# 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

**MSc Geomatics Thesis Proposal**

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## 1. Introduction / Motivation

Today, half of the world population and 80% of European citizens live in cities, the world urbanization continues to grow and the total population is expected to double by 2050 (*World Urbanization Prospects, 2014*) Furthermore, this increase has inevitably led to a simultaneous increase of vehicles. The combination of this growth with the fact that the size of the Earth remains the same, results in a significant problem for humanity which must be dealt with (*Rick Robinson, 2016*).

As an effort to solve this problem, there is the immediate demand for a better monitoring and exploitation of space using intelligent and sustainable environments which will offer citizens a high quality of life. This demand has leaded to the creation of the new term and worldwide trend toward the “Smart Cities” (*European Innovation Partnership on Smart Cities and Communities, 2013*). The significance of this effort can also be demonstrated by the fact that the European Union has already devised a strategy for supporting the Smart Cities concept. It has developed a range of programs as well as subsidizing related research to ‘smarten up’ Europe's urban areas. It is estimated that the global market for smart urban services will be $400 billion per year by 2020 (*Department for Business Innovation & Skills, 2013*).

The turn toward smart cities consists of two main concerns: the chase of sustainability as a way to support a more inclusive, diverse and sustainable environment, green cities with less energy consumption (*Mark Deakin, 2014*) and the increasing use of new internet technologies such as mobile phones, smart devices, sensors and the Internet of Things (*Mark Deakin, 2014*). The combination of the latter concern with theories and methodologies from other fields, such as knowledge and innovation management, is possible to overturn the established way of urban development and planning (*Mark Deakin, 2014*). Three terms can be used to describe the main steps of the evolution of urban planning as part of the “Smart Cities” concept: 1) the *interconnection*, as the ability to take advantage of the technology and the use of internet in order to enable different parts of a system to be joined and communicate to each other *(Miller, 2015)*; 2) the *instrumentation*, as the appropriate use of this system in a city to get data all around the clock as key performance indicators; and 3) the *intelligence*, as the ability to use the gathered information to develop behavior patterns and predictive models of urban flows (*Mark Deakin, 2014*). Thus, the existed new technologies in combination with the use of internet can act as a collection way of useful information for the city planning procedure. The exploitation of this system can be done both before, as pre-processing data provider, and after the urban planning, as a way to evaluate the effect of changes (post-processing tool).

The required information for the city development and planning consists of the road modality and the relative occupancy patterns. Knowledge about the percentage of pedestrians, bicyclists, and vehicles as well as the rhythm of their changes during the time will constitutes the essential foundation for the urban design. Moreover, apart from the city planning, this information can be efficiently used for many other purposes, such as monitoring of traffic networks, crowd control, use of facilities, and marketing purposes.

However, the collection of this information constitutes the most difficult part of this effort. During the previous years, the sample counting of vehicles and pedestrians by people in specific parts of the research area was the most frequently used method of data collection. It is a method which is very accurate and the results represent the reality but there are many disadvantages. Firstly, it is time consuming and many employees are required to collect the data only for a small part, as each of them can count one category of road users. Furthermore, as this method is based on manpower, it is clear that it cannot be applied for long periods of time to a large area under, perhaps, difficult weather conditions. Finally, despite the accuracy of this method, it is not possible to have real-time results as well as monitoring which is required for the identification of occupancy patterns (*Traffic Monitoring Guide, 2013*).

As a result of all disadvantages of the classical method of counting, there exists a demand for alternative ways of data collection and the evolution of technology constitutes a determinant factor for this investigation. Already there are many different kind of methods which can be used like inductive loops, pressure sensors, infrared cameras, and video detection system. However, each method has weaknesses which do not allow the independent and exclusive use of it. For instance, the inductive loops system cannot count pedestrians, especially in group movements, pressure sensors are quite expensive to be installed, infrared cameras system cannot distinguish between bicyclists and pedestrians, while algorithms for the video detection systems is still under development. Moreover, both of them do not provide the ability to "follow" users, under the relative privacy directions, as a way for the identification of occupancy patterns (*Traffic Monitoring Guide, 2013*).

One other alternative method, the use of which is continuously increased during the last years, is the Wi-Fi monitoring. Nowadays most people carry one or more mobile devices around with them that have Wi-Fi and Bluetooth functionality. Furthermore, all the contemporary vehicles are constructed with the ability to link to a smartphone or contain already a kind of smartphone as service. Thus, when users switch on the relative Wi-Fi or the Bluetooth functionality, devices start to send out a signal all the time in their search for a Wi-Fi access point. This signal contains an ID number, MAC address, which is unique for each device. Taking advantage of the technology, many companies have produced sensors which can detect these signal transmissions and count them within a relative range as well as some more details such as the received signal strength indication (RSSI) and the vendor of the device. Based on that, it is possible to use this method as a way to count these devices but also to investigate their movement in space by the installation of a network of sensors in the research area (*Musa et al., 2012*).

