Degree Thesis in Microdata Analysis
Level: Master’s degree

Identify the driving behaviour in a parking lot in terms of distance.

Author: Salim Saif Saeed Ahmed
Supervisor: Johan Häkansson
Co-supervisor: Vijay Pratap Paidi
Examiner: Siril Yella
Subject/main field of study: Microdata Analysis
Course code: MI4002
Credits: 15 ECTS
Date of examination: 19/03/2018

At Dalarna University it is possible to publish the student thesis in full text in DiVA. The publishing is open access, which means the work will be freely accessible to read and download on the internet. This will significantly increase the dissemination and visibility of the student thesis.

Open access is becoming the standard route for spreading scientific and academic information on the internet. Dalarna University recommends that both researchers as well as students publish their work open access.

I give my/we give our consent for full text publishing (freely accessible on the internet, open access):

Yes ☒
No ☐
Abstract

Parking a vehicle can often lead to frustration, air pollution and congestion due to limited availability of parking spaces. With increasing population density this problem can certainly increase unless addressed. Parking lots occupy large areas of scarce land resource therefore it is necessary to identify the driving behaviour in a parking lot to improve it further. This Paper tries study the driving behaviour in the parking lot and for this endeavours it conducted direct observation in three parking lots and used GPS data that was collected prior to this study by the University of Dalarna.

To evaluate the driving behaviour in the parking lot direct observation was conducted to obtain overall indices of the parking lot vehicles movement. The parking route taken by the driver was compared with the optimal path to identify the driving behaviour in parking lot in terms of distance. The collected data was evaluated, filtered and analysed to identify the route, the distance and the time the vehicle takes to find a parking space.

The outcome of the study shows that driving behaviour in the parking lots varies significantly among the parking user where most of the observed vehicles took unnecessary long time to complete their parking. The study shows that 56% of the 430 observed vehicles demonstrated inefficient driving behaviour as they took long driving path rather the than the optimal path. The study trace this behaviour to two factors, first, the absent of parking guidance in the parking lots and the second is the selectivity of the drivers when choosing the parking space.

The study also shows that the ability of GPS data to identify the driving behaviour in the parking lots varies based on the time interval and the type of the device that is being used. The small the time interval the more accurate the GPS data in detecting the driving behaviour in the parking lots.

Keywords: Driving behaviour, Parking lots, GPS and Optimal path
Acknowledgement

I would like to give a sincere thanks to my supervisor Johan Håkasson and co-supervisor Vijay Pratap Paidi, for their constant guidance as well as for providing necessary information and the direction that was essential in enabling me to proceed with my work and reach the desired outcomes. I would like also to give a special thanks to my teachers and to thank Mr. Daniel Brandt the program manager for his generous support, and Mr. Hassan Fleyeh, that without them, this thesis would not have been possible.

Last but not the least, I would like to thank my family for providing me the unfailing support and the continuous encouragement, throughout my course of study and through the process of researching and writing this thesis. This accomplishment would not have been possible without them.

Thank you.
Table of Contents
ABSTRACT .................................................................................................................. 1
ACKNOWLEDGEMENT ............................................................................................... 2
LIST OF TABLES .......................................................................................................... 4
LIST OF FIGURES ......................................................................................................... 4
1. INTRODUCTION ...................................................................................................... 5
3. LITERATURE REVIEW ............................................................................................. 6
3. OBJECTIVE .............................................................................................................. 10
4. METHODOLOGY ...................................................................................................... 10
4.1. DATA PRE-PROCESSING .................................................................................... 12
5. RESULT AND ANALYSIS ......................................................................................... 14
5.1. DIRECT OBSERVATION ....................................................................................... 14
5.2. THE GPS DATA .................................................................................................... 16
5.2.1. THE 30-SECOND GPS DATA ......................................................................... 17
5.2.2. THE 5-SECONDS GPS DATA ....................................................................... 19
5.2.3. THE SMARTPHONE 15-SECOND GPS DATA ............................................... 20
6. DISCUSSION ............................................................................................................ 22
7. CONCLUSION .......................................................................................................... 26
REFERENCE: ............................................................................................................... 27
APPENDIX A ............................................................................................................... 30
TABLE A1 .................................................................................................................... 30
TABLE A2 .................................................................................................................... 30
List of Tables

