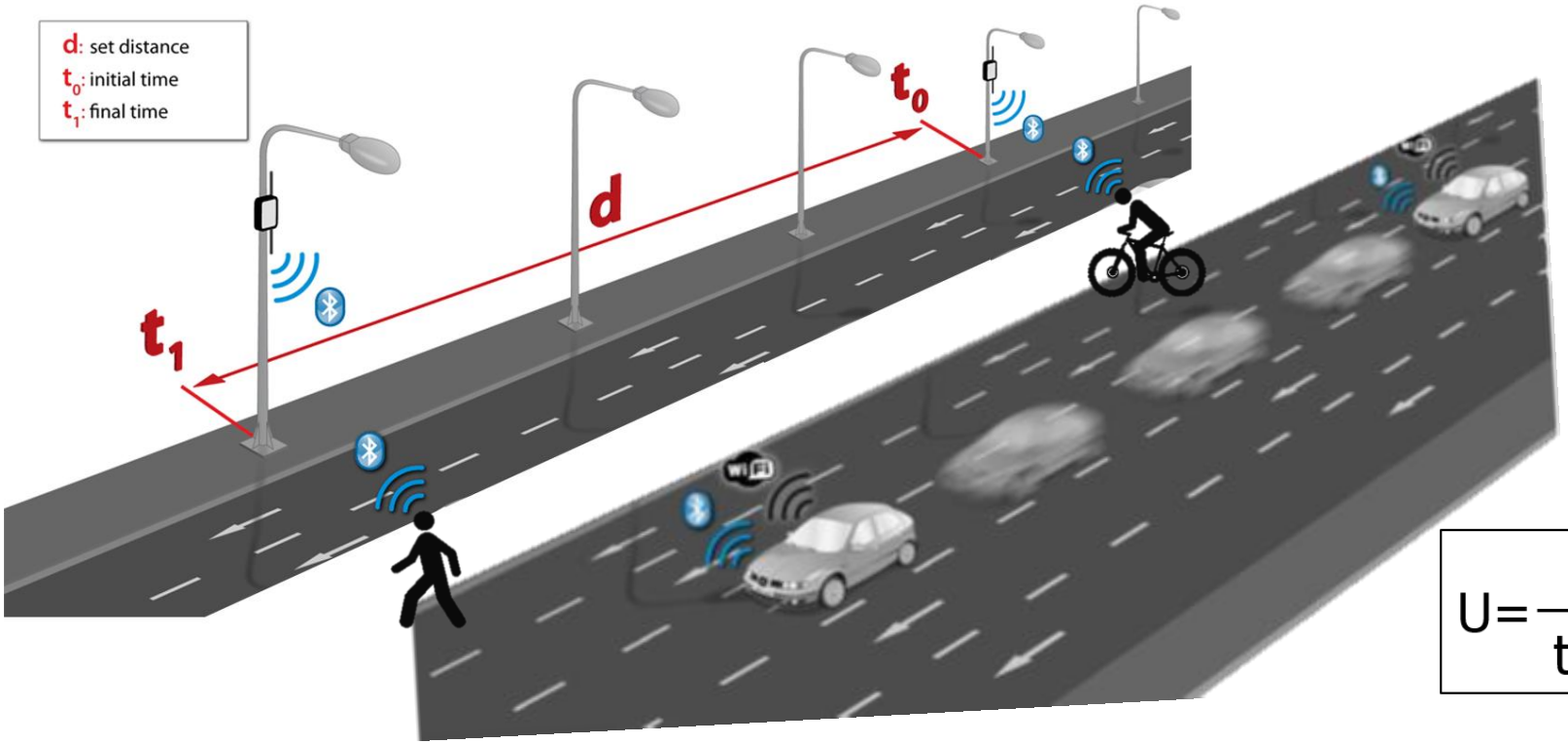
-Computation of time difference between sensors



-Computation of movement speed

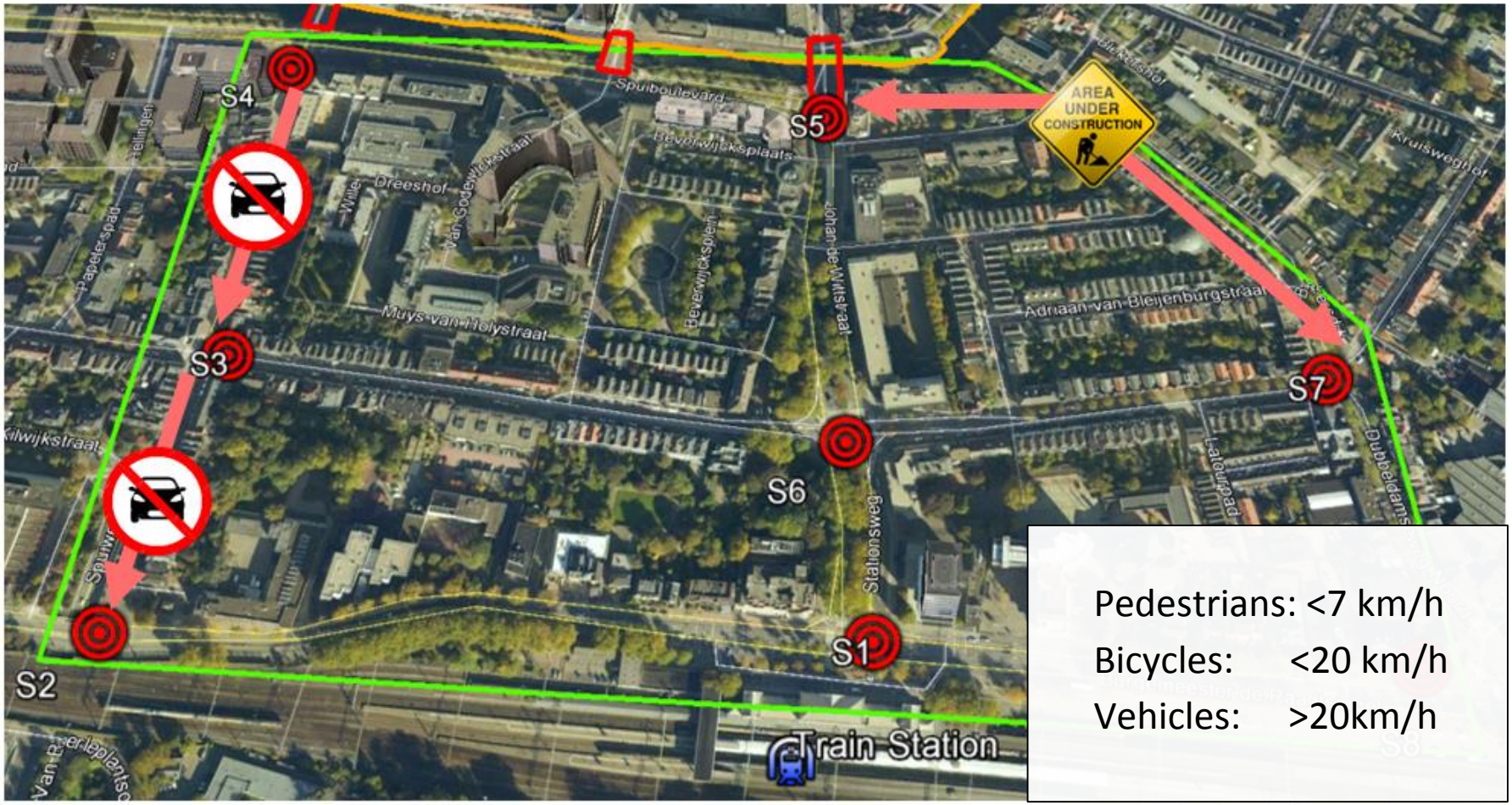


-Computation of movement speed

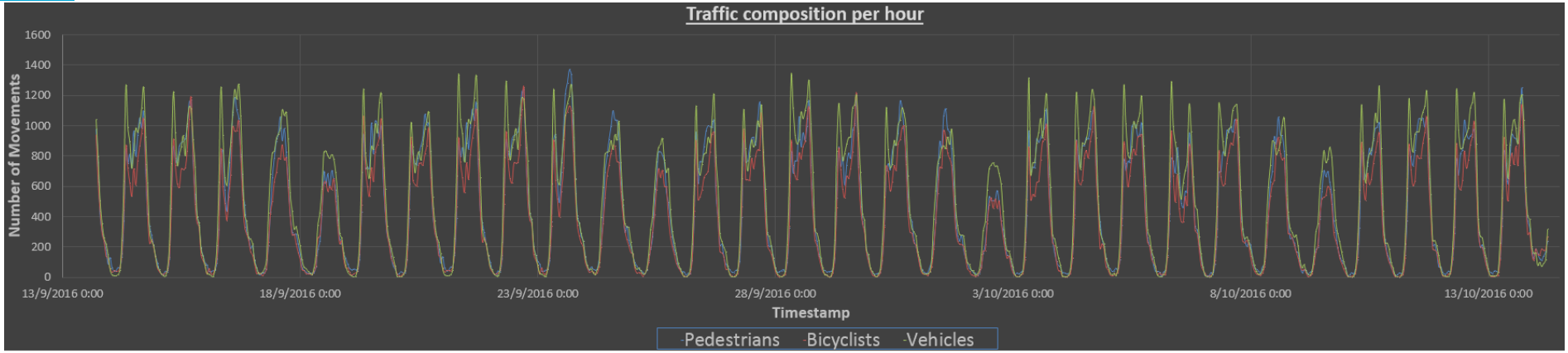


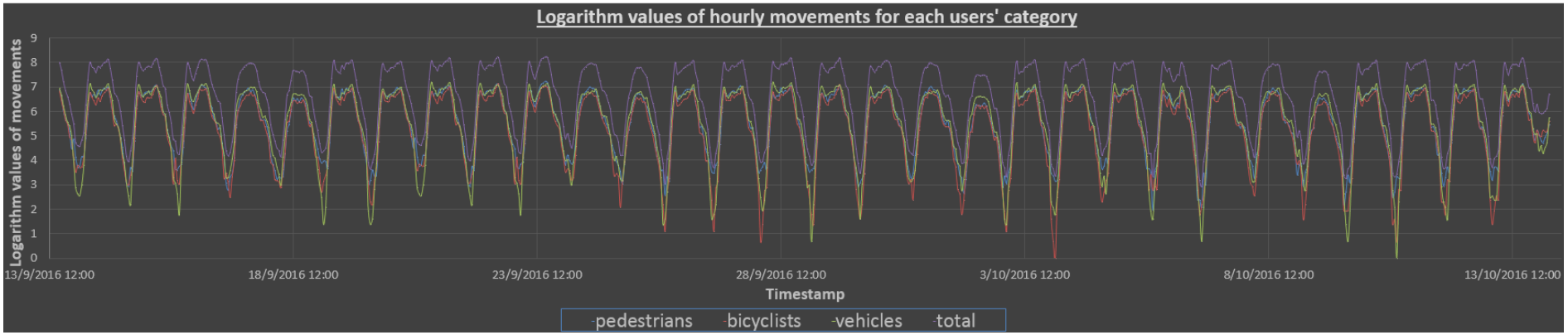
$$U = \frac{d}{t_1 - t_0}$$

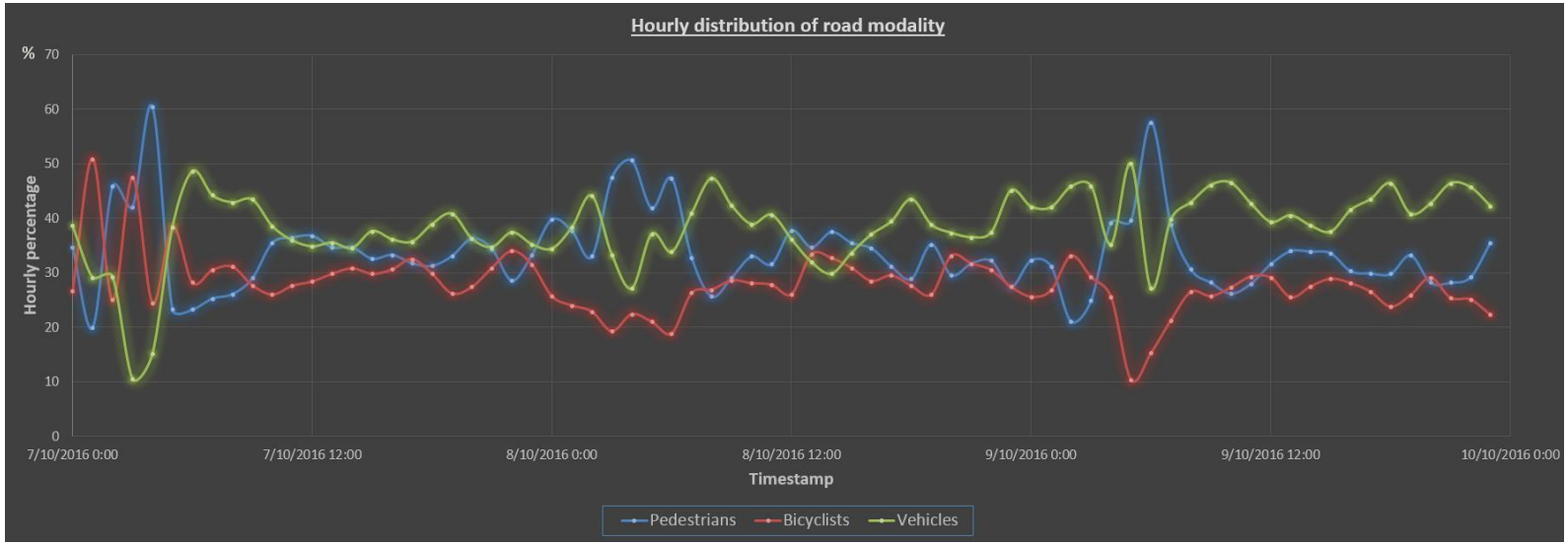
-Combination of movement speed & street-uses criteria for the characterization of devices