An important advantage over other techniques, is that Wi-Fi monitoring system does not require the active participation of users and it works without any modification, as it is not necessary to install any application on the relative device. Furthermore, despite other methods such as GPS, it is not necessary to request the provider to get access to the relative data since, by the use of sensors, the owner can have real-time access to the collected information. Finally, apart from the monitoring ability, Wi-Fi sensors can also be used as a way to offer (free) Wi-Fi network. By this way, the activation of Wi-Fi functionality by more users can be promoted leading to a higher amount and more representative data.

Taking into account the abovementioned advantages of the Wi-Fi system, it is clear that it can be used for the creation of a real-time monitoring, if it is required for the relative purpose, and data collection system as a way to support the main philosophy of the 'Smart cities' concept.

For this thesis, a part of the city of Dordrecht will be used as the research area, where the relative methodology, tests, and results, apart from the scientific purposes, will be applied to support "the Smart City of Dordrecht" concept. In following chapter it will described in depth the characteristics of the area and the reasons of its selection.

# 2. Literature Review

Location monitoring techniques can be classified into two categories:

- Systems which require the "active" participation of people (active systems). This means that the person is carrying an electronic device sending information to the system.

- Systems using passive localization (passive systems). This means the position is estimated based on the variance of a measured signal (*Deak et al., 2011*).

During the last years, taking advantage of the evolution of technology, many "active" and "passive" techniques have been invented in order to be used for the identification of road modality and occupancy patterns. Each of them has unique benefits over the others but also significant drawbacks which do not allow their independent application without the need for other method (*Traffic Monitoring Guide, 2013*).

According to (*Traffic Monitoring Guide, 2013*), the most frequently used and known techniques are:

**-** *Inductance Loop*: Inductance loop detectors operate by circulating a low alternating electrical current through a formed wire coil embedded in the pavement. The alternating current creates an electromagnetic field above the formed wire coil, and a conductive object, like a car or a bike, passing through the electromagnetic field will disrupt the field by a measurable amount. The sensitivity of an inductance loop can be changed in order to increase the detection accuracy of motorcycles or bicycles. However, the increased sensitivity often leads to cars overcounting. Furthermore, this method cannot be used for the research of pedestrians' movement while accurate problems exist in cases of groups.

-*Magnetometer:* It operates by detecting changes in the normal magnetic field of the Earth caused by a ferrous metal object. As the previous method, it cannot be applied in cases of pedestrian's movement while few commercially available magnetometers designed for bicycle detection and counting exist.

-*Pressure, Seismic sensor:* Pressure sensors operate by detecting changes in force, weight, while seismic sensors use the passage of energy waves through the ground caused by feet, bicycle tires, or other non-motorized wheels as a way for movement detection. As main disadvantages of these methods we can refer the high-cost for their placement under the road, the limited number of commercially available sensors as well as the low accuracy for the separation pedestrians and bicyclists.

-*Video imaging system:* One other technique is the use of video image processing. It operates by using visual pattern recognition in order to identify and count a pedestrian or bicyclist movement through a video camera's range. Despite the significant improvement of the pattern recognition algorithm, problems about the separation of users in cases of group travelling have not yet solved as well as the influence of weather and lighting conditions to the outcome accuracy (*Zervos, 2013*).

Apart from the automatic detection use of video system, there is also the manual option of this system by viewing recorded video from intersection control or surveillance cameras. This manual approach is practical and low-cost for periodic short-term counts, but is not sustainable for continuous monitoring purposes.

-*Infrared cameras:* As it is clear from the name, in this technique a specific light sensor is used to detect a select light wavelength in the Infrared spectrum. Thus, there are difficulties in the separation between bicyclists and pedestrians as well as in cases of multiple person's movement.

-*Pneumatic Tube:* In this method, an air switch is used to detect short burst of air from a passing motorized or non-motorized vehicle. Despite the fact that it is considered a low-cost and portable approach, it can be applied only for counting of bicyclists.

| Technology | Typical Applications | Strengths | Weaknesses |
|---|---|---|---|
| **Inductance Loop** | Permanent counts<br>Bicyclists only | Accurate when properly installed and configured<br>Uses traditional motor vehicle counting technology | Capable of counting bicyclists only<br>Requires saw cuts in existing pavement or pre-formed loops in new pavement construction<br>May have higher error with groups |
| **Magnetometer** | Permanent counts<br>Bicyclists only | May be possible to use existing motor vehicle sensors | Commercially-available, off-the-shelf products for counting bicyclists are limited<br>May have higher error with groups |
| **Pressure sensor/pressure mats** | Permanent counts<br>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<br>Bicyclists and pedestrians separately | Potential accuracy in dense, high-traffic areas | Typically more expensive for exclusive installations<br>Algorithm development still maturing |
| **Infrared – Active** | Short-term or permanent counts<br>Bicyclists and pedestrians combined | Relatively portable<br>Low profile, unobtrusive appearance | Cannot distinguish between bicyclists and pedestrians unless combined with another bicycle detection technology<br>Very difficult to use for bike lanes and shared lanes May have higher error with groups |