Table 1. GPS positional recordings based on the time intervals..........................13
Table 2. Number of filtered positional recording in each parking lot. ......................17
Table 3. Number of filtered positional recording in each parking lot. ......................20

List of Figures

Figure 1. The distribution of Direct observation. Fel! Bokmärket är inte definierat.
Figure 2. Shows an inefficient vehicles approach for parking lot. ..........................5
Figure 3. Shows an efficient vehicles approach for parking lot. ..............................16
Figure 4. The distribution of GPS and Smartphone data. .....................................17
Figure 5. Two positional recordings with 30-second GPS data...............................18
Figure 6. A Single 30-second GPS data positional recording. ...............................19
Figure 7. The distribution of 5-seconds GPS data. Fel! Bokmärket är inte definierat.
Figure 8. Shows a driver in parking lot with 5-seconds. .....................................20
Figure 9. A single positional recordings in parking lots with 15-second. .................21
Figure 10. Shows positional recordings in parking lots using 15-second Smartphone
            GPS data........................................................................................................21
Figure 11. Shows one track using 15-second Smartphone GPS data. .....................22
Figure 12. Shows a long vehicle path for getting a nearest vacant parking space.....23
Figure 13. Shows a long vehicle path for getting a nearest vacant parking space....233
Figure 14. Shows one route within parking lots using 5-second GPS.....................244
Figure 15. Shows a driver in parking lot with 5-seconds. .....................................25
1. Introduction

In the recent years there has been an increased concern regarding the problems associated with vehicles in the large cities worldwide. Car parking is one of those problems that has become a research subject since the early 1930s. This because of its implication in traffic congestion and the issues that associate with it such as pollution frustration and time consumption. The scale of urbanization has changed profoundly in early years driven by the industrialization, in which the dilemma of city expansion starts to exacerbate Schönfelder et al. (2010) therefore the number of cars on road becomes one of the most crucial issue in the modern cities. However car parking problem is not only a traffic congestion but it has also an economic impact in addition to the increase of pollution, time consumption, scale of accidents and many other social issues Shoup (2006). For instance the traffic congestion cost the European cities about 110 billion Euro annually Christidis et al. (2012) while it cost the US 101 billion dollars of fuel and delay Eltis (2014). In addition, those problems are expected to escalate sharply due to the increase of urbanization.

According to the UN estimations, 66% of world population will be living in urban areas by 2050, World Urbanization Prospects (2014). Most of the world large cities have been already suffering of high pollution caused by vehicles and a great deal of this pollution caused by vehicles searching for parking space. This behaviour account for over 40% of entire cities daily traffic. However, this percentage is even doubled during the weekends and before Christmas Vianna et al. (2004).

Car parking become part of people day to day life. Some studies associate car parking with 30% of the entire traffic in large cities Rhodes, Callum et al. (2014) Meanwhile vehicle is a reasonably big object, and the number of on road vehicles are considerably huge and they require a huge area for parking as well. Studies shows that the average time vehicle spends in parking is 95% of its life Shoup (2005) as of 2010 statistics there has been more than a billion vehicles on the road (excluding off the road vehicles that are still in market or not in use for one reason or other). However this number has increased considerably since then. A report from Macquarie Bank, revealed that 88.1 million vehicles were sold worldwide in 2016 alone David Scutt (2016) with inefficient use of parking areas this number could have even greater impact especially on world large cities as explained above.
For the above-mentioned reasons, car parking become a research subject for so many years Shoup (2006). Mahmud et al. (2013) suggests an intelligent parking system that is reliable to enhance the efficiency of parking lots and overcome some of the above mentioned problems. The study suggests a variety of systems that can be used to construct the intelligent parking lots. The Systems that Mahmud et al. Suggested are: Vehicular communication systems, GPS based systems, Vision based systems, and Fuzzy logic based systems, Expert systems and other similar System that can improve the management of parking facilities.