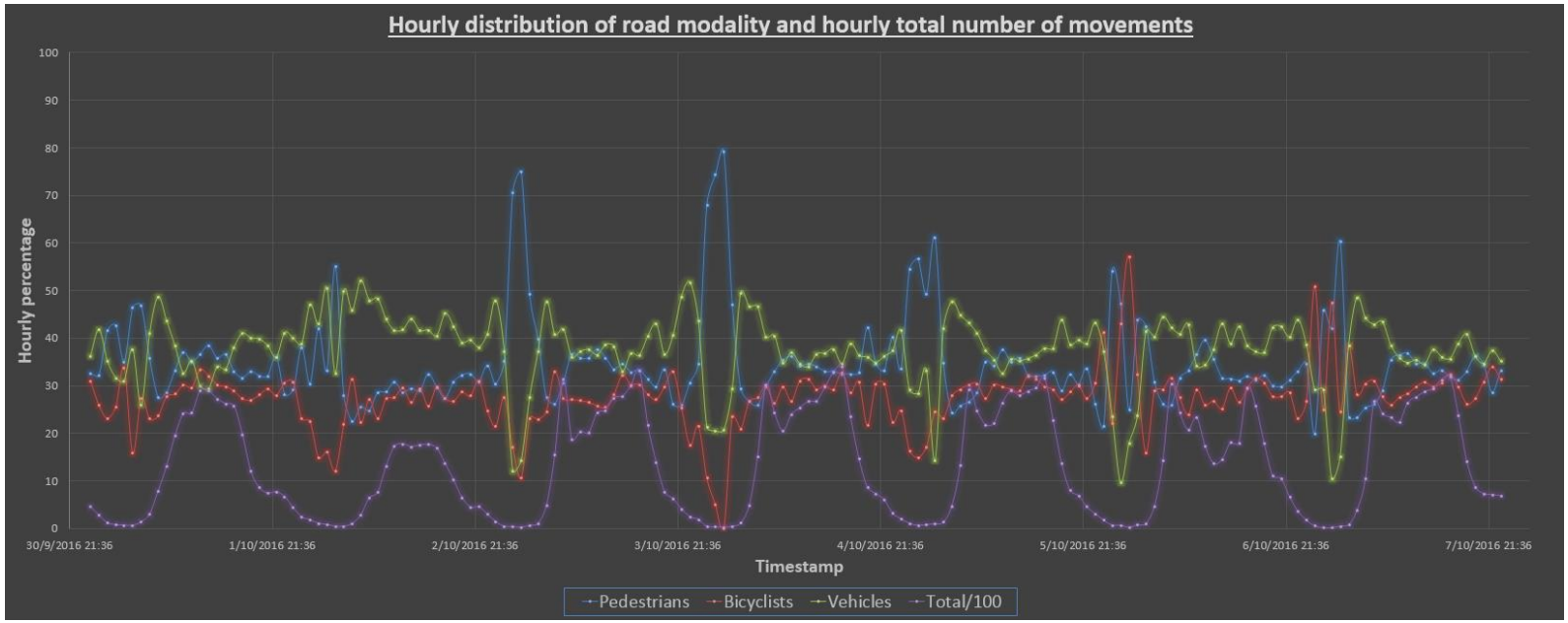


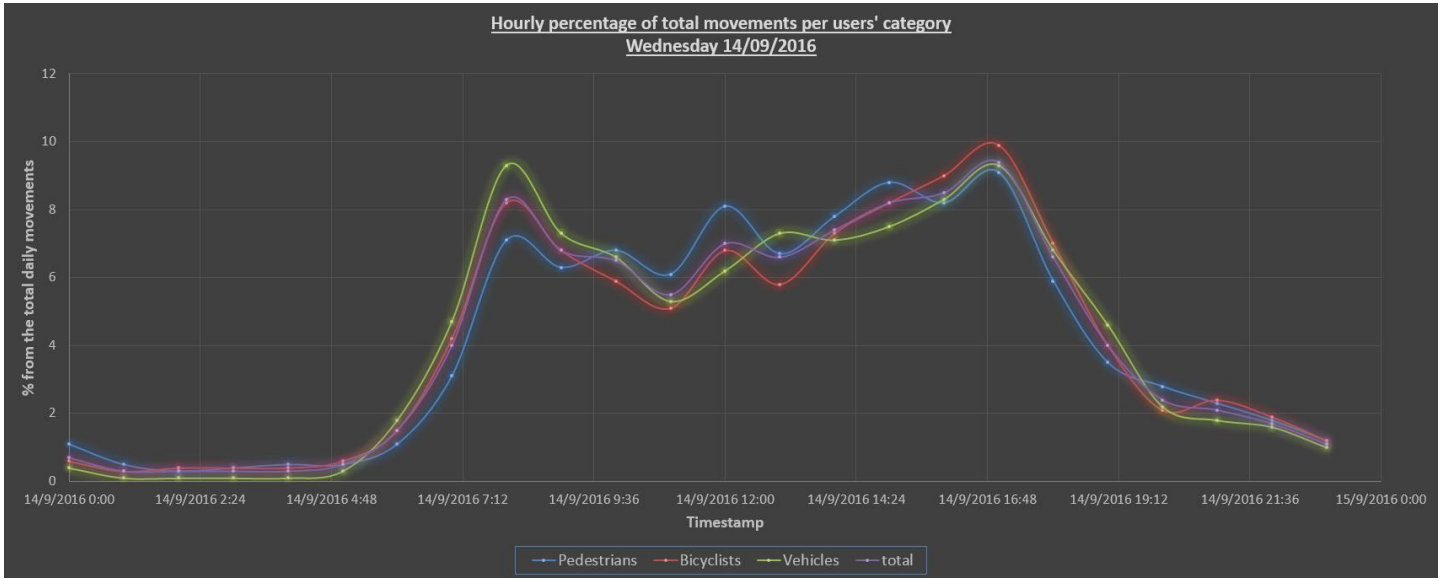
Correlations	Values
Pedestrians -Vehicles	0.965
Pedestrians - Bicyclists	0.981
Bicyclists - Vehicles	0.980

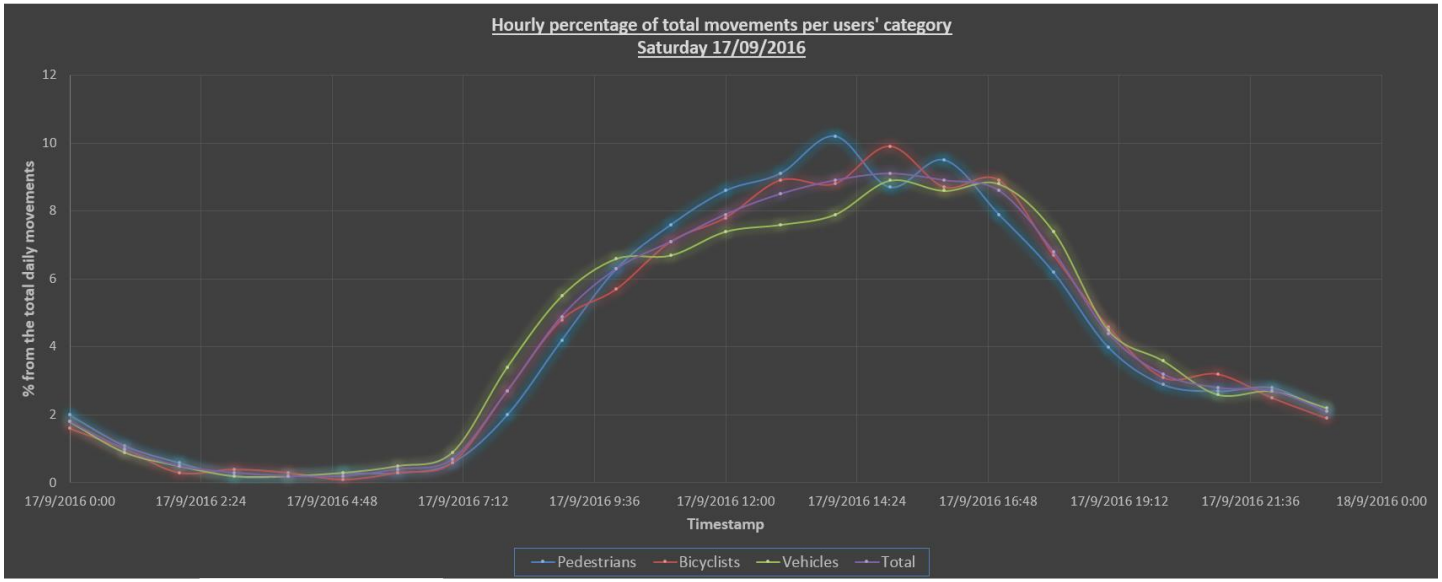


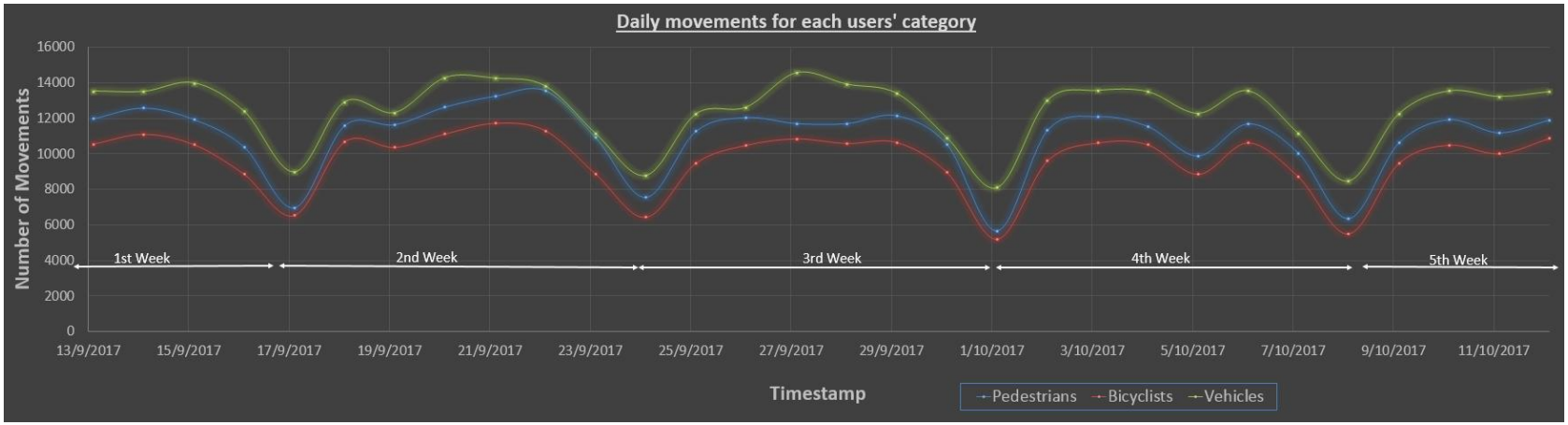


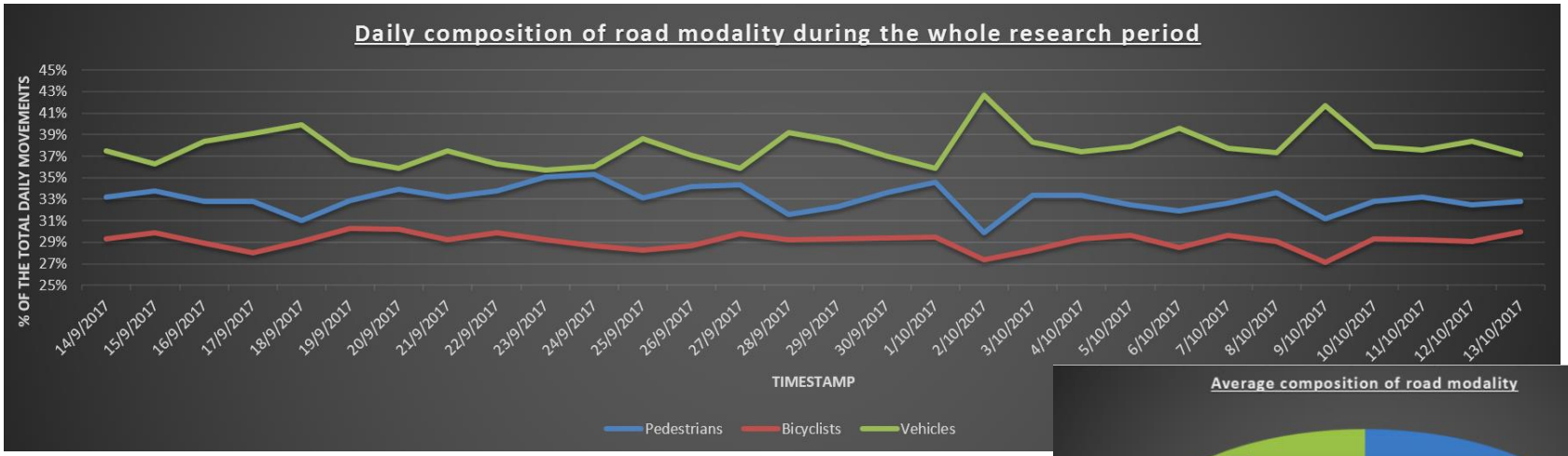

Hourly distribution of road modality
%
Hourly percentage
70
60
50
40
30
20
10
0
7/10/2016 0:00
7/10/2016 12:00
8/10/2016 0:00
8/10/2016 12:00
9/10/2016 0:00
9/10/2016 12:00
10/10/2016 0:00
Timestamp
Pedestrians
Bicyclists
Vehicles

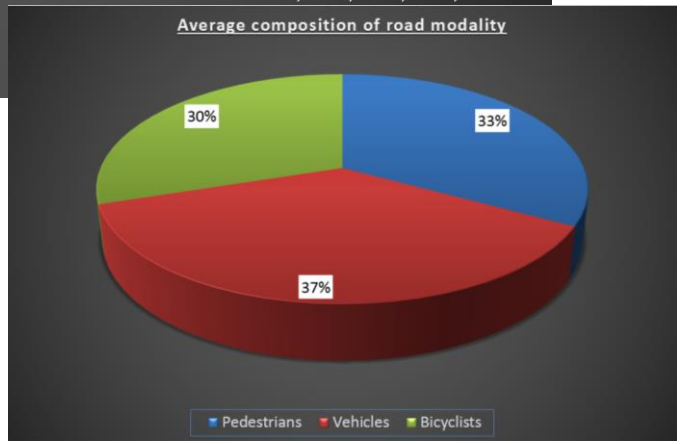

Hourly distribution of road modality and hourly total number of movements
Hourly percentage
100
90
80
70
60
50
40
30
20
10
0
30/9/2016 21:36
1/10/2016 21:36
2/10/2016 21:36
3/10/2016 21:36
4/10/2016 21:36
5/10/2016 21:36
6/10/2016 21:36
7/10/2016 21:36
Timestamp
Pedestrians
Bicyclists
Vehicles
Total/100


Hourly percentage of total movements per users' category
Wednesday 14/09/2016
% from the total daily movements
12
10
8
6
4
2
0
14/9/2016 0:00
14/9/2016 2:24
14/9/2016 4:48
14/9/2016 7:12
14/9/2016 9:36
14/9/2016 12:00
14/9/2016 14:24
14/9/2016 16:48
14/9/2016 19:12
14/9/2016 21:36
15/9/2016 0:00
Timestamp
Pedestrians
Bicyclists
Vehicles
total


Hourly percentage of total movements per users' category
Saturday 17/09/2016
% from the total daily movements
12
10
8
6
4
2
0
17/9/2016 0:00
17/9/2016 2:24
17/9/2016 4:48
17/9/2016 7:12
17/9/2016 9:36
17/9/2016 12:00
17/9/2016 14:24
17/9/2016 16:48
17/9/2016 19:12
17/9/2016 21:36
18/9/2016 0:00
Timestamp
Pedestrians
Bicyclists
Vehicles
Total


Daily movements for each users' category
Number of Movements
16000
14000
12000
10000
8000
6000
4000
2000
0
1st Week
2nd Week
3rd Week
4th Week
5th Week
13/9/2017
15/9/2017
17/9/2017
19/9/2017
21/9/2017
23/9/2017
25/9/2017
27/9/2017
29/9/2017
1/10/2017
3/10/2017
5/10/2017
7/10/2017
9/10/2017
11/10/2017
Timestamp
Pedestrians
Bicyclists
Vehicles


Daily composition of road modality during the whole research period
% OF THE TOTAL DAILY MOVEMENTS
45%
43%
41%
39%
37%
35%
33%
31%
29%
27%
25%
14/9/2017
15/9/2017
16/9/2017
17/9/2017
18/9/2017
19/9/2017
20/9/2017
21/9/2017
22/9/2017
23/9/2017
24/9/2017
25/9/2017
26/9/2017
27/9/2017
28/9/2017
29/9/2017
30/9/2017
1/10/2017
2/10/2017
3/10/2017
4/10/2017
5/10/2017
6/10/2017
7/10/2017
8/10/2017
9/10/2017
10/10/2017
11/10/2017
12/10/2017
13/10/2017
TIMESTAMP
Pedestrians
Bicyclists
Vehicles