Table 1: Commercially-available bicyclist and pedestrian counting technologies (*Traffic Monitoring Guide, 2013*)

Table 1 contains a summary of the characteristics of each method with the relative benefits and drawbacks while figure 1 shows the same techniques grouped by their application and the duration of the data collection.

1. What Are You Counting?

| 2. How Long? | 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 | ○ | ○ | ○ | ● | $-$$$ |
| Temporary/ Short Term | Manual Observers | ● | ● | ● | ● | $$-$$$ |

○ Indicates what is technologically possible.
● Indicates a common practice.
◐ Indicates a common practice, but must be combined with another technology to classify pedestrians and bicyclists separately.
$, $$, $$$: Indicates relative cost per data point.
[1] Typically requires a unique loop configuration separate from motor vehicle loops, especially in a traffic lane shared by bicyclists and motor vehicles.
[2] Permanent installation is typical for asphalt or concrete pavements; temporary installation is possible for unpaved, natural surface trails.
[3] Requires specific mounting configuration to avoid counting cars in main traffic lanes or counting pedestrians on the sidewalk.

Figure 1: Simplified flowchart for selecting non-motorized count equipment (*Traffic Monitoring Guide, 2013*)

As it is clear from the short description of the techniques, none of them can be applied independently for the identification of the road modality. Each method focuses more on one category but there is no a unique technique which can count simultaneously the vehicles, the bicyclists, and pedestrians. Furthermore, none of the above mentioned methods can be used for the investigation of movement and occupancy patterns as they have the capability to count but not to monitor devices as users change locations.

One other method which is frequently used for detecting, analyzing, and modeling human movement behavior is the Global Positioning System, GPS. The position of the device is calculated based on the information it receives from several satellites and the computation of the relative distances to them (*Hofmann et al., 2008*). Using GPS technology, researchers can collect data on the routes followed by individuals to analyze how they interact with the geographical features in the area. However, despite the capability of this method to “follow” the devices in space, it is very difficult to get the relative data, as it is necessary to request the provider and maybe pay for that. Also, the filtering of data based on the research area is one other problem as well as the inability for a real time access and analysis. Finally, in high-density areas, such as city centers, there are problems from signal reflections due to surrounding buildings, reducing considerably the relative accuracy (*van der Spek et al., 2013*).

As an alternative method trying to overcome the problems of the previous-mentioned techniques, it is possible to use the Wi-Fi signal. This can be done by access points, APs, or by the use of scanning devices that are made for this purpose (*Henniges, 2012*). During the last years smartphone sales and use have seen explosive growth while the majority of them come with a Wi-Fi network interface. Searching for available access points, devices send out a signal all the time. Thus, it is possible to detect these transmissions by the use of Wi-Fi monitoring equipment. Furthermore, as each transmission contains a unique identifier, called MAC address, this Wi-Fi monitoring system can be applied as a means for aggregate movement research in a specific area of interest and not only as a counting method (*Musa et al., 2012*).

However, due to privacy issues, the MAC addresses collected by the sensors have to be hidden in order to avoid possible misuse of this information. In Europe, a MAC address is considered private personal information by the European Personal Data Protection directive. In Opinion 9/2014, on device fingerprinting from the Article 29 Working Party (WP29), accessing the MAC address of a WiFi device is considered to be covered by Article 5 of the ePrivacy Directive. This is because even though the MAC address itself does not provide information about an individual, it is permanent to a given device and because it is easy to intercept using a WiFi network adapter, router; or a simple sensor. Therefore, a MAC address can be used for the research of the movement of a person as his or her MAC address is detected at different sensor points (European Digital Rights, 2015). Apart from the hiding need of MAC address, as it was mentioned in Article 6, personal data could be collected for specified, explicit and legitimate purposes including historical, statistical or scientific purposes provided the appropriate safeguards. Thus, measures mandated by the Personal Data Protection directive of the European Union, as well as those given by the 2002/58/EC Directive ,which safeguards personal data in electronic communications, should be complied within the data collection procedure by the sensors for this thesis and as well as for use of the Wi-Fi monitoring system.