3. Literature Review

Cruising for parking is one of the oldest traffic problem. This problem was observed in the early 30s of the 20th century when vehicles in some crowded streets were queuing for parking and cause traffic congestion Shoup (2006). Moreover, the race between transportation components goes in favour of the number of vehicles on the roads rather in developing transportation facilities and infrastructure. The slow pace of developing and expanding traffic infrastructure compared to great economic and population growth exacerbate the problem Ribeiro and Kobayashi (2007).

There has been many studies that try to tackle this issue. Some of those studies try to explore driving behaviour such as speed, taking risk, taking rational decision in choosing routes Maycock et al. (1999), Ellison et al. (2010) and Wallén et al. (2006). Other studies focuses on how the new technology could affect the driving behaviour and mitigate congestion and traffic related problems. Mahmud et al. (2013) reviewed several parking systems that are used for parking guidance and parking facility management. The study tend to implement the new technology to reduce the time for searching for available parking space, guide for optimal driving path and negotiate for parking fees consequently increase the efficiency of using the routes and parking utilization.

Other studies tackle transportation problem in general Pojani et al. (2015) proposes a set of solutions to overcome urban transport in developing world. The study suggests nine solutions urban transport, those solutions varied among road infrastructure to support for non-motorized travel modes and technological solutions. The solution includes an intelligent transportation systems. Moreover, in the recent years, technology tries to cope with modern traffic escalated problems. Smart Traffic Management System is one example for how technology can approach the problem in
an innovative way to make it possible for traffic problem to be overcome or managed effectively. This can be possible by integrating and interconnection of traffic management system with other related systems such as parking management systems and parking guidance information and management system Oh et al. (2002) suggests an integrated system capable of providing "real time parking occupancy information" that helps for avoiding e.g. congestion.

In travel guidance, the Global Positioning Systems (GPS) system is so far the leading technology. It also become essential in most of traffic management and parking management system as it is still the dominant technology in acquiring navigation direction. Meanwhile, this technology creates a great opportunity for developing sub-systems in navigation and traffic domain, hence it has changed the way we observe the traffic, the way we approach our destination and it also opened new ways for performing tracking and monitoring. Additionally, the GPS device is being used effectively as a tool for collecting data that helps in environmental studies and studying people activities and their effect Zhao (2014).

This technology has developed rapidly in the last few years and became part of our day to day life. Furthermore the development of other technology and enabling them with built-in GPS for navigation and orientation such as in Smartphone and other communication devices is other potential of GPS development. All in all, it can be said that GPS technology is the effective way so far that can track mobile objects time, speed, altitude, longitude and latitude. This technology can be described as a reliable and accurate resource for high data quality in navigation and orientation aspects Zhao (2014).

In the recent years people commonly use Smartphone as a GPS enabler for navigation and orientation. It satisfies the daily need for people since they find it a reliable device in many aspects. A field study experiment shows that the accuracy of GPS enabled Smartphone is not as high as the portable GPS device, however, it reasonably suite its purpose. According to the study the GPS-Smartphone enables data has accuracy range less than 10 meters comparing with GPS handset device which reach level less than 3 meters Yin (2014)

Finally the GPS technology is an effectual for tracking vehicles location and determining an alternative routes for a specific destination. It is being used in many
different ways to help drivers and related service providers accomplish their tasks timely and accurately. One of the most useful way that GPS is being used in the recent years, is Urban Traffic Management and Control (UTMC) system/Intelligent Transport System (ITS) Nellore et al. (2016) and Smart Parking Management System to offer information to determine the availability of parking spaces at the destination. Pullola et al. suggests system called (Nearest Available Parking lot Application NAPA) which is associated with GPS to formulate a smart parking system. The system identifies the nearest parking to the required destination. Then it detects the user when s/he occupied space in the parking and when this space is available. The NAPA server also calculates parking time and charges the user the appropriate fee Pullola et al. (2007).