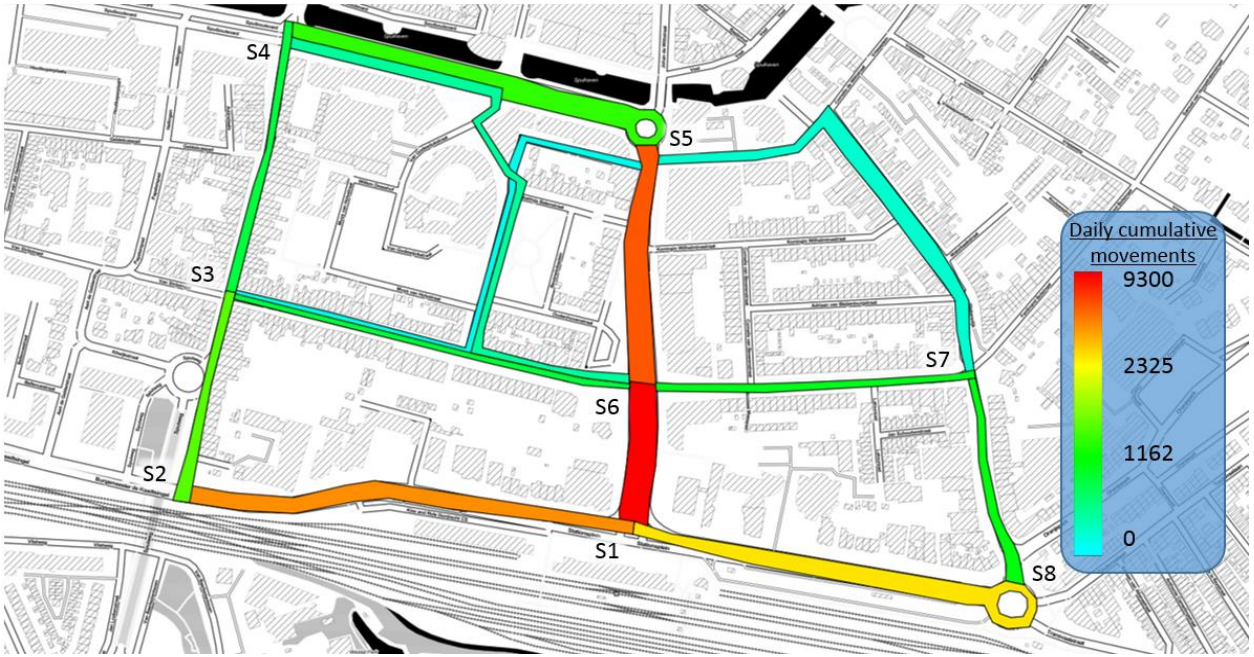

Average composition of road modality
30%
33%
37%
Pedestrians
Vehicles
Bicyclists

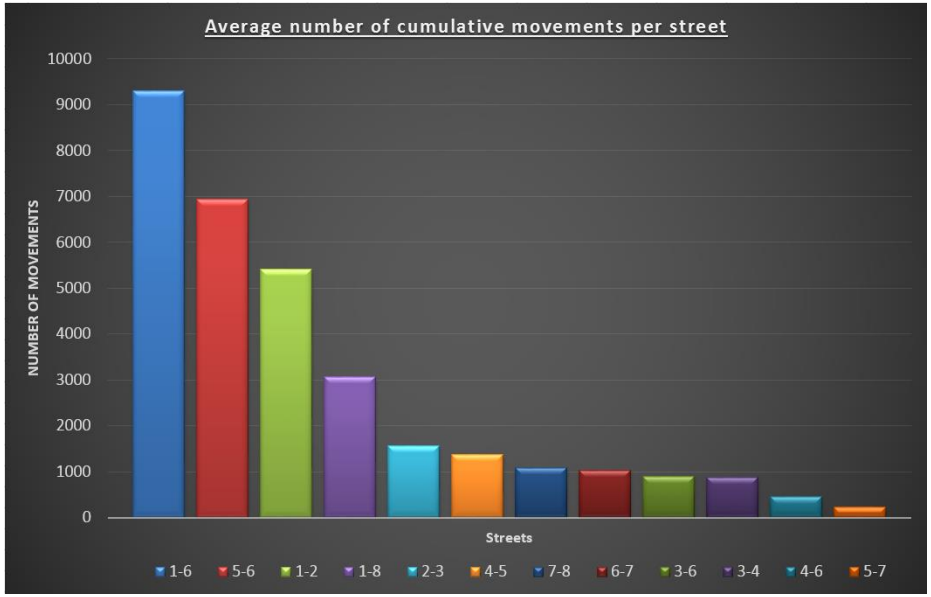
Computation of movement patterns

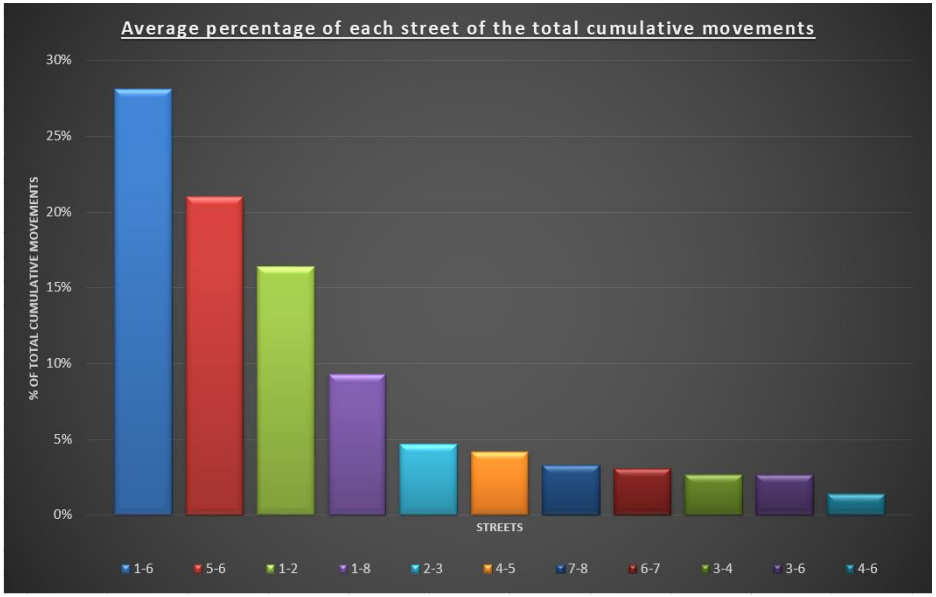
Patterns	Monday-Thursday %	Friday %	Saturday %	Sunday %	Overall %
2	74.2	74.6	73.4	73.2	73.9
3	20.8	20.5	21.4	21.6	21.1
4	4	3.9	4	4.1	4.0
Other	1	1	1.2	1.1	1.1

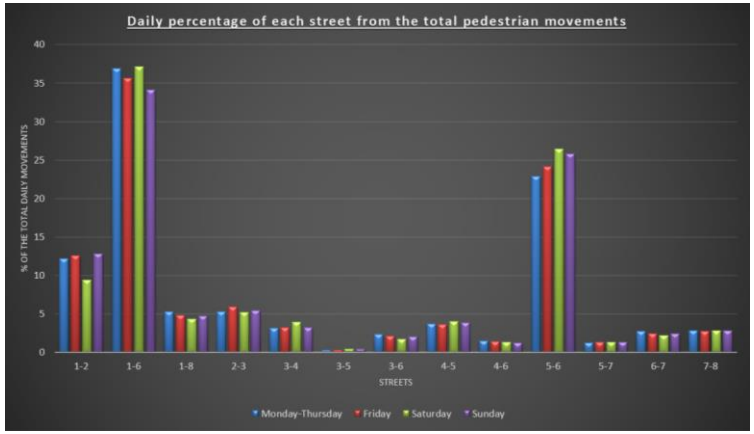
Patterns	Monday-Thursday %	Friday %	Saturday %	Sunday %	Overall %
2	70.5	70.4	69.8	69.4	70.0
3	23.7	23.8	24.4	24.1	24.0
4	4.8	5.1	5.1	5.5	5.1
Other	1	0.7	0.7	1	0.9

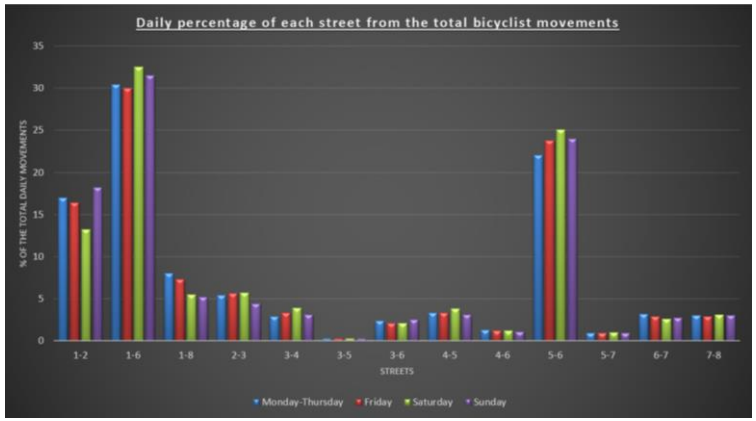
Patterns	Monday-Thursday %	Friday %	Saturday %	Sunday %	Overall %
2	67.4	67.2	67.3	66.5	67.1
3	25.8	25.9	26.1	26.3	26.0
4	5.7	5.9	5.5	6.3	5.9
Other	1.1	1	0.9	0.9	1.0

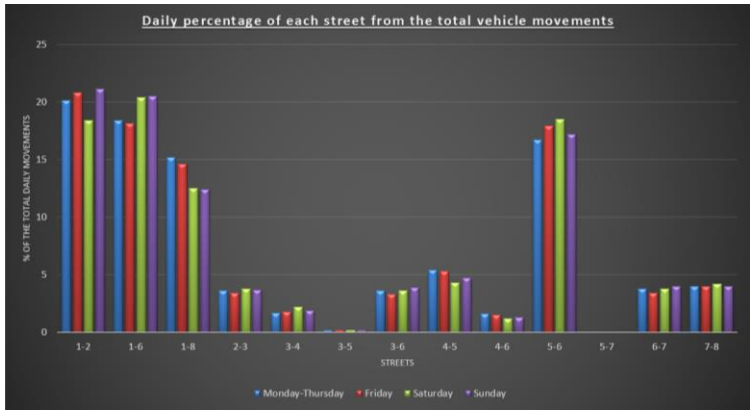

S4
S5
S3
S7
S6
S2
S1
S8
Daily cumulative movements
9300
2325
1162
0

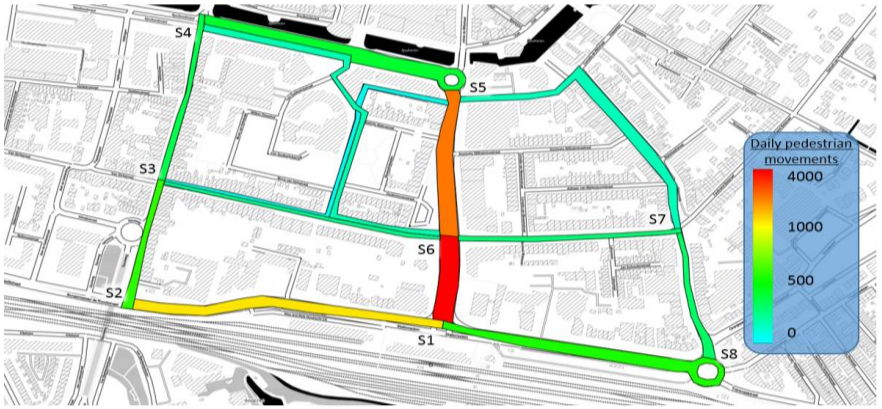

Average number of cumulative movements per street
NUMBER OF MOVEMENTS
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Streets
1-6
5-6
1-2
1-8
2-3
4-5
7-8
6-7
3-6
3-4
4-6
5-7

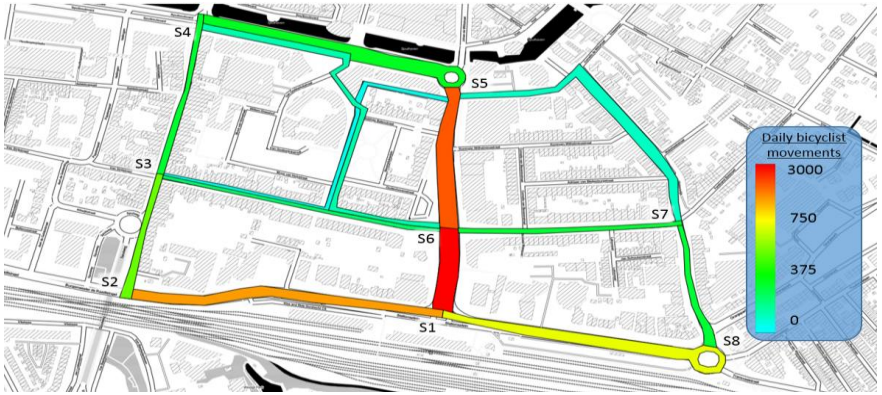

Average percentage of each street of the total cumulative movements
% OF TOTAL CUMULATIVE MOVEMENTS
30%
25%
20%
15%
10%
5%
0%
STREETS
1-6
5-6
1-2
1-8
2-3
4-5
7-8
6-7
3-4
3-6
4-6

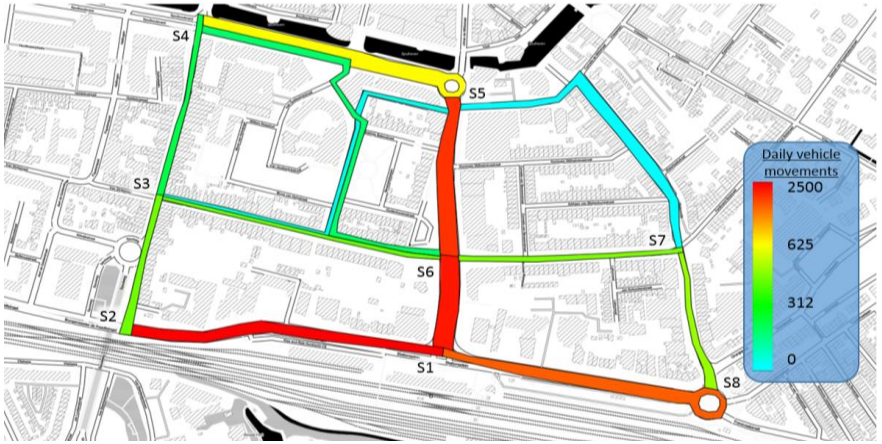

Daily percentage of each street from the total pedestrian movements
% OF THE TOTAL DAILY MOVEMENTS
STREETS
1-2
1-6
1-8
2-3
3-4
3-5
3-6
4-5
4-6
5-6
5-7
6-7
7-8
Monday-Thursday
Friday
Saturday
Sunday

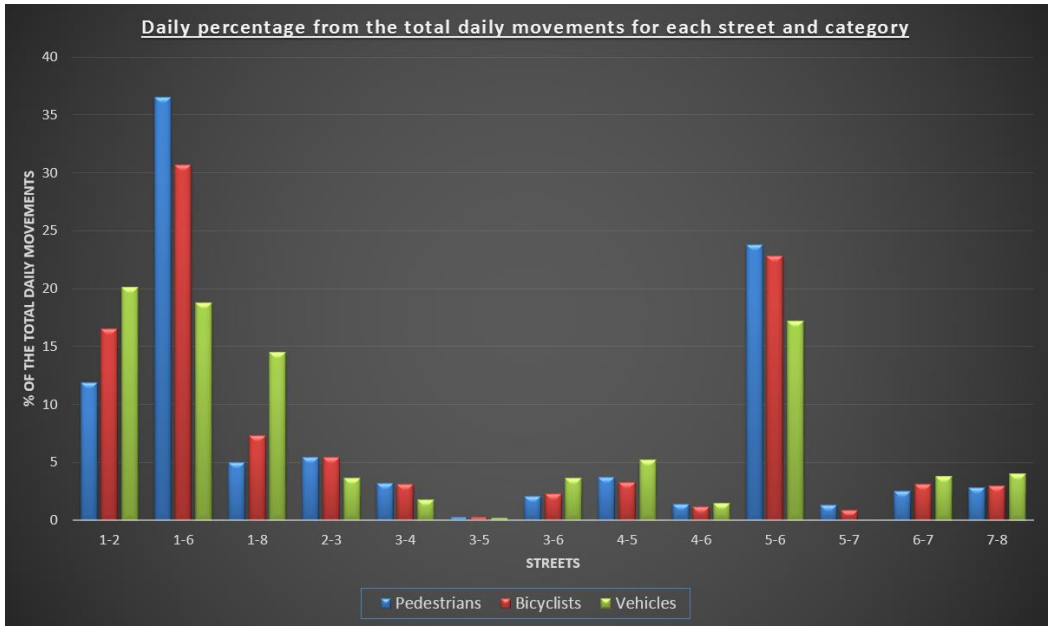

Daily percentage of each street from the total bicyclist movements
% OF THE TOTAL DAILY MOVEMENTS
STREETS
1-2
1-6
1-8
2-3
3-4
3-5
3-6
4-5
4-6
5-6
5-7
6-7
7-8
Monday-Thursday
Friday
Saturday
Sunday

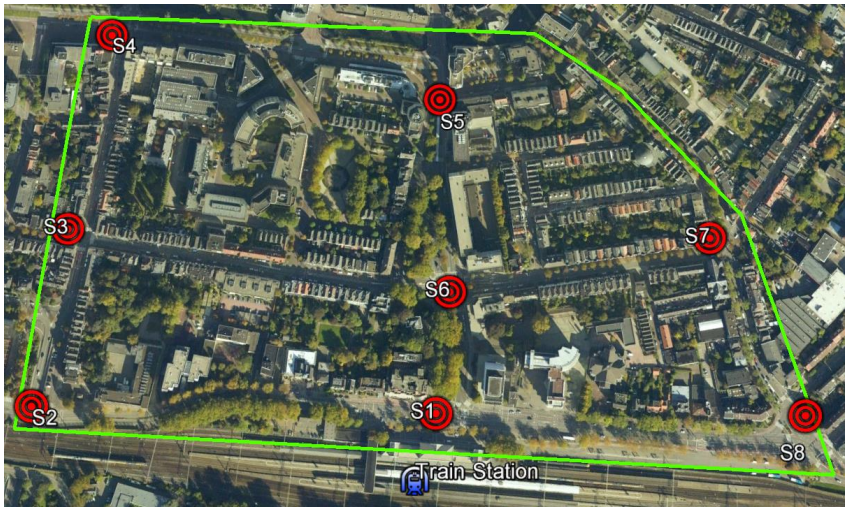

Daily percentage of each street from the total vehicle movements
% OF THE TOTAL DAILY MOVEMENTS
STREETS
1-2
1-6
1-8
2-3
3-4
3-5
3-6
4-5
4-6
5-6
5-7
6-7
7-8
Monday-Thursday
Friday
Saturday
Sunday