The use of the Wi-Fi signal can be done by active or passive way. In the first case, Wi-Fi localization requires the modification of each device in order to listen the un-instrumented stationary access points. On the other hand, the passive Wi-Fi monitoring system consists of a number of sensors and a central server without the active participation of users, being one the main advantages of the method (*Musa et al., 2012*). Taking into account the capabilities of this method as well as the fact that the range of the Wi-Fi monitoring sensors is bigger than the ordinary streets width at cities, it is clear that this system can be used as a permanent way of data collection. Furthermore, apart the monitoring capability, Wi-Fi sensors can also act as usual Wi-Fi routers. Thus they can be used for the installation of a WLAN, supporting by this way the increased trend for available WLANS in public spaces under the main philosophy of the “Smart Cities” concept. Finally, unlike the previous mentioned techniques, the collection the total amount of devices with on the Wi-Fi functionality in the range of sensors is feasible, without limitations about the category in which the owner of the device belongs (pedestrian, bicyclist, vehicle). However, due to this massive data collection, further research is required for the identification of the road modality.

During the last years there are many efforts about the use of the Wi-Fi system of sensors. In the research of Rose et al., (*2010*), Wi-Fi detections were used to predict bus and train arrival times based on Wi-Fi access points installed in these vehicles while Musa and Eriksson (*2012*) use Wi-Fi monitors in order to track unmodified smartphones. Moreover, many efforts are focused on the research of human behavior under different circumstances. Duynstee et al., (*2016*) installed a network of four Wi-Fi monitoring sensors in the city center of Dordrecht for a period of two weeks. By the use of this system, details about all devices with enable the Wi-Fi functionality were collected and after a relative analysis pedestrian movement patterns were identified. Differences about the use frequency of the streets were investigated as well as "hot" periods and changes during the week. As a validation method, data from counting cameras system were used designating a close linear relation between total amount of pedestrians and total amount of detected devices, verifying by this way the efficient use of this method. Finally, the same technique was used by Kalogianni et al.(*2015*) in the campus area of TU Delft in order to investigate the number of people who visit multiple buildings in a certain timespan. By this way, useful information about the shared facilities of different buildings and the occupancy management of the area was exported.

Due to the evolution of technology during the last fifteen years there have been significant improvements in the monitoring technology providing the opportunity to have a wide range of georeferenced disaggregate spatial behavior data (*Jung et al. 2012*) and investigate the moving point of objects over time (*Kwan 2004; Andrienko et al. 2008; Orellana et al. 2010*). Unlike the potential diversity of movement, people usually follow simple and predictable movement patterns which can be very useful to explain the interactions between moving entities and between those entities and the environment (*Orellana et al., 2012*). For instance, figure 2 illustrates the trajectories of four moving entities over twenty steps. From these trajectories we can identify: a flock of three entities over five time-steps, a periodic pattern where an entity shows the same spatio-temporal pattern with periodicity, a meeting place where three entities meet for four steps, and finally, a frequently visited location which is a region where a single entity spends a lot of time (*Gudmundsson, Laube, & Wolle, 2008*).

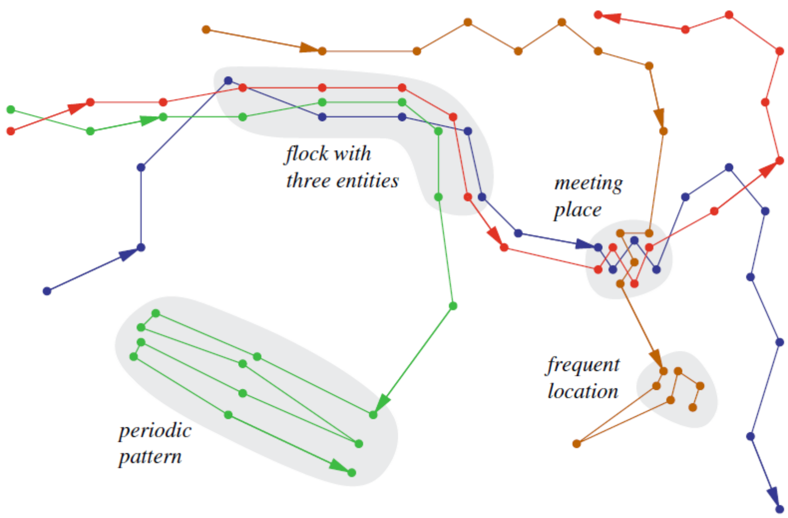


Figure 2: Patterns of Trajectory Movements
(*Gudmundsson, Laube, & Wolle, 2008*)

# 3. Research Objectives

## 3.1 Objectives

The main research question for this thesis is:

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

To be able to answer this main question, secondary questions have been formulated:

- 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?