Driving behaviour in the parking lot is also one of the issues that can affect the efficiency of using the parking lots as well as the flow of traffic. In some modern parking lots technology plays a vital role in parking management Pullola et al. (2007) and reduce time of parking process including search for appropriate parking space and payment. However, parking behaviour is consider one of the areas of development that needs to be studied in order to develop parking lots management and to improve traffic safety in general.

Fraifer et al. (2016) reviewed a range of parking management systems in which communication technology is being applied. Those systems vary amongst Multi-Agent Model, Fuzzy Logic System, Wireless Sensor Network, and Vehicular to Infrastructure Communication (V2I), GPS Parking System, Computer Vision System, RFID Technology System and Hybrid M2M, IOT System. This variety of systems can lead to the design of an efficient parking management and resolve the problems that take place due to the absence of a reliable parking management system.

Choosing a way to the parking lots and cruising for appropriate parking space still one of the most important contributors to congestion outside and within the parking lots. One of the common causes of movement blocking accrues in the parking lots when the driver approach the parking lots with no idea about the available parking space and the optimal path to reach it. This study defines the optimal path in the parking lot as the shortest distance between the parking entrance and the parking space, measured by meters. However, this optimal path is not always obvious to most drivers, furthermore, the distance in meters is not always the case if the optimal path in such case is the busiest one. Yuru et al. (2015) suggested establishing of an internal parking
guidance system. In their study they used "grey entropy relation grade Multiple Decision Making" to help drivers value the parking space and identify the optimal path to parking space and walking distance. The study suggests this guidance system as a solution to mitigate driver’s dissatisfaction about the pre-assigned parking space. The study try optimize the efficiency of the guiding system by considering the driver perception and make the system more trustable.

The driving behaviour while searching for parking lots is one of the research concerns since it causes most of traffic problems as it is the main contributor for traffic congestion. Furthermore, the increase in on street car number increases the demand on parking lots, therefore it become more crucial to study driving behaviour in the parking lots to develop an effective parking management system Bonsall and Palmer (2004) used PARKIT parking choice simulator data to determine the off-street parking behaviour and how it impact on route and car park choice of journey time and cost variables. Meanwhile, Benenson et al. (2008) presented PARKAGENT to simulate car driver’s behaviour such as costs, search time and walking distance. The study shows how the additional parking supply influence the extreme value and the average time for parking search.

Bogoslavskyi et al. (2015) proposed the use of Markov Decision Processes) MDP-based planner to minimizes search time for parking space that satisfy the driver needs. They suggest the use of MDP planer to help driver find suitable parking space quickly. They argue that this approach is better technique comparing with other approaches for calculating the route information and the probability of parking space availability based on real world data.

Vo et al. (2016) suggests using Micro-simulation to help increase the understanding of driver movements while using parking lot and the implication of the behaviour in parking management. The study applied multi-agent modelling environment NetLogo to study the factors that affect driver’s behaviour and the efficiency of using parking lots space. The study sought a better understanding of parking behaviour that enable in improving the design of parking lots layout. Furthermore, Waerden et al. (2013) studied how the habitual parking behaviour can be influenced by car driver characteristics while choosing parking lots facility.
Some studies indicate several habitual behaviours and factors that effects the way of choosing parking space in the parking facilities such as distance between parking space and desired destination Bonsall, P., & Palmer, I. (2004) driver perception, parking space characteristics Benenson et al. (2008) distance to ticket machine Van et al. (2003) car size and gender Vo et al. (2016). However, there has been lack of studies that attempted to discuss driving behaviour in parking lots to identify ways of choosing driving path and parking spot and how it effect the driving distance and time which the current study mainly focuses on. The similarity of those paper with the current one that they all studies traffic problem in the shade of increase of the number of vehicle in the modern cities. They tried to tackle the rout and parking problems and their implication in traffic. The studies used a range of new technology, methods and approaches in their endeavours in overcoming modern traffic problem such as congestion and the utilization of routs and parking lots. However, the current study is aimed at studying the driving behaviour inside parking lots in term of distance and how the driver chose the driving path to find parking spot and how this behaviour impact the driving distance and time.