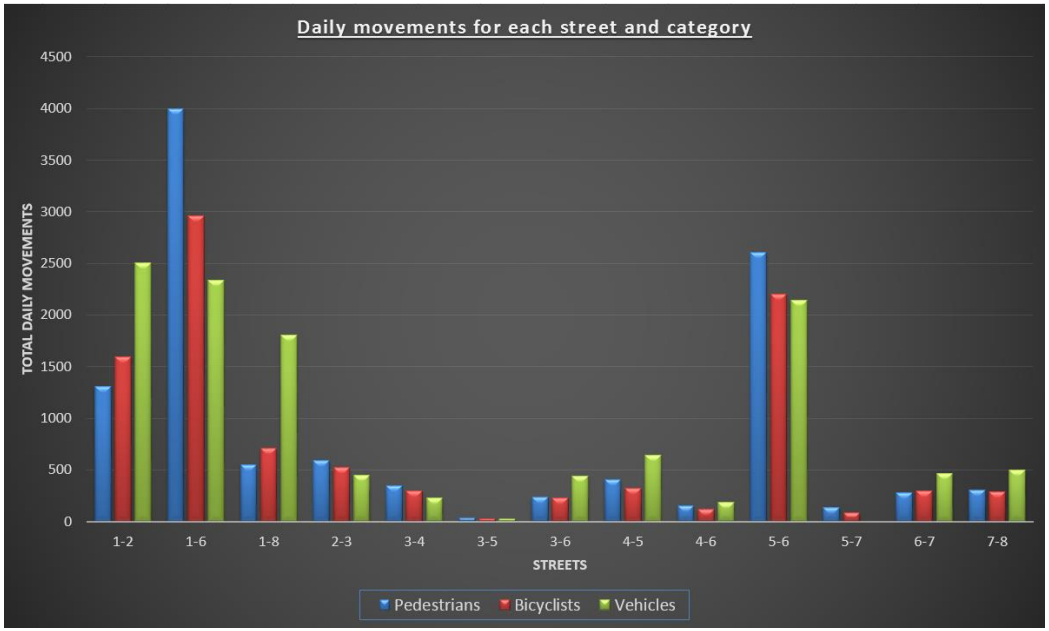

S4
S5
S3
S7
S6
S2
S1
S8
Daily pedestrian movements
4000
1000
500
0


S4
S5
S3
S7
S6
S2
S1
S8
Daily bicyclist movements
3000
750
375
0


S4
S5
S3
S7
S6
S2
S1
S8
Daily vehicle movements
2500
625
312
0

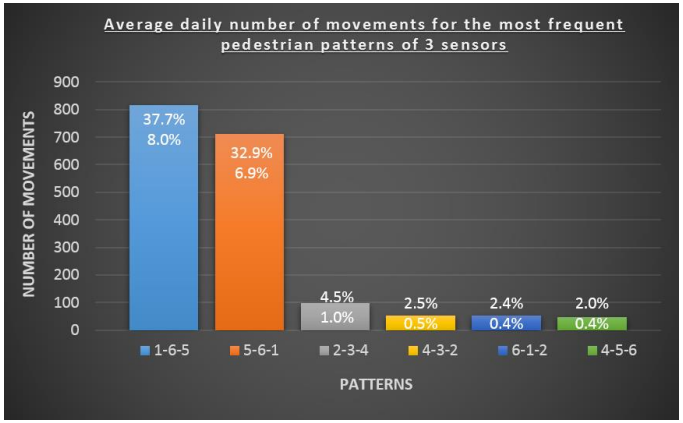

Daily percentage from the total daily movements for each street and category
% OF THE TOTAL DAILY MOVEMENTS
40
35
30
25
20
15
10
5
0
1-2
1-6
1-8
2-3
3-4
3-5
3-6
4-5
4-6
5-6
5-7
6-7
7-8
STREETS
Pedestrians
Bicyclists
Vehicles

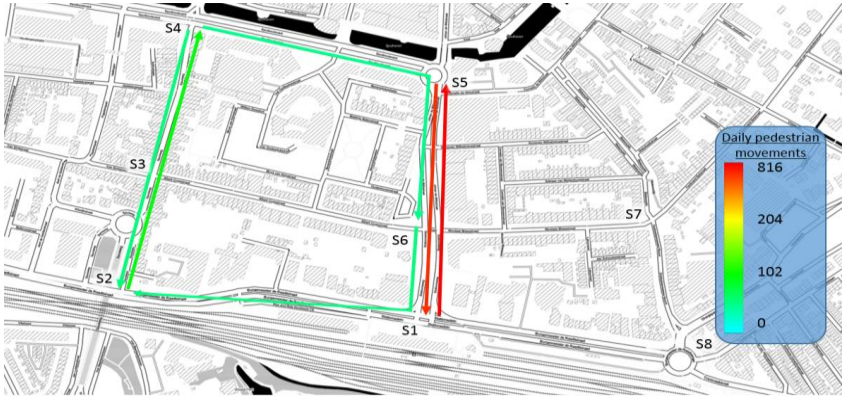

S4
S5
S3
S7
S6
S2
S1
S8
Train Station

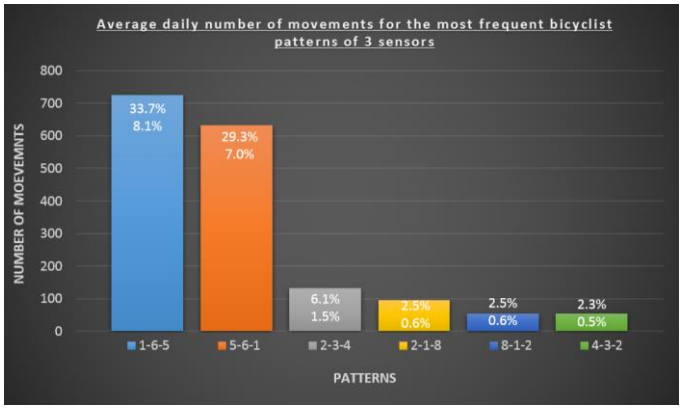

Daily movements for each street and category
TOTAL DAILY MOVEMENTS
4500
4000
3500
3000
2500
2000
1500
1000
500
0
1-2
1-6
1-8
2-3
3-4
3-5
3-6
4-5
4-6
5-6
5-7
6-7
7-8
STREETS
Pedestrians
Bicyclists
Vehicles

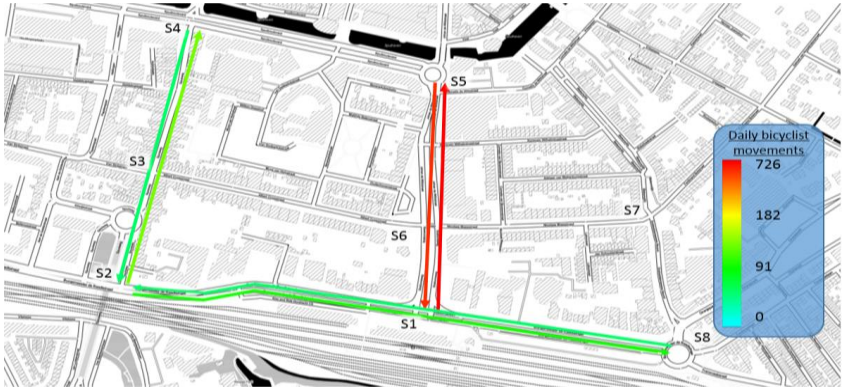
Patterns between 3 sensors

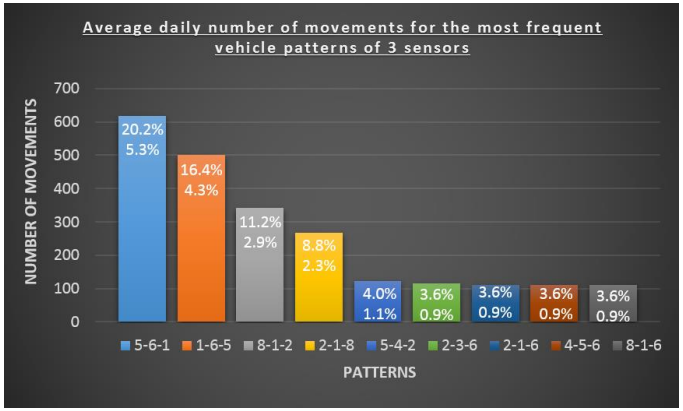
Pedestrians Patterns	Daily Amount	Relative% (absolute%)	Bicyclists Patterns	Daily Amount	Relative% (absolute%)	Vehicles Patterns	Daily Amount	Relative% (absolute%)
165	942	38.6 (8.0)	165	771	31.2 (7.4)	561	675	19.7 (5.1)
561	726	29.8 (6.2)	561	683	27.7 (6.6)	165	542	15.8 (4.1)
612	64	2.6 (0.5)	234	107	4.3 (1.0)	218	373	10.9 (2.8)
456	57	2.3 (0.5)	218	89	3.6 (0.9)	812	358	10.4 (2.7)
234	57	2.3 (0.5)	812	78	3.1 (0.7)	456	148	4.3 (1.1)
216	49	2.0 (0.4)	216	74	3.0 (0.7)	236	143	4.2 (1.1)
761	49	2.0 (0.4)	461	63	2.5 (0.6)	216	133	3.9 (1.0)
432	49	2.0 (0.4)	612	52	2.1 (0.5)	816	112	3.3 (0.9)
461	34	1.4 (0.3)	618	44	1.8 (0.4)	167	112	3.3 (0.9)
654	30	1.2 (0.2)	432	41	1.6 (0.4)	781	97	2.8 (0.7)

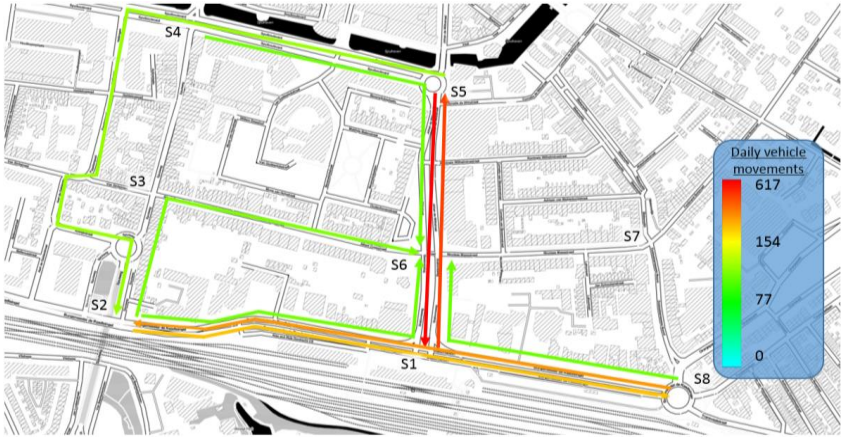

Average daily number of movements for the most frequent pedestrian patterns of 3 sensors
NUMBER OF MOVEMENTS
900
800
700
600
500
400
300
200
100
0
37.7%
8.0%
32.9%
6.9%
4.5%
1.0%
2.5%
0.5%
2.4%
0.4%
2.0%
0.4%
1-6-5
5-6-1
2-3-4
4-3-2
6-1-2
4-5-6
PATTERNS


S4
S5
S3
S7
S6
S2
S1
S8
Daily pedestrian movements
816
204
102
0


Average daily number of movements for the most frequent bicyclist patterns of 3 sensors
NUMBER OF MOEVEMNTS
800
700
600
500
400
300
200
100
0
33.7%
8.1%
29.3%
7.0%
6.1%
1.5%
2.5%
0.6%
2.5%
0.6%
2.3%
0.5%
1-6-5
5-6-1
2-3-4
2-1-8
8-1-2
4-3-2
PATTERNS

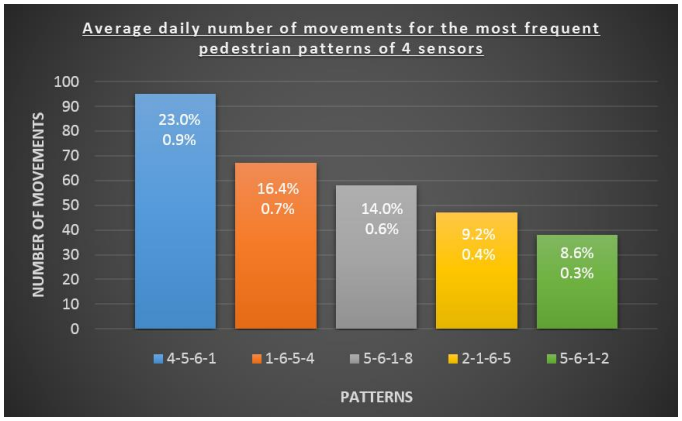

S4
S5
S3
S7
S6
S2
S1
S8
Daily bicyclist movements
726
182
91
0

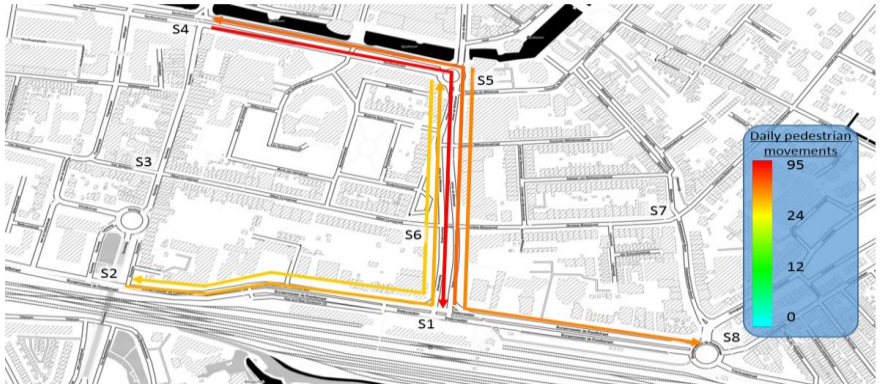

Average daily number of movements for the most frequent vehicle patterns of 3 sensors
NUMBER OF MOVEMENTS
700
600
500
400
300
200
100
0
20.2%
5.3%
16.4%
4.3%
11.2%
2.9%
8.8%
2.3%
4.0%
1.1%
3.6%
0.9%
3.6%
0.9%
3.6%
0.9%
3.6%
0.9%
5-6-1
1-6-5
8-1-2
2-1-8
5-4-2
2-3-6
2-1-6
4-5-6
8-1-6
PATTERNS

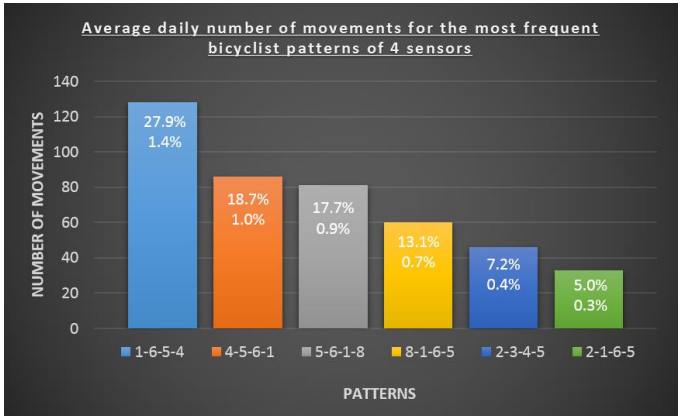

S4
S5
S3
S7
S6
S2
S1
S8
Daily vehicle movements
617
154
77
0

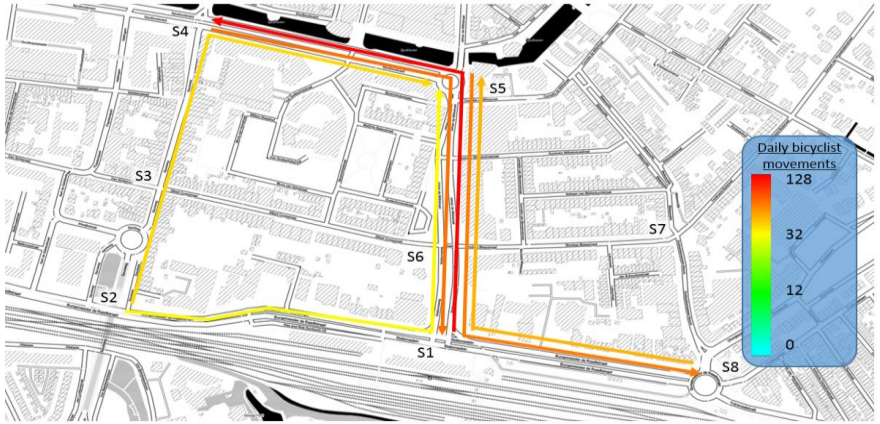
Patterns between 4 sensors

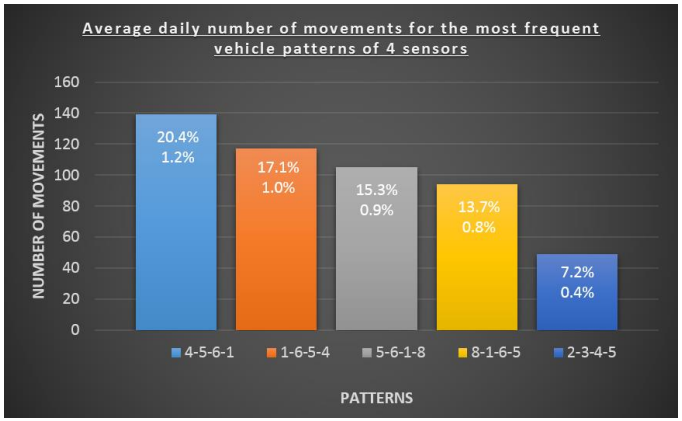
Pedestrians Patterns	Daily Amount	Relative% (absolute%)	Bicyclists Patterns	Daily Amount	Relative% (absolute%)	Vehicles Patterns	Daily Amount	Relative% (absolute%)
4561	141	30.0 (1.2)	**1654**	167	33.3 (1.6)	**4561**	208	27.4 (1.6)
1654	94	20.0 (0.8)	**4561**	90	18.1 (0.9)	**1654**	173	22.8 (1.3)
5618	66	14.0 (0.6)	**5618**	76	15.3 (0.7)	**5618**	88	11.7 (0.7)
8165	38	8.0 (0.3)	**8165**	63	12.5 (0.6)	**8165**	61	8.1 (0.5)
2165	28	6.0 (0.2)	**2165**	42	8.3 (0.4)	**2345**	58	7.6 (0.4)
2367	28	6.0 (0.2)	**5612**	28	5.6 (0.3)	**2167**	35	4.6 (0.3)
2167	19	4.0 (0.2)	**2345**	21	4.2 (0.2)	**2367**	35	4.6 (0.3)
8754	19	4.0 (0.2)	**2167**	14	2.8 (0.1)	**5612**	27	3.6 (0.2)
5612	19	4.0 (0.2)				**7812**	27	3.6 (0.2)
2345	19	4.0 (0.2)				**7612**	15	2.0 (0.1)