As it is clear, the abovementioned sub-questions can be grouped in four categories based on their focus. Thus, the first one is related about the technical parameters of the used method, the next category focuses on the movement patterns while the last two sets of sub-questions are associated with the identification of road modality and occupancy patterns respectively.

### 3.2 Scope of research

This thesis will focus on the use of Wi-Fi monitoring sensors data from the research area in order identify the relative road modality and occupancy patterns. The identification of the most appropriate Wi-Fi network configuration will not be investigated in this research. However, the influence of some parameters to the final result such as the total number of sensors is possible to be studied.

## 4. Research Area

As it was mentioned in previous chapter, the application of this research will be made in a part of the city of Dordrecht, and more specifically in the area between the city center and the central railway station. There are many reasons to justify the choice of this area. First of all, Dordrecht is a city with a great deal of interest and enthusiasm for the “Smart Cities” idea. Many research projects have already begun for the development of the city and the exploitation of the technology, like the “Smart City of Dordrecht”.

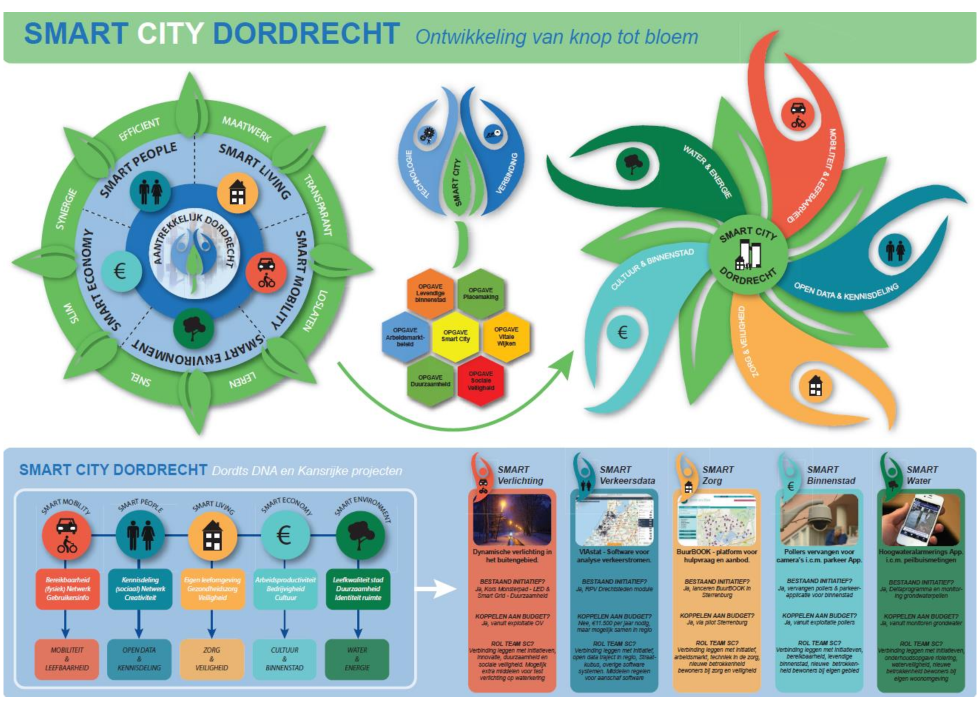


Figure 3: Poster about the Smart City project from the Municipality of Dordrecht

The selected part of the city constitutes the interface between the city center, where the majority of shops and offices are situated, and the central station, which comprises the basic means of transport to and from neighboring cities like Rotterdam. This close distance to Rotterdam is also one of the main reasons that the city is used more as place of residence. Thus, significant changes in the movement flows and occupancy patterns are expected during the day when citizens go and return from their jobs. Furthermore, due to the significance of this region local authorities want to rebuild it in order to change the land uses and increase the level of public services. There is no preliminary information about the road modality and occupancy patterns of the region and thus the outcome of this research will be very useful for the urban planning of the area (pre-processing tool). Finally, the addition ability of Wi-Fi sensors to act of Wi-Fi router is directly related to the willingness of the municipality of Dordrecht to set a free WLAN network, while a possible future installation of this system will be used for the evaluation of changes, as a post-processing tool.


Figure 4: Part of the city of Dordrecht. Green line represents the boundary of the research area while the orange one the city center

## 5. Methodology

The research methodology that is going to be applied in order to address the abovementioned issues consists of the following six key stages:

- Design of the observation network, zero-level test and data collection
- Data preparation
- Movement patterns
- Road Modality
- Occupancy patterns
- Validation
- Test setup

The first two stages can be characterized as pre-processing procedure while the following four constitute the main steps for the analysis.