3. Objective

The objective of the study is to identify the driving behaviour in a parking lot in terms of distance. A secondary objective of the study is to identify if GPS can be used to observe driving behaviour in a parking lot.

4. Methodology

This study aimed at identifying the driving behaviour in parking using direct observation to identify driving behaviour in the parking lots such as choosing the driving path, and how the driver choose a specific parking spot the way of approaching it. This entails the comparison of the chosen path with the optimal one. The study also is to identify whether GPS data is able to track this driving behaviour using different data interval.

The study used direct observation to manually record vehicles movement in the assigned parking lots while searching and choosing a vacant parking spot. The direct observation was applied in three biggest parking lots to monitor the vehicle movements in the parking lots. This include recording notes about driving behaviour starting from the point where the vehicle enter the parking lot the along the driving path way of
choosing parking vacant and how the driver approached parking spot. The observation was conducted randomly in three biggest public parking lots in Borlänge city as: (Centre Stations, Kupolen and Ikea) to monitor the vehicle movement’s and record data such as time, distance, driving route, the alternative driving path and other driving aspects. The observation was conducted during the period from 26 Sep 2017 to 6 Oct 2017, for total of 430 vehicle, to obtain precise data of the driving behaviour inside the parking lot regarding vehicles movement. The observations took place during day time for two hours in different time between 8:00 and 18:00. The observation activities include recording time of movement in the parking lot before occupying parking space and drawing the driving route, and direction then drawing the optimal path to be compared with. Then the observation outcome data was digitized by ArcGIS.

The Study also used GPS data which was provided by Dalarna University and this data was recorded in three different interval 5 and 30 second data was collected using Bluetooth GPS data logger (BT-338X) and 15 second data that was collected through Smartphone to record vehicle movements. The 30-second interval GPS data was collected by 316 volunteers while the 5-seconds interval was collected by 2 volunteers all volunteers belong to four sport associations (Domnarvets GOIF, Kvarnsveden Hockey, Stora Tuna IK and Torsångs) each of them holds a unique ID number to be identified with easily. The GPS devices were mounted in the vehicles to record their daily movements. The data collection period started on March 29 and ended on May 15 in 2011 for the 30-second interval while the collection period for the and 5-seconds interval the data collection period started on March 30 and ended on April 26 in 2011.

The total number of GPS movements recorded data within Sweden consisted of 363,862 positional recordings. By extracting the movements which had been recorded within the city of Borlänge, we left with 255,168 positional recordings. The positional recording that was recorded using 30 second interval were 159,141 positional, and 96,027 positional were recorded by 5 seconds. The study was applied in seven parking lots in Borlänge as: (Biltema, Centre Stations, Högskolan, Kupolen, Scandic, Trafikverket and Willys). Therefore, the GPS data was filtered to exclusively include those specific parking lots.

The Smartphone GPS data was collected by 23 volunteers using their Smartphone with 15 second time interval. The data collection period started on 1, May and ended
on 30, August 2017. The total positional recordings of all movements within Sweden were 268,584 positional recordings. By extracting the positional recordings that took place within the city of Falun which are 105,246 positional recordings, and excluding those which were recorded outside Falun which were 163,338 positional recordings. The Smartphone GPS data was filtered for three parking lots in Falun as: (Hemköp, ICA Maxi and Scandic).

For the purpose of this study the above mentioned ten parking lots were chosen as they are the biggest open space parking lots. Also those parking are commonly near to the cities centre, so that they facilitate the requirement of the most popular shops and public facilities in those two cities. For analysing this data, the ArcGIS software was used to visualize the data as can be seen in Table A1 in Appendix A.