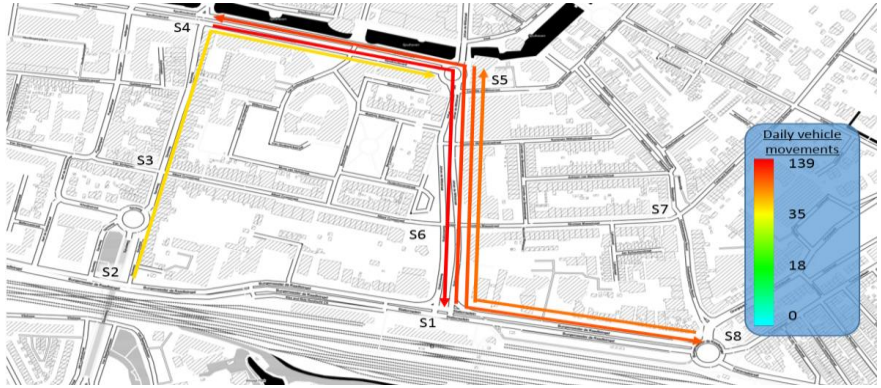

Average daily number of movements for the most frequent pedestrian patterns of 4 sensors
NUMBER OF MOVEMENTS
100
90
80
70
60
50
40
30
20
10
0
23.0%
0.9%
16.4%
0.7%
14.0%
0.6%
9.2%
0.4%
8.6%
0.3%
4-5-6-1
1-6-5-4
5-6-1-8
2-1-6-5
5-6-1-2
PATTERNS

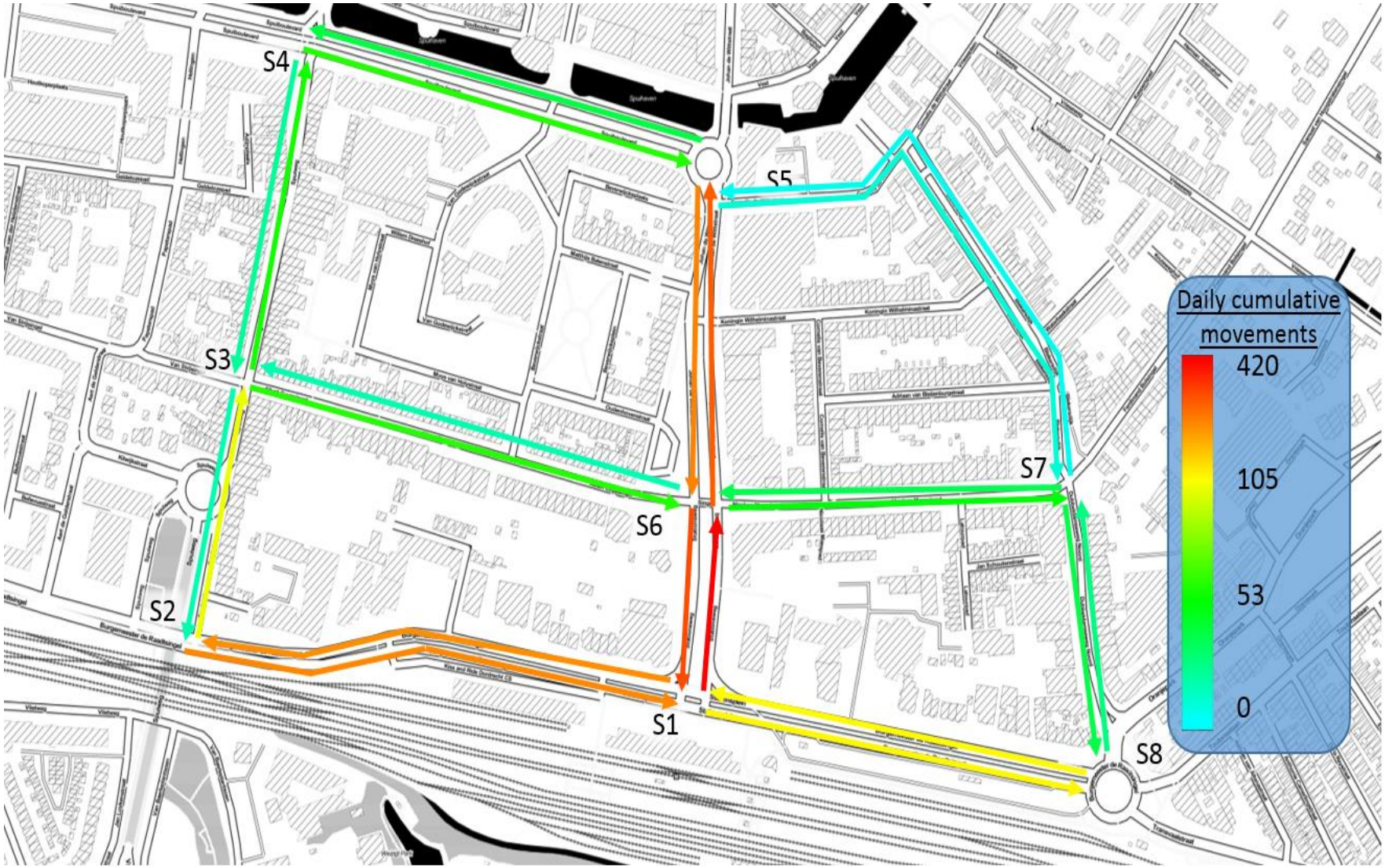

S4
S5
S3
S7
S6
S2
S1
S8
Daily pedestrian movements
95
24
12
0


Average daily number of movements for the most frequent bicyclist patterns of 4 sensors
NUMBER OF MOVEMENTS
140
120
100
80
60
40
20
0
27.9%
1.4%
18.7%
1.0%
17.7%
0.9%
13.1%
0.7%
7.2%
0.4%
5.0%
0.3%
1-6-5-4
4-5-6-1
5-6-1-8
8-1-6-5
2-3-4-5
2-1-6-5
PATTERNS


S4
S5
S3
S7
S6
S2
S1
S8
Daily bicyclist movements
128
32
12
0


Average daily number of movements for the most frequent vehicle patterns of 4 sensors
NUMBER OF MOVEMENTS
160
140
120
100
80
60
40
20
0
20.4%
1.2%
17.1%
1.0%
15.3%
0.9%
13.7%
0.8%
7.2%
0.4%
4-5-6-1
1-6-5-4
5-6-1-8
8-1-6-5
2-3-4-5
PATTERNS

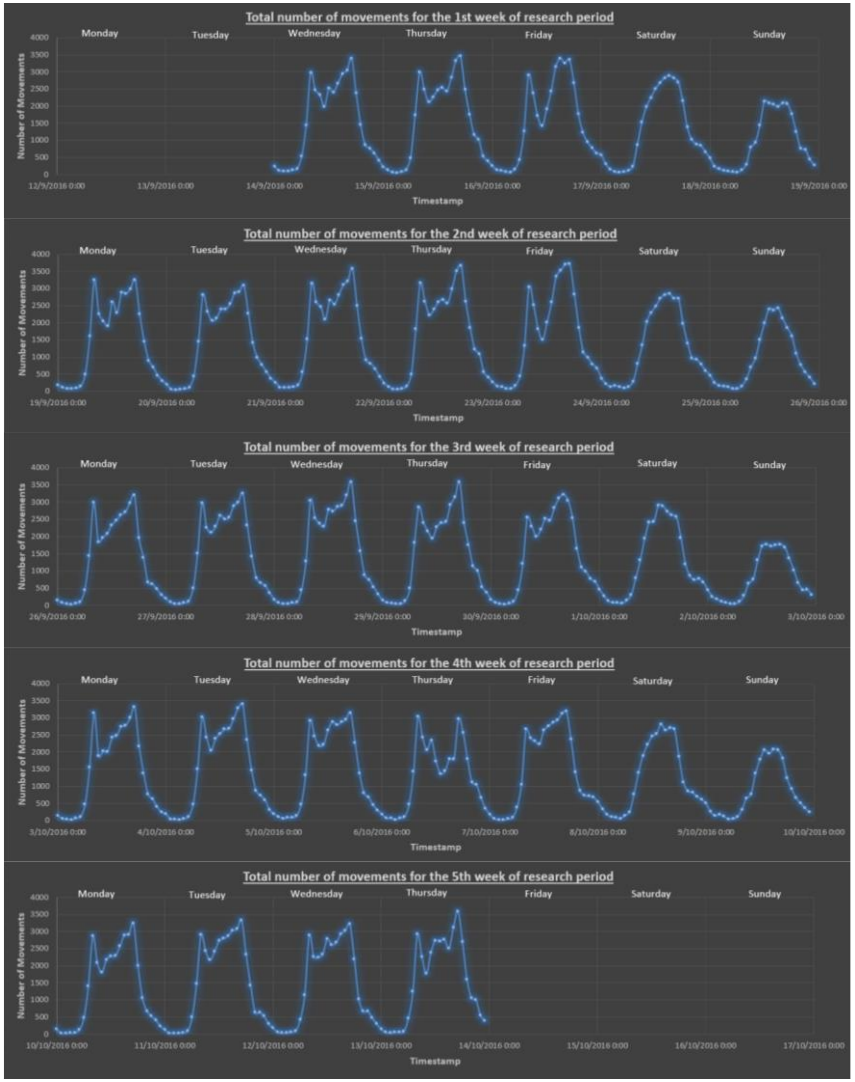

S4
S5
S3
S7
S6
S2
S1
S8
Daily vehicle movements
139
35
18
0

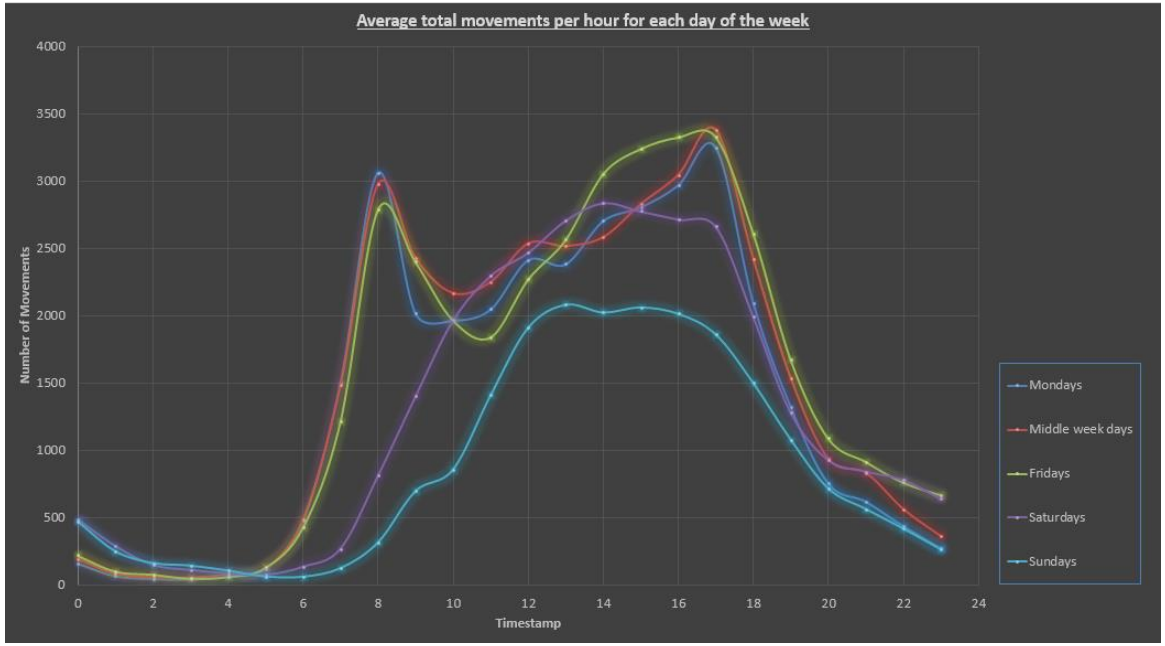


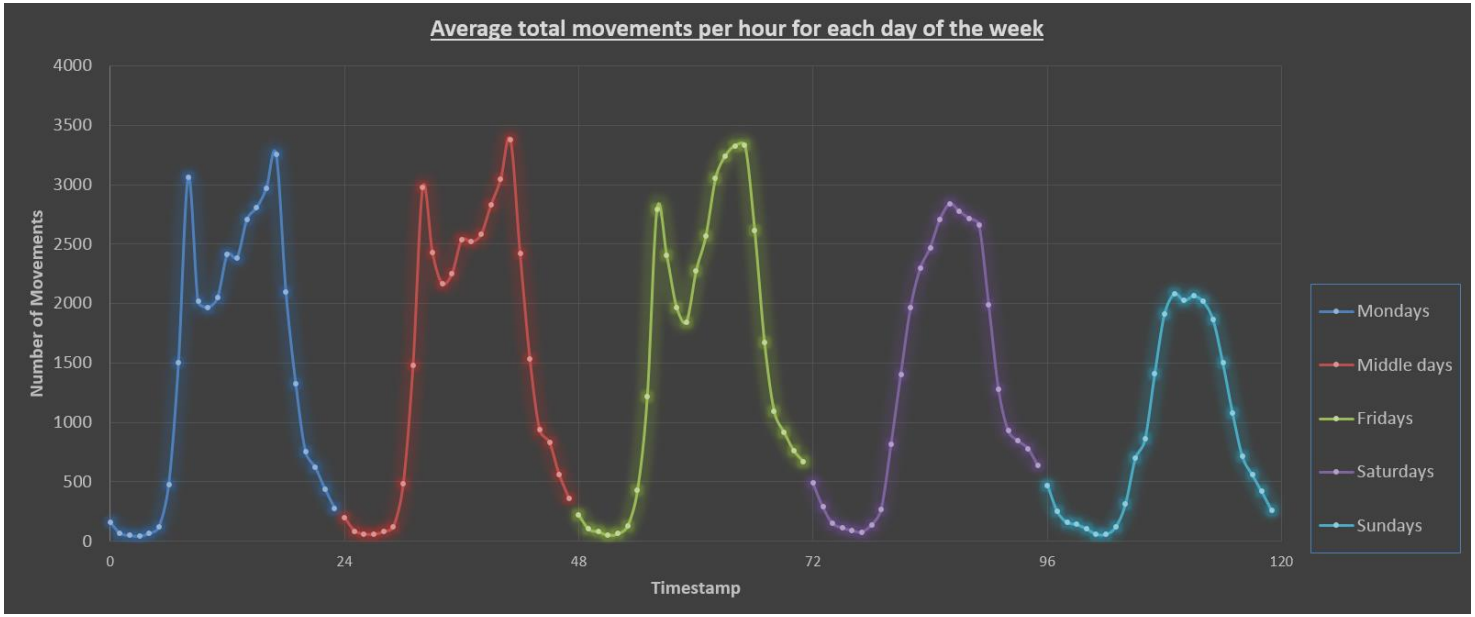
Visualization of cumulative movement flows for Thursday 22/09/2017 between 17:00 – 18:00

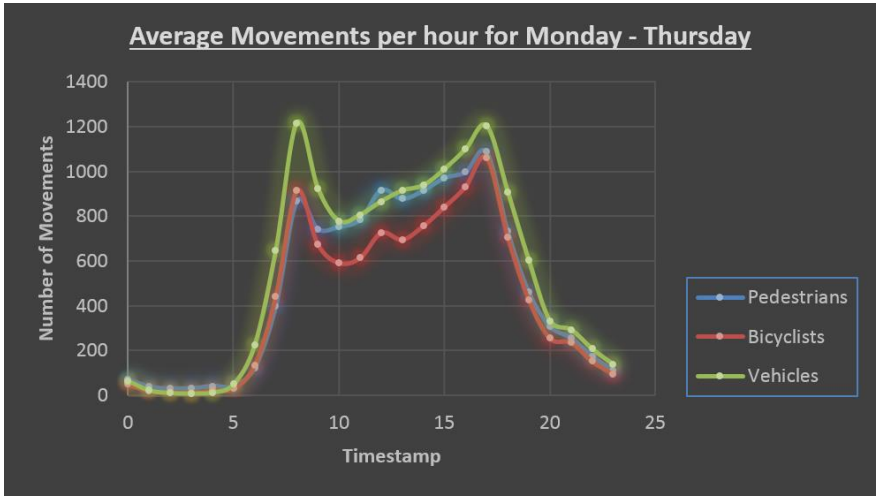
Computation of occupancy patterns

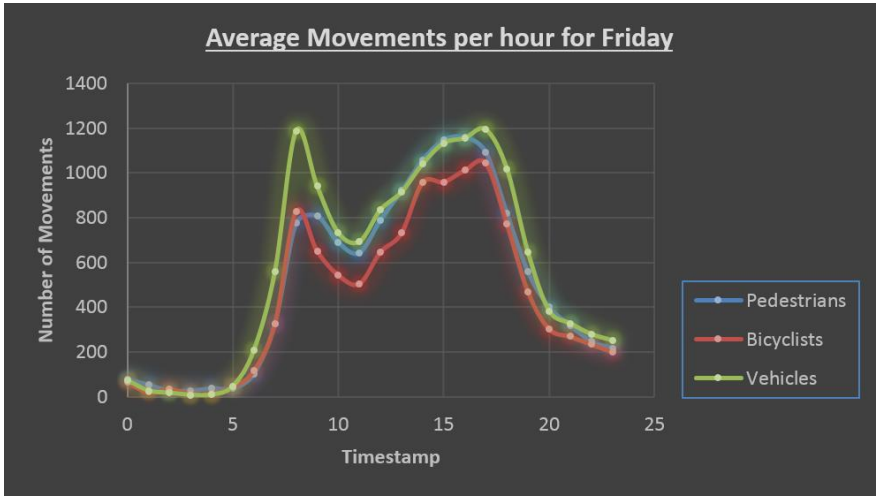
-Occupancy patterns in the research area