More specifically, an observation network has to be designed in the area where the Wi-Fi monitoring method will be applied. In order to do it, there are many parameters which should be taken into account. First of all, the number of available sensors should be distributed evenly over the space with the same level of cover in order to allow a representative data collection. Furthermore, technical specifications of devices such as the range of devices, the water protection and the need for continuous access to electric power will affect the design of the network. Taking into consideration the above parameters, an initial plan about the appropriate places of sensors was prepared as it is illustrated in the following figure (Figure 5).


Figure 5: Visualization of the observation network in the research area

Based on this observation plan, eight Wi-Fi sensors will be placed for a period of one month at the cross sections of the main streets giving the opportunity to research the movements in each street separate as well as the correlation between them. However, before the data collection a zero-level test is required in order to verify that each sensor covers the whole area which is expected from the network.

Secondly, before the analysis part a data preparation is required. Due to privacy issues, it is necessary to encrypt the MAC addresses of the recorded devices. During the data collection procedure with the use of Meshlium sensors, the user has the option to either encrypt or not, the MAC address of recorded devices. However, the encryption option of these sensors has as disadvantage that the encrypted code for each device changes every day. Furthermore, one other problem is that each sensor encrypts the same device in a different way and thus using the final data list it is not possible to identify movement patterns (*Duynstee et al., 2016*). Because of these problems, automatic encryption will not be used during the data collection; instead a script code will be used at the end of the data collection period in order to encrypt the MAC address of devices before the following steps of analysis. Furthermore, a filtering of collected data is necessary. During the whole period of data collection, there would be many static devices, such as printers, Wi-Fi routers, automatic food devices, parking payment devices, etc., as well as devices which will be detected for only one sensor during the day. As these records cannot be used for the goal of this research, they can be characterized as outliers and be removed from the relative dataset.

Later on, filtered data will be used for the identification of movement patterns. By definition, moving objects are entities whose positions of geometric attributes change over time (*Dodge, 2008*). The space in which people move is described by coordinate systems and thus the relative human movements can be geo-referenced. If we are able to specify the start and end time for each movement, we can identify the relative trajectory by ordering several movements of one individual device. Based on this idea, these trajectories can be analyzed. As there are many different kinds of patterns, it is important to clarify that this research will investigate the cases of spatio-temporal movement patterns as well as the co-locations in space. We can speak for co-location when individual users share some locations during their movement in the space. There are three types of co-locations in space: 1) the ordered one where some locations are shared by multiple trajectories in the same order; 2) unordered co-location where the shared places are reached in different ways; and 3) the symmetrical one which occurs when the common places are visited in the opposite way (*Dodge, 2008*). With these kinds of pattern, the most frequently visited and shared locations could be identified.