The study used ArcGIS software and data mining techniques (Data pre-processing using to evaluate the accuracy of GPS data) for extracting, filtering, analysing the data. The research work includes extracting, filtering, and analysing the data as follow:

- Extracting and Filtering the data: In this stage the data was extracted to obtain the data which belong to the two cities Borlänge and Falun. The purpose of filtering was to ensure the data validation in the chosen ten parking lots. The filtration process has been achieved based on time, date and the path tracking.

- Data analysis: to determine the driving behaviour, two factors were considered and calculated: (1) the path that the driver choose to approach the parking space and (2) the time which measures the duration it takes the driver to finish parking. Then the parking route that the drivers took was compared with the optimal path.

4.1. Data Pre-processing

The GPS data was proceeded by following these steps:

- Extract data with 5 and 30 second interval in Borlänge city and data with 15 second in Falun city. The following Table 1 shows the number of positional recordings which were extracting from the main data for each parking lots in the two cities.
Table 1. GPS positional recordings based on the time intervals.

<table>
<thead>
<tr>
<th>Description</th>
<th>Parking lots</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Biltema</td>
<td></td>
</tr>
<tr>
<td>positional recording using 30-second</td>
<td></td>
<td>69</td>
</tr>
<tr>
<td></td>
<td>Centre Stations</td>
<td>1,502</td>
</tr>
<tr>
<td></td>
<td>Högskolan</td>
<td>205</td>
</tr>
<tr>
<td></td>
<td>Kopolen</td>
<td>1,155</td>
</tr>
<tr>
<td></td>
<td>Trafikverket</td>
<td>135</td>
</tr>
<tr>
<td></td>
<td>Scandic</td>
<td>371</td>
</tr>
<tr>
<td></td>
<td>Willys</td>
<td>243</td>
</tr>
<tr>
<td></td>
<td>Hemköp</td>
<td>3680</td>
</tr>
<tr>
<td></td>
<td>ICA Maxi</td>
<td></td>
</tr>
<tr>
<td>positional recording using 5-seconds</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>11,352</td>
</tr>
<tr>
<td></td>
<td></td>
<td>456</td>
</tr>
<tr>
<td></td>
<td></td>
<td>620</td>
</tr>
<tr>
<td></td>
<td></td>
<td>12,428</td>
</tr>
<tr>
<td>positional recording using 15-second</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>77</td>
</tr>
<tr>
<td></td>
<td></td>
<td>262</td>
</tr>
<tr>
<td></td>
<td></td>
<td>344</td>
</tr>
</tbody>
</table>

- Filtering the data which were wrongly recorded due to an error in GPS and Smartphone device recording or improper use of the GPS and Smartphone devices by volunteers, this includes the following:
  i) A single positional recording without path,
  ii) Missing data points due to lack of GPS and Smartphone signal,
  iii) Continuity of recording after the halting of the vehicle,
  iv) Some parking lots are penetrated by public roads, so in this case some recording were excluded as they were belonged to road's users,
  v) Impossible positional recordings combinations e.g. on building surfaces.

- Examining the validation of the data was performed by filtering the data in parking lots by specifying the parking lots and checking the points by time, date, and the positioning paths,

- Gathering the valid positional recordings of tracks at the ten above mentioned parking lots.

Table A2 in Appendix A shows the valid data tracks GPS and Smartphone data in ten parking lots.

The pictures of the parking lots that are being used in this study were not taking in the time of the data collection. They were taking from the Esri ArcGIS as to be used to depict the data on them to make the data more presentable and easy to be read. When the data was depicted on the associated parking lots the optimal paths were chosen in the related parking as the shortest alternative driving distance between the parking entrance and the parking space. This distance was measured by meters regardless the parking lot situation during the time when the data was collected. Therefore, this gives further use of direct observation which is to
validate this data and add more clarification regarding to the driving behaviour and the optimal path. Both the actual path the vehicle took, according to the collected data, and the optimal path, according to the observation, were depicted on the parking lots background pictures to make it more understandable when comparing the two paths. Also the efficient and inefficient driving behaviour was observed and the paper came out with number of factors that seem to behind most of the inefficient driving behaviour.