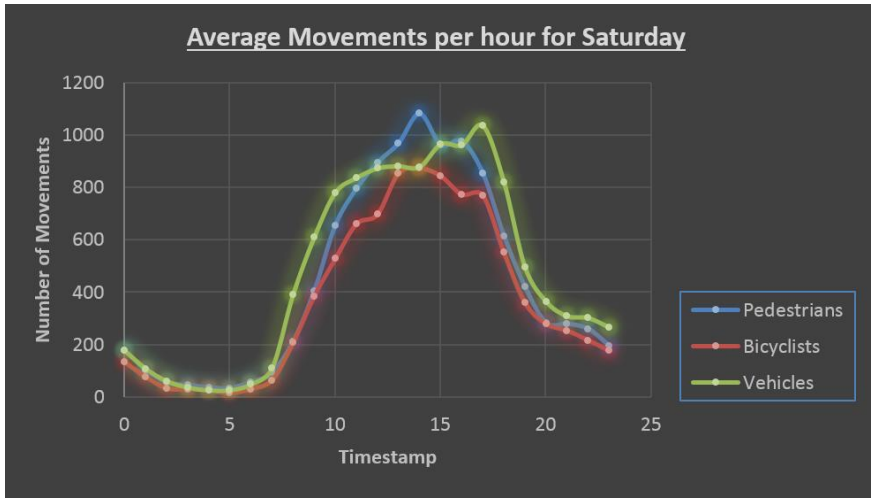


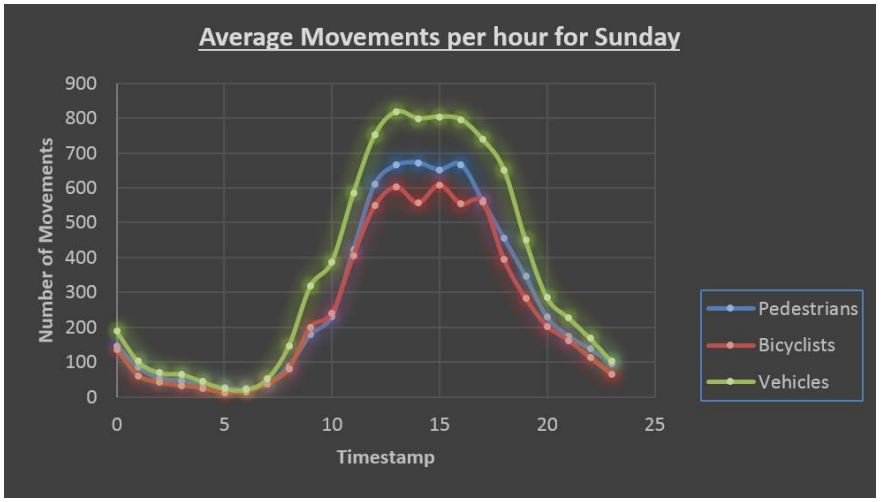

Average total movements per hour for each day of the week
Number of Movements
Timestamp
Mondays
Middle week days
Fridays
Saturdays
Sundays

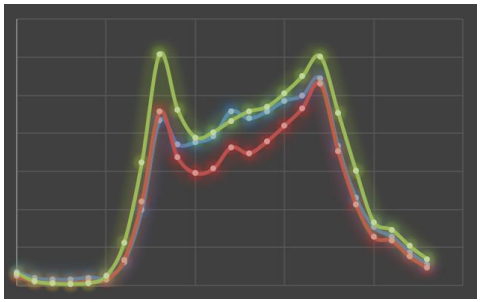

Average total movements per hour for each day of the week
Number of Movements
Timestamp
Mondays
Middle days
Fridays
Saturdays
Sundays

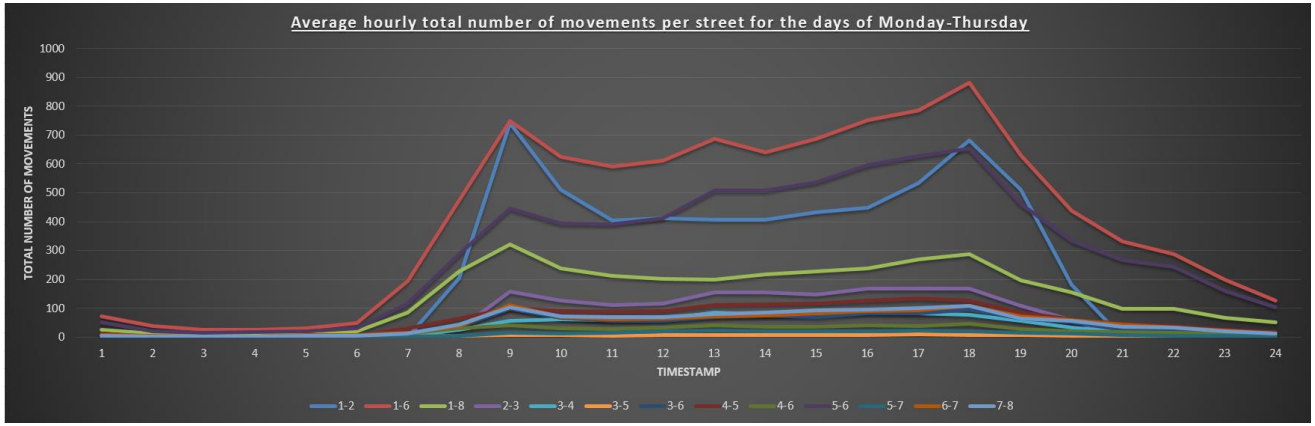

Average Movements per hour for Monday - Thursday
Number of Movements
1400
1200
1000
800
600
400
200
0
0
5
10
15
20
25
Timestamp
Pedestrians
Bicyclists
Vehicles

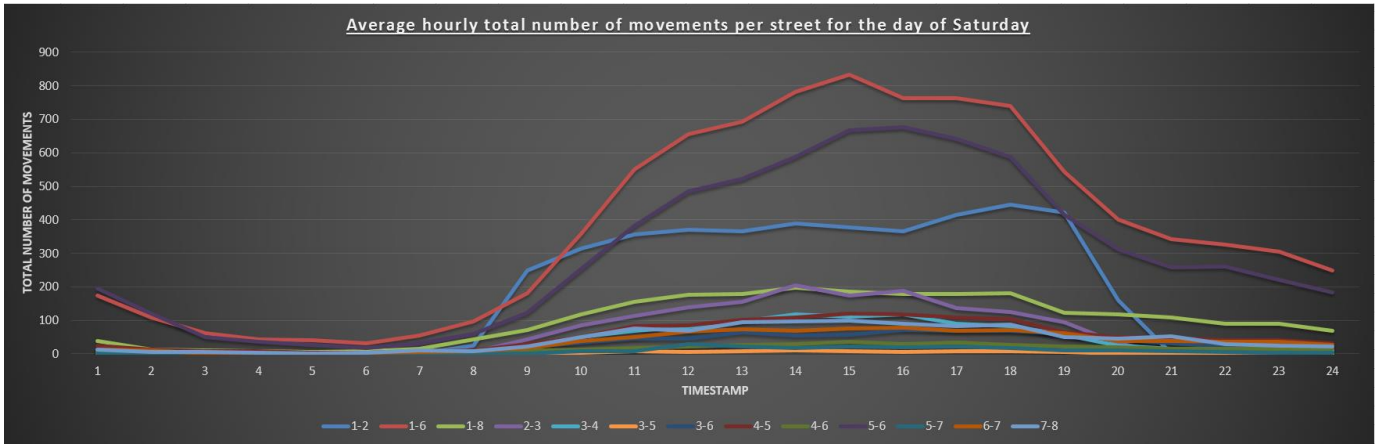

Average Movements per hour for Friday
Number of Movements
1400
1200
1000
800
600
400
200
0
0
5
10
15
20
25
Timestamp
Pedestrians
Bicyclists
Vehicles

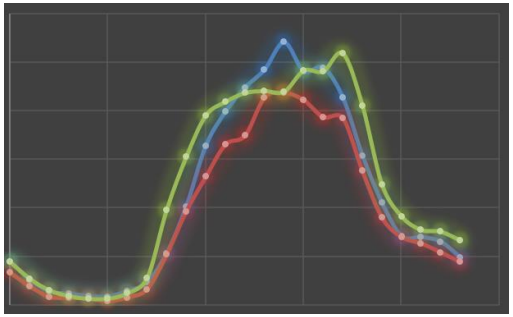

Average Movements per hour for Saturday
Number of Movements
1200
1000
800
600
400
200
0
0
5
10
15
20
25
Timestamp
Pedestrians
Bicyclists
Vehicles


Average Movements per hour for Sunday
Number of Movements
900
800
700
600
500
400
300
200
100
0
0
5
10
15
20
25
Timestamp
Pedestrians
Bicyclists
Vehicles

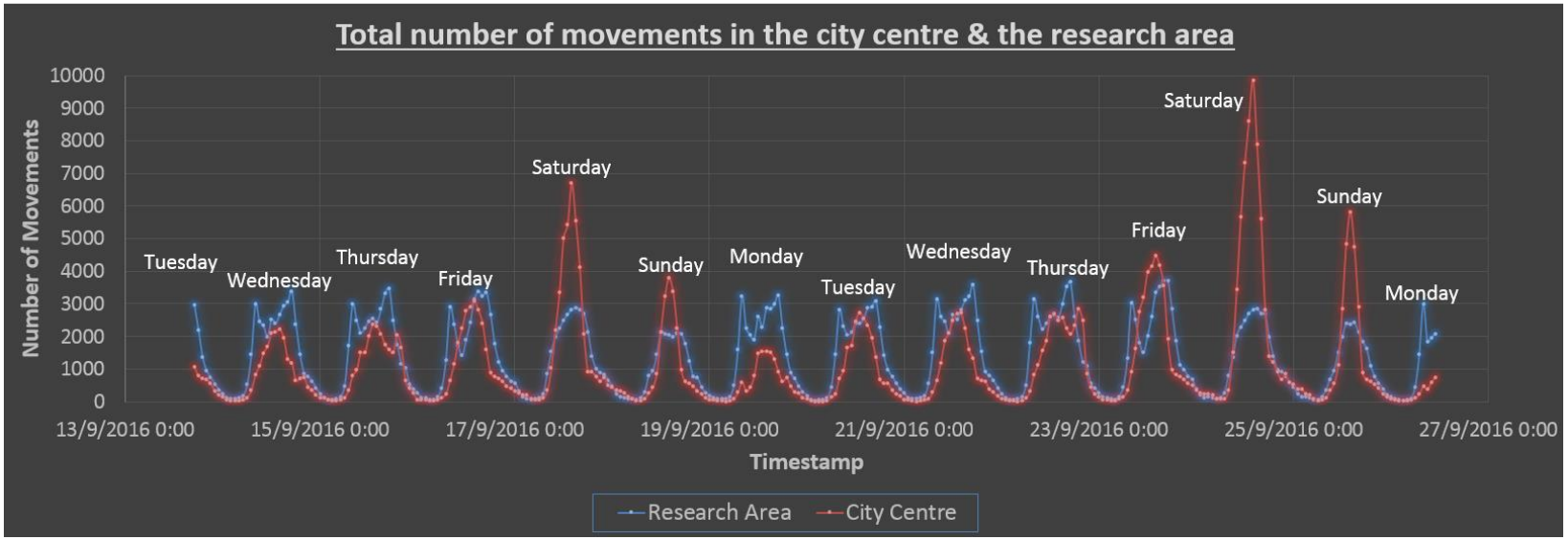


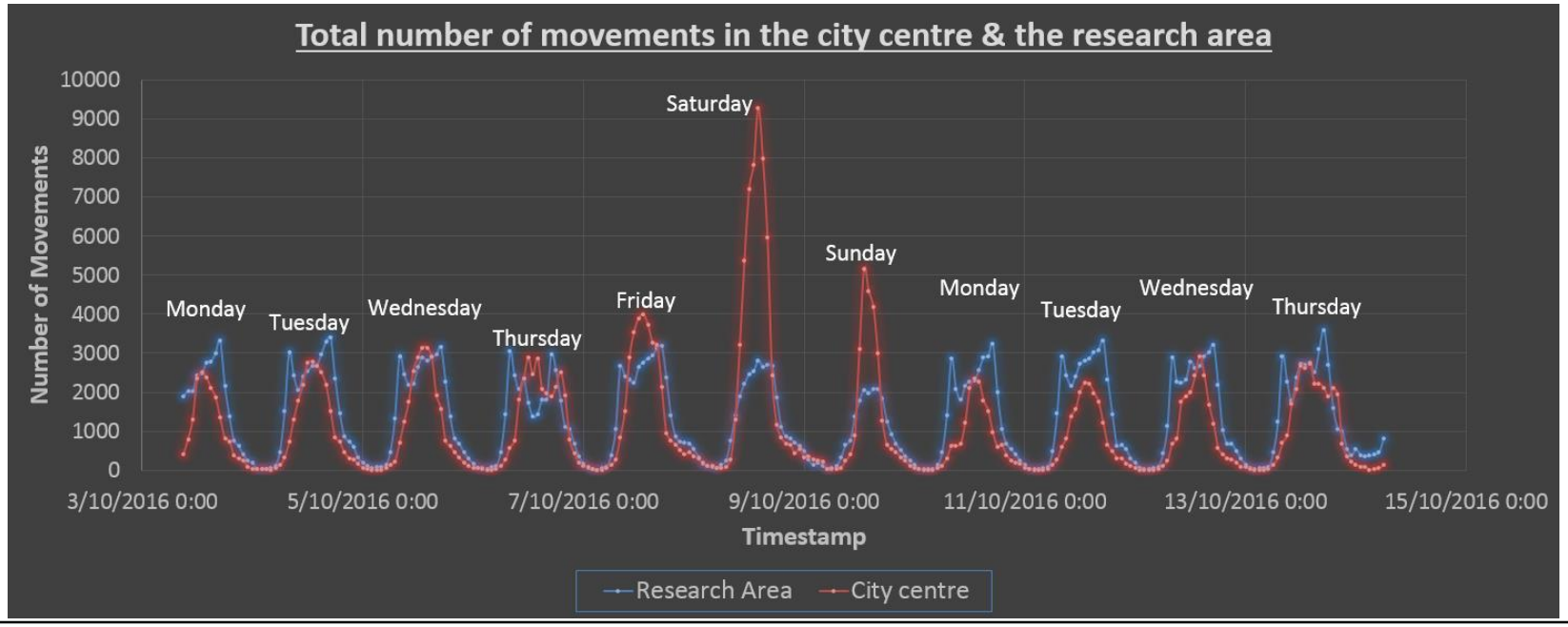

Average hourly total number of movements per street for the days of Monday-Thursday
TOTAL NUMBER OF MOVEMENTS
TIMESTAMP
1-2 1-6 1-8 2-3 3-4 3-5 3-6 4-5 4-6 5-6 5-7 6-7 7-8


Average hourly total number of movements per street for the day of Saturday
TOTAL NUMBER OF MOVEMENTS
TIMESTAMP
1-2 1-6 1-8 2-3 3-4 3-5 3-6 4-5 4-6 5-6 5-7 6-7 7-8