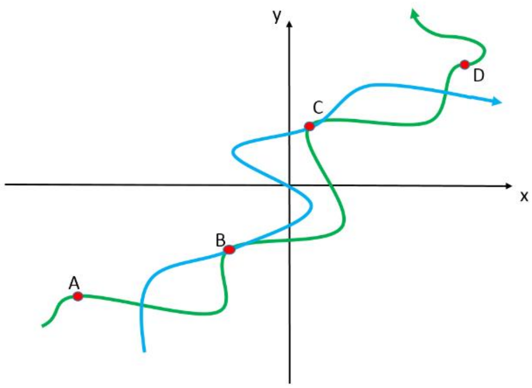


Figure 6: Ordered co- locations

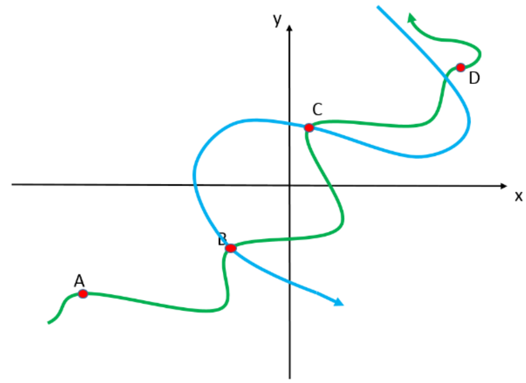


Figure 7: Symmetrical co-locations

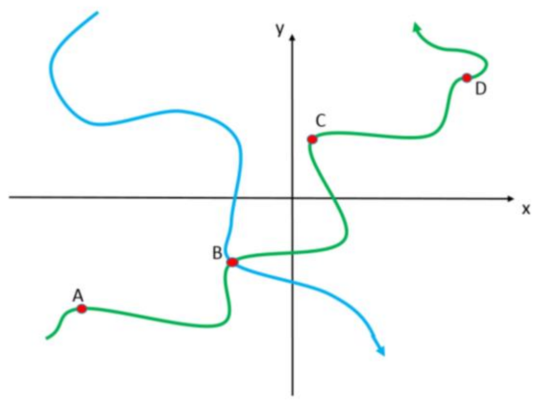


Figure 8: Unordered co-locations

After the identification of movement patterns, the computation of road modality will consist the following step. As outcome of this part, a feature should be given to each detected device as 'pedestrian', 'bicyclist', or 'vehicle'. In order to achieve this, a factor which will be used is the time difference between the detections of the same device from different sensors. In this way, as the distances between the locations of sensors are known, we can compute the relative speed and use it as a criterion for the categorization of the devices. However, as in many cases the movement speeds of bicycles and vehicles in a city area are similar, the movement patterns from the previous step in combination with details about the land uses of the area and the streets will be taken into account. For example, movements in pedestrian road or between the city center and the train station with a quite high speed can be characterized as 'bicyclist' as there is no parking in the train station. Moreover, information which is possible to be recorded by the sensors such as the relative strength of the signal (RSSI), the vendor of smartphone as well as the Class of Device (CoD), in case of Bluetooth, will also be used as parameters for the computation of road modality.

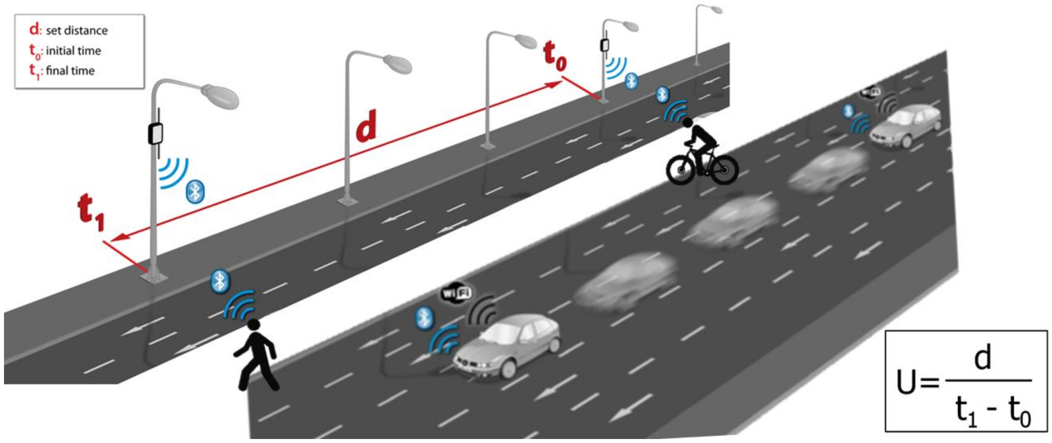


Figure 9: Example about the use of speed as a parameter for the separation of the different kinds of users

Knowing the moving patterns and the road modality, it will be possible to identify occupancy patterns for the research area. Flow and direction between states can be defined providing the ability to check the relative shapeliness and compute very useful statistical results about the behavior of the users. For instance, timeslots or days with higher traffic flows, totally or for a specific category, would be identified. Thus, based on the spatio-temporal movement analysis, it would be possible to answer questions like “when do people go to the city center” or “which is the most crowed period for the train station”. Furthermore, if sensors “catch” for instance 200 devices between location A and B, it does not mean that 100 users go to the location A and 100 to location B. The percentage of users per direction changes during the day and this rhythm of change would be investigated by this research. In the same way, having as known the road modality the relative rhythm of change between the different categories of users will be computed for a short or long time periods. Moreover, taking advantage of movement patterns it will be feasible to identify possible hotspots; places of more than usual interest, activity, or popularity. Based on the spatio-temporal analysis, some of them could be final destinations, such as the train station, while some other could be just an inevitable meeting point, like a roundabout.

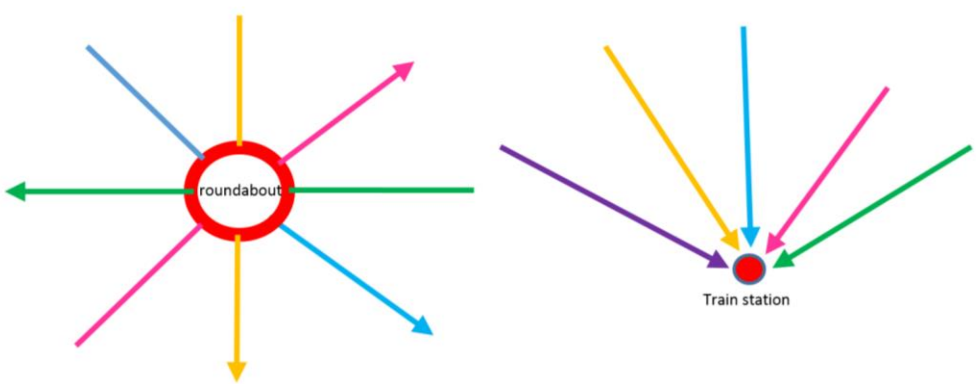


Figure 10: Examples of different kind of hotspots

Moreover, the effect of weather on road modality and the occupancy patterns will be investigated. It is very common to have different road modality under different weather conditions. For that reason, information about the weather in the research area will be stored during the observation period in order to be used at the analysis procedure. Thus, the relative influence of rainy or warm weather to the choice of means of transport will be studied.