5. **Result and Analysis**

When a driver chooses a vacant parking space, s/he my go for one of two options: first, if the driver has her/his own pre-idea where to park the vehicle s/he would sacrifice the driving time and distance in order to fulfil her/his idea. However, in this case, the driver might choose the optimal path, but it is not the driver’s priority. The only maters in this case; the driver perception, the driver final destination or the type of the vehicle that may needs more comfortable spot. In some cases the driver intentionally choose to drive along till the end of the parking lot, passing by many vacant parking space. This gives an indicator that the driver for some reason carefully select his parking space. While in other cases the driver may choose efficiently the first available parking space as it for some reason suite her/his intention to park at the beginning of the parking lot.

Second, if the driver seeks the nearest available parking space, then in this case the driving time and distance is carefully considered by the driver as a result of time and/or fuel concern. However, this is not always the case as the driver intention might not be fulfilled due to a lack guidance. The driver might choose a specific path as an optimal path toward a prospective parking vacant then s/he may discover that the chosen path was not the optimal one because there were no parking vacant in that direction. The probability of choosing the longest path rather than the optimal one increases when the parking lot is busy as the driver could not predict the vacant parking spot. Nevertheless, some studies suggest “Smart Parking Guidance System” to overcome this problem as mentioned in the literature review.

5.1. **Direct Observation**

The obtained observation data contains the recording of the movement for 430 vehicles, which were distributed among the three parking lots in Borlänge city (Centre Stations, Kupolen and Ikea). The time the vehicles took for searching parking spot
varied significantly between 5 seconds and 180 second which gives clear indicator of how the driving behaviour influence traffic in the parking and consequently the efficiency of its usage, as in figure 1 bellow.

![Efficient vs Inefficient Driving](image)

**Figure 1. The distribution of Direct observation**

From the total 430 observed vehicle 44% of them almost took the optimal path in the parking while approaching the parking spot which can be describe as an efficient driving behaviour. While 56% of the vehicles the driver was inefficient in using the parking lots as they use long cruising path to reach a vacant parking spot. Some of the (8% of the observed vehicles) the drivers seemed to be selective in choosing the parking spot. Those were recognized during the observation as they for some reason pass by a number of vacant parking spots to choose sometimes the farther once. The optimal and the actual path are demonstrated in Figure 2 in which the orange line represent the actual driving path while the optimal path shows in blue line. In picture (a) the vehicle was observed during 16:21-16:26 which it took 70 second driving time traveling along 150 meter path (in orange line) rather than taking the optimal path which is 25 meter (in blue). Picture (b) shows the vehicle that was observed during 17:08-17:12. The vehicle took 180 second driving time in the parking lot traveling 416 meter actual path while the optimal path is 50 meter. Meanwhile Figure 3, shows the picture where the actual path the drivers took are at the same time the optimal paths.
5.2. The GPS data

This section analyses the GPS data that has been already recorded in city of Borlänge and the city of Falun. Most of the data was recorded near to a commercial centres in three biggest parking lots as: Centre Stations, Kupolen and Willys, as it shows high traffic density. Those three parking lots occupied 83% of the GPS data (tracks) as can be seen in Figure 4(a). Whereas only few tracks (17%) were recorded in other places rather than the commercial centres or the centre stations. The same was for the Smartphone GPS data, 98% of tracks were recorded near commercial centres as can be seen in Figure 4(b) below:
Figure 4. The distribution of GPS and Smartphone data.

5.2.1. The 30-second GPS Data
As a result of processing and filtering the GPS data, 830 valid positional recording were identified out of 3680, in the specified parking lots as it shows in table 2 below.

Table 2. Number of filtered positional recording in each parking lot.