-Occupancy patterns in the surrounding area





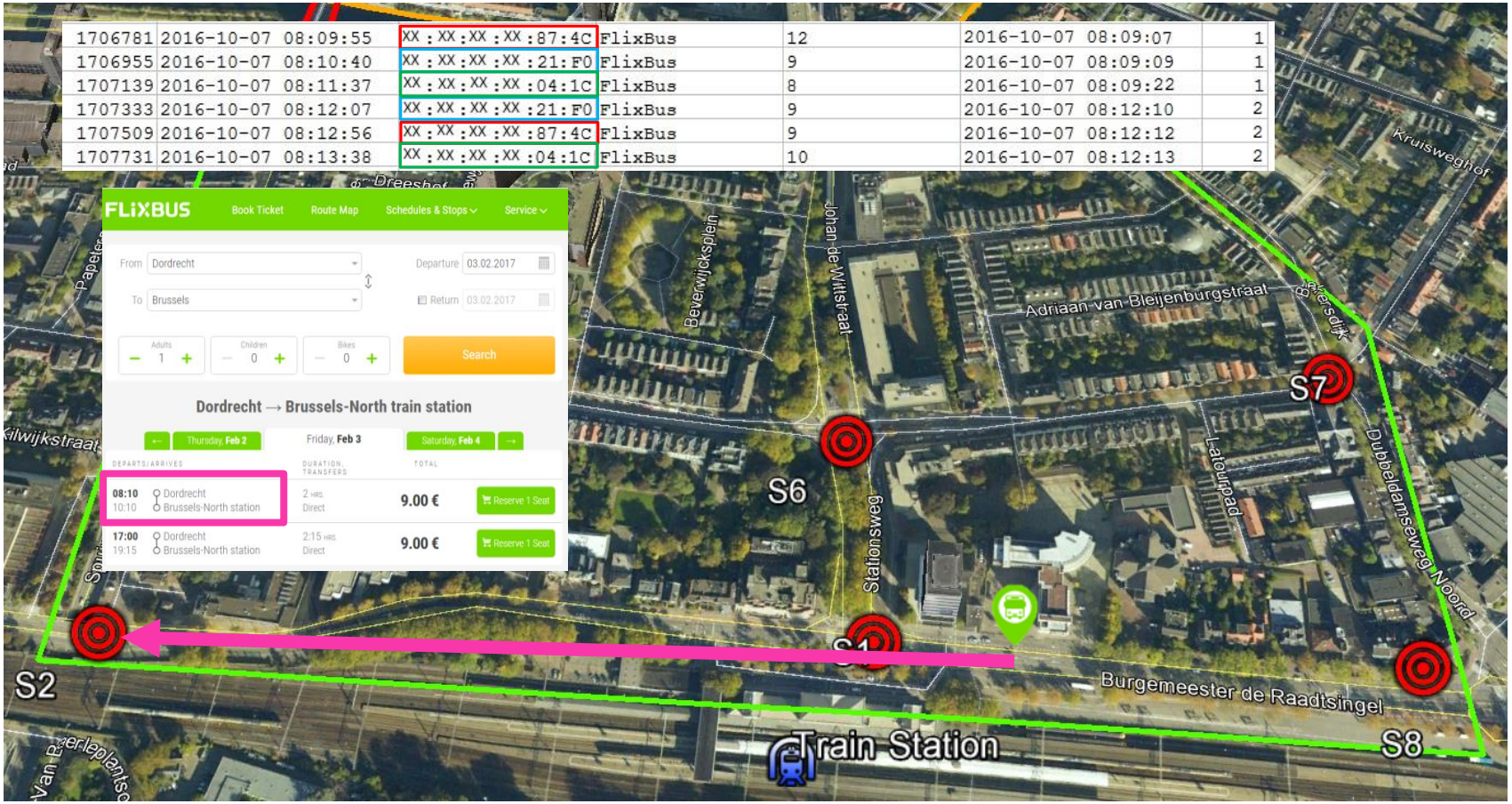
Buses

	id_frame integer	timestamp timestamp without time zone	mac character varying(17)	ssid character varying(32)	rssi character varying(3)	correct_timestamp timestamp without time zone	sensor integer
1	13186145	2016-10-07 07:20:41	00:0C:42:E0:7E:6E	RET WIFI	31	2016-10-07 06:55:22	4
2	13186161	2016-10-07 07:20:49	00:0C:42:E0:7E:6E	RET WIFI	19	2016-10-07 06:55:30	4
3	17275414	2016-10-07 06:55:47	00:0C:42:E0:7E:6E	RET WIFI	11	2016-10-07 06:55:53	5
4	17275528	2016-10-07 06:56:25	00:0C:42:E0:7E:6E	RET WIFI	11	2016-10-07 06:56:30	5
5	23465601	2016-10-07 06:56:38	00:0C:42:E0:7E:6E	RET WIFI	5	2016-10-07 06:56:45	6
6	1689138	2016-10-07 06:56:46	00:0C:42:E0:7E:6E	RET WIFI	8	2016-10-07 06:56:50	1
7	31872167	2016-10-07 06:58:25	00:0C:42:E0:7E:6E	RET WIFI	19	2016-10-07 06:58:31	8

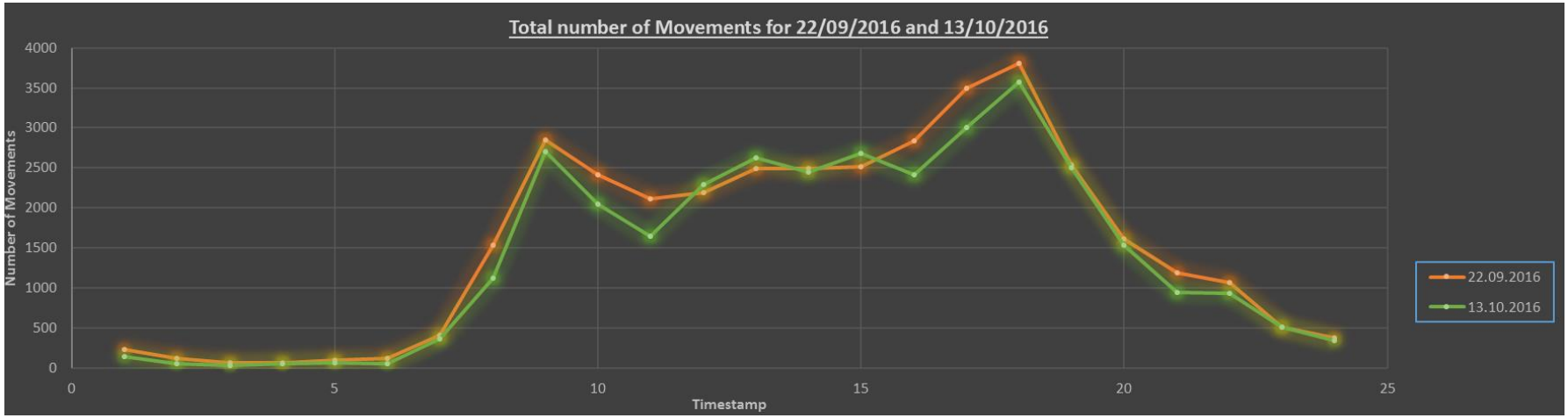
id_frame integer	timestamp timestamp without time zone	mac character varying(17)	ssid character varying(32)	rssi character varying(3)	correct_timestamp timestamp without time zone
1944102	2016-10-08 01:31:21	4C:5E:0C:BF:E5:3C	HotspotArriva 0075	33	2016-10-08 01:31:30
3684238	2016-10-08 01:31:59	4C:5E:0C:BF:E5:3C	HotspotArriva 0075	9	2016-10-08 01:32:09
1944222	2016-10-08 01:32:09	4C:5E:0C:BF:E5:3C	HotspotArriva 0075	27	2016-10-08 01:32:20
3684379	2016-10-08 01:32:23	4C:5E:0C:BF:E5:3C	HotspotArriva 0075	9	2016-10-08 01:32:33
1944335	2016-10-08 01:32:45	4C:5E:0C:BF:E5:3C	HotspotArriva 0075	27	2016-10-08 01:32:56
3684462	2016-10-08 01:33:19	4C:5E:0C:BF:E5:3C	HotspotArriva 0075	9	2016-10-08 01:33:32
1944466	2016-10-08 01:33:27	4C:5E:0C:BF:E5:3C	HotspotArriva 0075	25	2016-10-08 01:33:37

id_frame integer	timestamp timestamp without time zone	mac character varying(17)	ssid character varying(32)	rssi character varying(3)	correct_timestamp timestamp without time zone
2045701	2016-10-08 10:35:48	4C:5E:0C:BF:97:2F	Connexxion Mobile Hotspot	11	2016-10-08 10:36:00
31941463	2016-10-08 10:35:48	4C:5E:0C:BF:97:2F	Connexxion Mobile Hotspot	38	2016-10-08 10:36:01
31941473	2016-10-08 10:36:04	4C:5E:0C:BF:97:2F	Connexxion Mobile Hotspot	16	2016-10-08 10:36:18
2045911	2016-10-08 10:36:18	4C:5E:0C:BF:97:2F	Connexxion Mobile Hotspot	23	2016-10-08 10:36:31
8299285	2016-10-08 10:36:53	4C:5E:0C:BF:97:2F	Connexxion Mobile Hotspot	3	2016-10-08 10:36:55
2046078	2016-10-08 10:37:00	4C:5E:0C:BF:97:2F	Connexxion Mobile Hotspot	34	2016-10-08 10:37:12
2046172	2016-10-08 10:37:41	4C:5E:0C:BF:97:2F	Connexxion Mobile Hotspot	11	2016-10-08 10:37:53

1706781	2016-10-07 08:09:55	XX:XX:XX:XX:87:4C	FlixBus	12	2016-10-07 08:09:07	1
1706955	2016-10-07 08:10:40	XX:XX:XX:XX:21:F0	FlixBus	9	2016-10-07 08:09:09	1
1707139	2016-10-07 08:11:37	XX:XX:XX:XX:04:1C	FlixBus	8	2016-10-07 08:09:22	1
1707333	2016-10-07 08:12:07	XX:XX:XX:XX:21:F0	FlixBus	9	2016-10-07 08:12:10	2
1707509	2016-10-07 08:12:56	XX:XX:XX:XX:87:4C	FlixBus	9	2016-10-07 08:12:12	2
1707731	2016-10-07 08:13:38	XX:XX:XX:XX:04:1C	FlixBus	10	2016-10-07 08:12:13	2



Influence of the weather

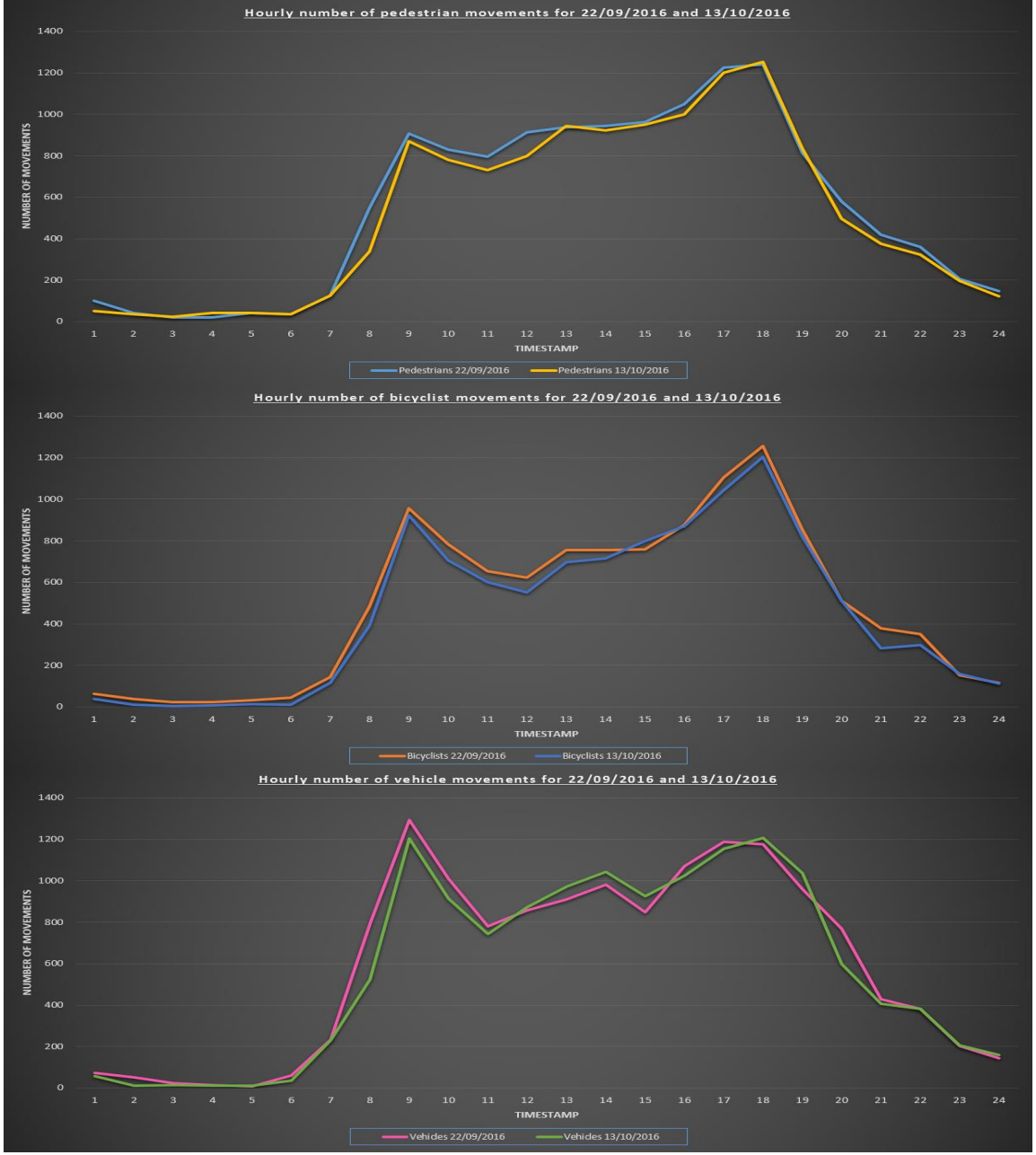


Thursday 22/09/2016

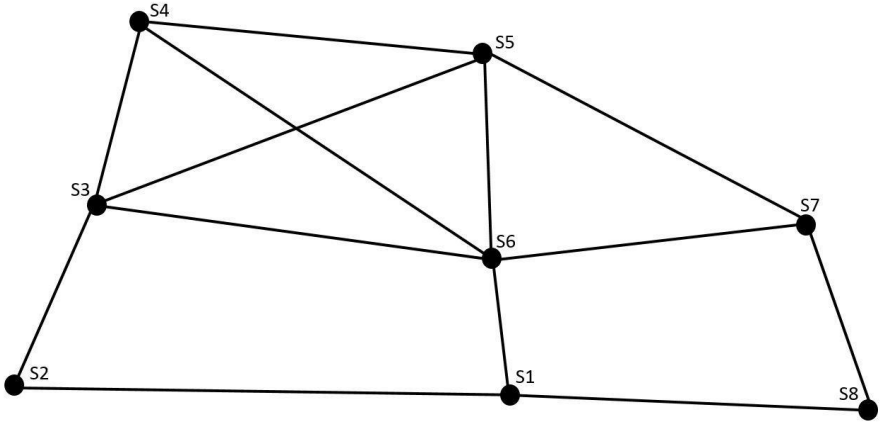
	12am	1am	2am	3am	4am	5am	6am	7am	8am	9am	10am	11am	12pm	1pm	2pm	3pm	4pm	5pm	6pm	7pm	8pm	9pm	10pm	11pm	12am
Forecast	Partly Cloudy	Partly Cloudy	Partly Cloudy	Cloudy	Cloudy	Cloudy	Mostly Cloudy	Mostly Cloudy	Partly Cloudy	Partly Cloudy	Showers	Partly Cloudy	Partly Cloudy	Showers	Partly Cloudy	Partly Cloudy	Partly Cloudy	Showers	Showers	Partly Cloudy	Cloudy	Cloudy	Partly Cloudy	Partly Cloudy	Partly Cloudy
Temp (°C)	13°	13°	13°	12°	12°	12°	12°	12°	13°	14°	16°	18°	19°	20°	21°	22°	21°	20°	20°	19°	17°	16°	15°	15°	14°
RealFeel®	12°	13°	13°	13°	12°	12°	12°	12°	13°	15°	16°	19°	20°	20°	21°	22°	20°	19°	17°	17°	17°	16°	15°	15°	14°
Wind (km/h)	9 E	7 E	7 E	6 ESE	6 ESE	6 SSE	6 SSE	6 SSE	6 SSE	7 SSE	7 SSE	9 SSE	9 S	11 S	11 S	11 SSW	11 SSW	9 SW	11 SSW	9 S	9 S	7 S	7 SSW	7 SW	7 SW

Thursday 13/10/2016

	12am	1am	2am	3am	4am	5am	6am	7am	8am	9am	10am	11am	12pm	1pm	2pm	3pm	4pm	5pm	6pm	7pm	8pm	9pm	10pm	11pm	12am
Forecast	Cloudy	Mostly Cloudy	Mostly Cloudy	Cloudy	Partly Cloudy	Mostly Clear	Mostly Clear	Mostly Clear	Mostly Clear	Mostly Sunny	Mostly Sunny	Partly Sunny	Partly Sunny	Partly Sunny	Partly Sunny	Partly Sunny	Partly Sunny	Partly Sunny	Partly Sunny	Partly Cloudy	Cloudy	Cloudy	Cloudy	Cloudy	Cloudy
Temp (°C)	7°	7°	6°	6°	6°	6°	5°	5°	6°	7°	8°	9°	10°	11°	11°	12°	12°	11°	11°	10°	10°	9°	9°	9°	9°
RealFeel®	4°	3°	3°	3°	2°	2°	2°	1°	1°	3°	3°	4°	5°	6°	7°	8°	8°	7°	7°	6°	6°	5°	5°	5°	4°
Wind (km/h)	13 ENE	15 ENE	15 ENE	15 ENE	15 ENE	15 ENE	17 E	17 E	17 E	18 E	22 E	28 E	30 E	30 E	28 E	28 E	28 E	26 E	26 E	24 E	20 E	18 E	18 E	20 E	20 E