One other factor which will be also investigated is the correlation between the number of devices and the total amount of users in the area. The reason is that in case that more than one device corresponds to each user, the relative influence of an identified pattern will be smaller. Thus, the more devices which correspond to one user, the smaller the relative effect of its pattern on the final result. Furthermore, it is important to know the percentage of actual users that have been covered and its variation. For the investigation of this correlation, some sampling data of pedestrians, bicyclists, and vehicles will be counted in different hours, days, and duration under the directions of a representative sampling in cooperation with students from the Da Vinci College of Dordrecht. Furthermore, a questionnaire will be used to get more information about the users such as the number of Wi-Fi-enabled devices that each user owns and some other factors like age and gender.

As a final step of this research, the influence of the Wi-Fi monitoring setup will be researched. As it was mentioned also in previous chapter, this research will not focus on which Wi-Fi network configuration is most appropriate for movements monitoring. However, it will be possible to investigate the influence of the total number of sensors by reducing gradually the relative number during the analysis procedure.

In order to make the outcomes of this research clear to the reader, a map visualization of them is essential. For this reason, heat maps and histograms will be used to visualize the movement and occupancy patterns respectively, based on the idea of the cartography map use cube (*Borchert et al., 2004*).

## 6. Time Planning

For the better control of the time spent in each activity, the work plan of MSc Thesis development is provided which is in accordance with the time available and the proposed approach. Two obligatory process reviews (P1 and P3) and three formal assessments (P2, P4 and P5) take place within this one year of research development during of which the exact dates of the presentations will be determined. Finally, despite the fact that a delay is always possible, it is important to try to pursue the deadlines set by the graduation plan.

| Month | February | | | March | | | | | April | |
|---|---|---|---|---|---|---|---|---|---|---|
| Week | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
| | | | | | | | | | | | |
| | | | | | | | | | | P1 | |
| | | | | | | | | | | Writing Proposal | |
| | Literature Review | | | | | | | | | Design of sensors Network | |

| Month | April | May | | | | June | | | | | July |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Week | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 |
| | | | | | | | | | | | |
| | | | | | | | | | P2 | | |
| | Writing Proposal | | | | | | | | Theoretical Framework | | |
| | Design of sensors Network | | | | | | | | | | |

| Month | July | | | August | | | | September | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Week | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 |
| | | | | | | | | | | | |
| | Theoretical Framework | | | | | | | Data Collection | | | |
| | Design of data analysis procedure | | | | | | | | | | |

| Month | September | October | | | | November | | | | December | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Week | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 | 49 |
| | | | | | | | | | | | |
| | | P3 | | | | | | | | | |
| | Data Collection | Data Analysis – Writing Report | | | | | | | | | |

| Month | December | | | January | | | | February | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Week | 50 | 51 | 52 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| | | | | | | | | | | | |
| | P4 | | | | | | | P5 | | | |
| | Finalizing MSc Thesis – Preparation for Final Presentation | | | | | | | | | | |

Table 2: Timeline of MSc Thesis development

# 7. Tools and Data

### 7.1 Tools

For the implementation of this research, several tools will be required in order to collect, store, process, and visualize the data. First of all, the Meshlium Wi-Fi and Bluetooth monitoring sensors of Libelium Company will be placed in the research area for a one-month period in order to collect the necessary information. The relative Meshlium Manager System software will be used for the wireless connection to the sensors and the downloading of the stored data. As it is possible that the Meshlium sensors could encrypt the same MAC address in a different way, an appropriate code will be written in Python for the hashing part and the insurance of privacy issues. Postgres will be the basic tool for the storage of data in a database and their process by the use of sql queries. Finally, QGIS or ArcGIS software will be used in order to visualize the outcomes of the research.

### 7.2 Data

To be able to answer the research question as well as the sub-questions, various datasets are required. First of all, apart from the metadata from the Wi-Fi monitoring part, a 2D map of the research area is needed in digital format in order to enable the visualization of outputs. Also, datasets by the national Cadaster and the municipality of Dordrecht about the spatial plans and land uses will be used for the identification of hotspots for each user category. During the observation period, information about the weather and the schedules of buses will be stored respectively. Finally, a questionnaire and sampling observations, by the support of students from the Da Vinci College of Dordrecht, will constitute the last sources of data which will be used for the validation step.

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