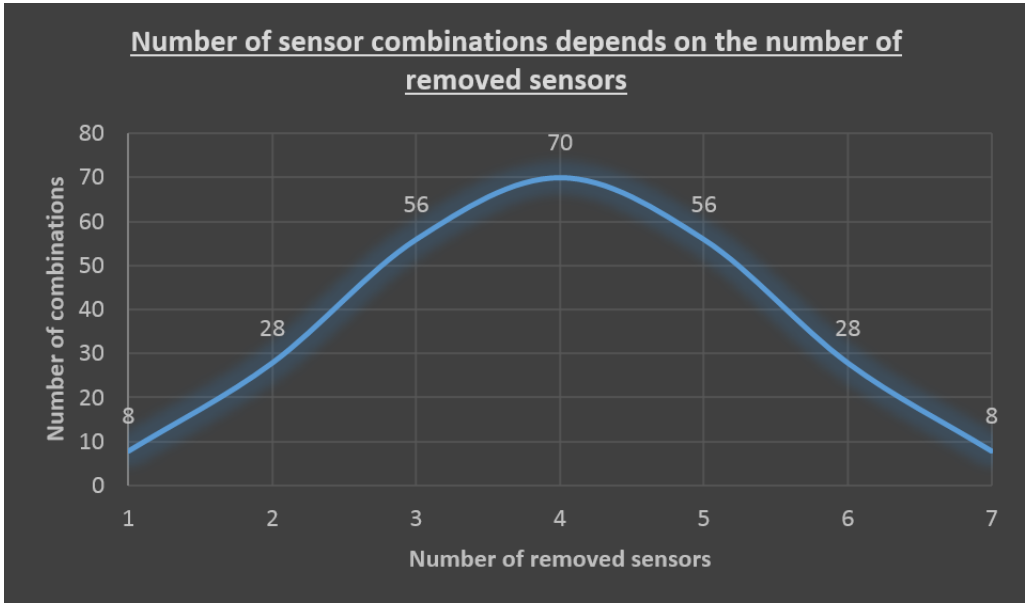

Hourly number of pedestrian movements for 22/09/2016 and 13/10/2016
NUMBER OF MOVEMENTS
TIMESTAMP
Pedestrians 22/09/2016
Pedestrians 13/10/2016
Hourly number of bicyclist movements for 22/09/2016 and 13/10/2016
NUMBER OF MOVEMENTS
TIMESTAMP
Bicyclists 22/09/2016
Bicyclists 13/10/2016
Hourly number of vehicle movements for 22/09/2016 and 13/10/2016
NUMBER OF MOVEMENTS
TIMESTAMP
Vehicles 22/09/2016
Vehicles 13/10/2016

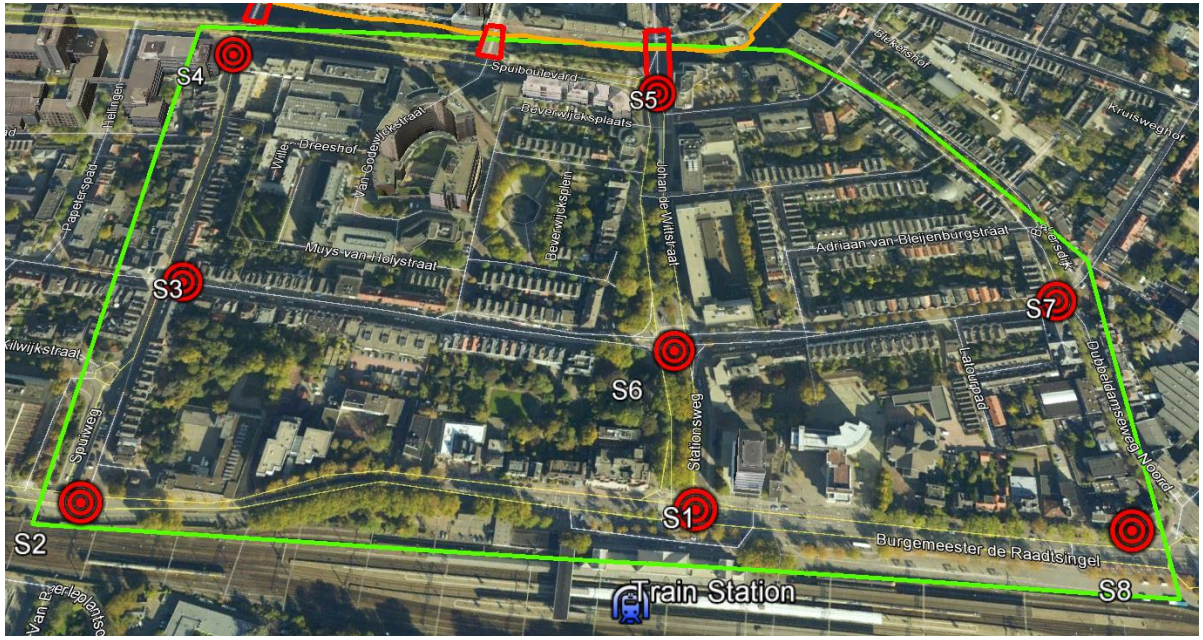
Influence of Wi-Fi monitoring setup



NP-complete problem

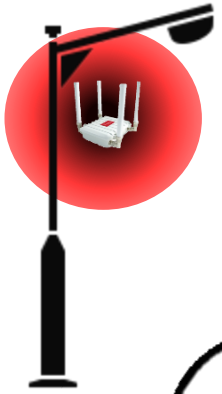
$$\binom{n}{r} = {}_nC_r = \frac{n!}{r!(n-r)!}$$

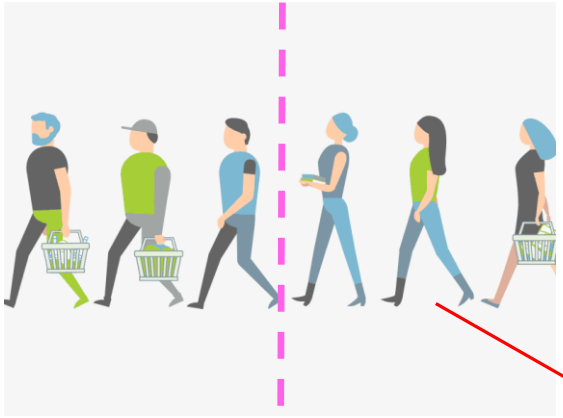


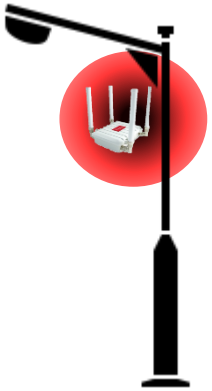


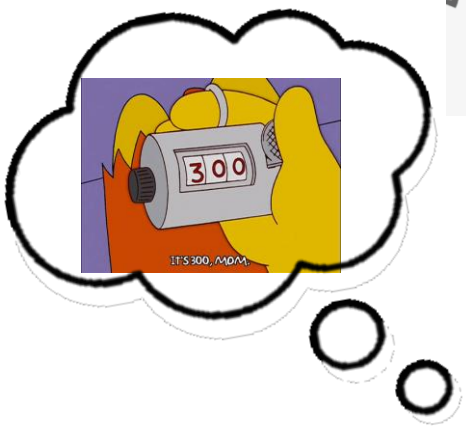
Sensor	Number of connected streets	Average number of related movements	Affected % of the total daily movements
1	3	16487	54.3
2	2	6479	21.4
3	4	3249	10.7
4	3	2553	8.4
5	4	8311	27.4
6	5	17669	58.2
7	3	2188	7.2
8	2	3750	12.4

Validation

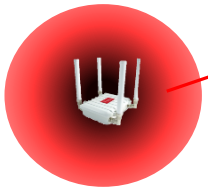








Validation



Total number of counted “pedestrians” devices

VS

Expected number of “pedestrians” devices

% of people with enabled Wi-Fi devices

Validation

- **Total number of pedestrians: N**
- **Number of asked pedestrians: n**
- **% of asked pedestrians who had enabled the Wi-Fi functionality: $\hat{p}_x$**
  Simple random sampling with Bernoulli trial (Yes /No)

If a population proportion is equal to p,
then the sampling proportion $\hat{p}_x$ follows the binomial distribution,
and the confidence interval in confidence level 1-α is:

$$\hat{p}_x - z_{1-\alpha/2}\sqrt{\frac{\hat{p}_x(1-\hat{p}_x)}{n}} \le p \le \hat{p}_x + z_{1-\alpha/2}\sqrt{\frac{\hat{p}_x(1-\hat{p}_x)}{n}}$$

Validation

Example:

- In a period of 1 hour 500 went from S1 to S2. We asked n= 80 and from them a percentage of $\hat{p}_x$=0.40 had enabled the Wi-Fi functionality.

- For confidence level 1-α=0.95 the confidence interval for the proportion is:

$$0.40 - 1.645\sqrt{\frac{0.40 \cdot 0.60}{80}} \leq p \leq 0.40 + 1.645\sqrt{\frac{0.40 \cdot 0.60}{80}}$$

$$0.31 \leq p \leq 0.49$$

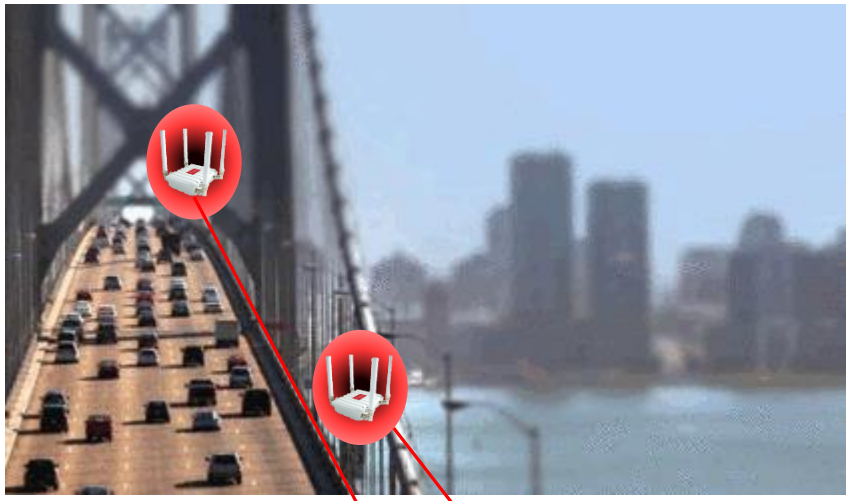
- Thus, the confidence interval limits for the total number of pedestrians are equal to:

(500 * 0.31 , 500 * 0.49)

(155 , 245)

Day	Date		Time	Direction	Tested category	Counted (N)	Questionnaire Sampling (n)	Enabled Wi-Fi (%)	Confidence Interval 90%	Sensors Outcome
Sunday	18-Sep-16		16-17	5→6	Pedestrian	343	62	42%	(109 , 179)	129
"	"		17-18	"	Bicyclist	254	32	39%	(63 , 135)	107
Monday	19-Sep-16		08-09	1→2	Pedestrian	381	66	42%	(122 , 198)	146
"	"		09-10	"	Bicyclist	226	31	38%	(53 , 118)	95
Tuesday		27-Sep-16	10-11	6→1	Pedestrian	348	59	41%	(106 , 179)	129
"		"	11-12	"	Bicyclist	281	33	40%	(73 , 152)	100
Wednesday	21-Sep-16		12-13	1→6	Pedestrian	406	64	41%	(125 , 208)	182
"	"		13-14	"	Bicyclist	153	32	43%	(44 , 88)	64
Thursday		29-Sep-16	14-15	2→1	Pedestrian	98	48	43%	(31 , 54)	39
"		"	15-16	"	Bicyclist	143	31	38%	(34 , 75)	56
Friday	23-Sep-16		16-17	6→5	Pedestrian	388	61	45%	(134 , 215)	169
"	"		17-18	"	Bicyclist	227	34	41%	(62 , 125)	97
Saturday		01-Oct-16	13-14	4→5	Pedestrian	102	49	47%	(36 , 60)	39
"		"	14-15	"	Bicyclist	97	32	44%	(29 , 57)	38

Validation



- Number of users in each vehicle
- % of users who have enabled the Wi-Fi functionality
- System counted accuracy

Total number of counted “car” devices

Total number of vehicles

Day	Date		Time	Direction	Counted (N)	Sensors Outcome	Estimated number of users	Estimated % of Enabled Wi-Fi (based on assumption)
Sunday	18-Sep-16		13-14	1→6	110	76	165	46.1
"	"		14-15	6→5	88	63	132	47.7
Monday	19-Sep-16		16-17	1→2	193	130	290	44.9
Tuesday		27-Sep-16	09-10	6→1	132	87	198	43.9
Wednesday	21-Sep-16		08-09	4→5	53	33	80	41.5
Thursday		29-Sep-16	12-13	3→6	22	16	33	48.5
"		"	17-18	1→8	141	99	212	46.8
Friday	23-Sep-16		15-16	5→6	165	111	248	44.8
"	"		18-19	6→7	44	28	66	42.4
Saturday		01-Oct-16	10-11	3→4	40	27	60	45.0
"		"	11-12	2→1	101	71	152	46.9

Conclusions

What kind of road modality and occupancy patterns can be recognized by Wi-Fi monitoring sensors in a city area in order to support the "Smart City" concept?

Road modality

In total

Per street

Occupancy patterns

- Congestions
- Recessions
- Trends throughout the day
- Differences between the different days

Research area

Surrounding area

Each user category

Cumulative movements

➢What is the influence of the Wi-Fi monitoring setup?

- Kind of antenna

360º

180º

- Time synchronization

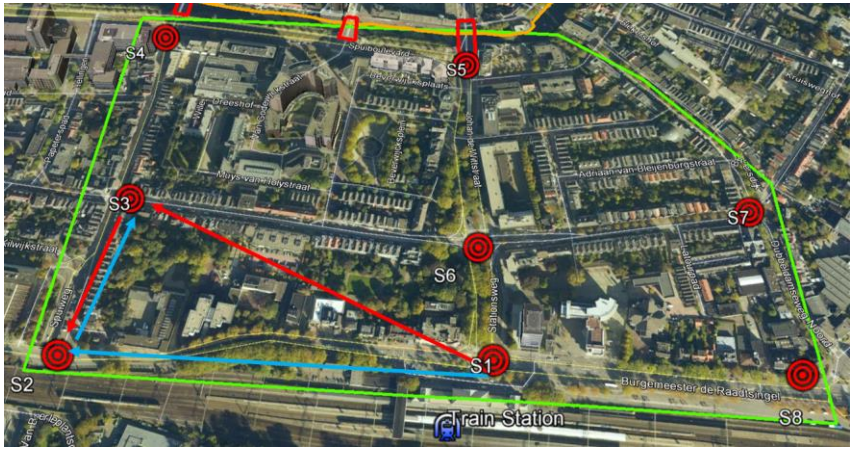
Exact selection of research area
Filtering procedure

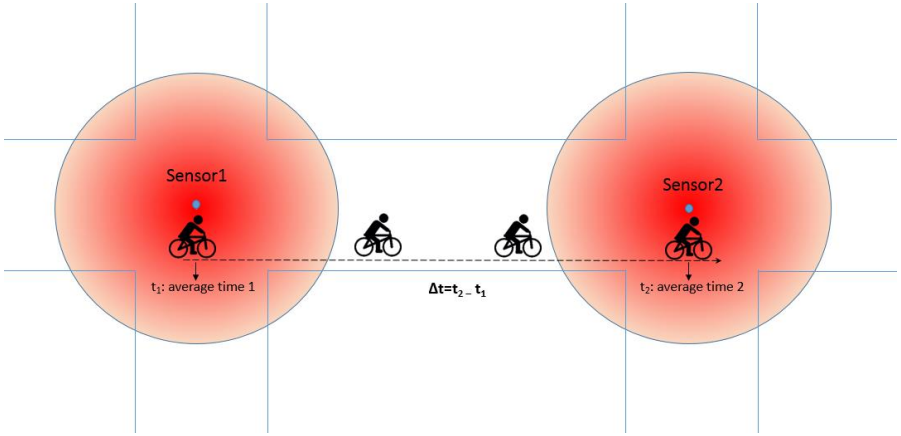
- Distances between sensors

s1-s1-s1…-s1-s2- s2-s2-s2…-s2

- Number of sensors & location of sensors

s1-s1-s1…-s1-s2-s1-s2-s1-s2-s2-s2…-s2





➢What are the performance parameters of Wi-Fi monitoring and how we can measure them?

Accuracy	Quite good
Availability	Very good
Continuity	Very good
Integrity	Quite poor
Yield & consistency	Quite good & fair
Overhead	Fair
Power consumption	High
Latency	Very low
Roll-out & operating costs	Moderate

Recommendations

- The identification of the optimal Wi-Fi network configuration
- Overlapping cases
- Larger areas, different environments (traffic jam)
- Fluctuated speed criteria (time, total number of scanned devices)
- Total number of records of each user category by each sensor
- Longer timeslots instead of hourly sets

- External data sources for validation
- Simultaneous comparison of system results with real data
- Average number of people per vehicle
- Average number of devices per user

- The identification of a higher number of user categories
- Repeatability in regard of the use of means of transport
- Computation of average speed for each user category
- Comparison of average speed with occupancy level
- Capacity level – Computation of Level Of Service (LOS)

Thank you for your attention