<table>
<thead>
<tr>
<th>Parking lots</th>
<th>Total</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Biltema</td>
<td>32</td>
<td>0.04</td>
</tr>
<tr>
<td>2 Center Stations</td>
<td>273</td>
<td>0.33</td>
</tr>
<tr>
<td>3 Högskolan</td>
<td>9</td>
<td>0.01</td>
</tr>
<tr>
<td>4 Kupolen</td>
<td>322</td>
<td>0.39</td>
</tr>
<tr>
<td>5 Trafikverket</td>
<td>54</td>
<td>0.07</td>
</tr>
<tr>
<td>6 Scandic</td>
<td>52</td>
<td>0.06</td>
</tr>
<tr>
<td>7 Willys</td>
<td>88</td>
<td>0.11</td>
</tr>
</tbody>
</table>

The result of the 30-second GPS data in Table 2, shows varies number of positional recording in the parking lots these variation was based on the size and locations. The second and the forth rows shows that about 72% of the total positional recording were recorded in two parking lots (Centre stations and Kupolen), which are the largest parking lots in the city. While the total positional recording in the first row (Biltema) shows lower positional recording for the same reason (small parking) as the traffic density is low in this parking lots. Finally the table shows in the third rows (Högskolan) the lowest number of positional recording due to the time and the date when the recording took place. In this parking the density of traffic occurred only when the Dalarna University is in full function.
The data shows the cruising time, however, it does not give further indicators about traffic routes in the parking lots. In addition, the 30-second GPS data has only about 11% of the data which has two positional recordings and three at most in the parking lots due to the large time interval which does not fit the short parking time. As can be seen in Figure 5 which shows one track in parking lot with two positional recordings, where $E$ are the parking entrances, $F$ is the first positional after entering the parking lot and $S$ is the second positional in the parking lot.

![Figure 5. Two positional recordings with 30-second GPS data.](image)

The large distance between the two points shows long time interval between the beginning point $F$ and the second point $S$, but that does not mean that $S$ is the final parking space that has been chosen by the driver. In addition, we cannot guess which route/s the vehicle took between the two points hence it is difficult to get even a probable sort of behaviour here as there are a countless alternatives routes and direction that the vehicle can choose within the parking lots. Where the distance between $F$ and $S$ is 90 meters, 137 meter and the final distaining is unpredictable. While about 89% of the data has only a single positional recordings within parking lot for each route, as can be seen in Figure 6.
5.2.2. The 5-seconds GPS Data

In filtering the 5-second time interval GPS data in Borlänge city, 8 valid tracks were found in the parking lots out of 12,428 positional recordings. However, the size of data was large due to recording time interval and the device seemed to continue recording even when the car was switch off.

Using the 5-second interval GPS data shows that the data were able to give enough positional recording to identify driving behaviour due to the small time interval. The data demonstrate the driving behaviour clearly starting at the parking entrance along way to the parking spot. The data shows that all positional recordings for the vehicles movements were valid in term of showing the crossing paths and driving behaviour. However the data shows that 88% of driving behaviour were efficient While 12% of the driving behaviour were inefficient. This does not reflect the driving behaviour in the parking lot in general due to the small size of the sample that being used but it shows the accuracy and efficiency of 5-seconds time interval GPS data for
identify driving behaviour in the parking lot. This was identified by the number of positional recording in which each route was demonstrated. That makes it easy to track the car movement in the parking lot. Figure 8 below shows a track in parking lots where the blue points are outside the parking lots, and $F$ is the first positional at the parking lot entrance and $S$ is the last positional within parking lot and the driving behaviour can be easily tracked.

![Figure 8](image)

Figure 8. Shows a driver in parking lot with 5-seconds.

### 5.2.3. The Smartphone 15-second GPS Data

When processing Smartphone data that was recorded in the parking lots in the city of Falun, only 116 valid tracking data were found out of 344 positional recordings. Table 3 shows the results of the valid tracks which were induced from the data in each parking lot.

Table 3. Number of filtered positional recording in each parking lot.

<table>
<thead>
<tr>
<th>Parking lots</th>
<th>Total</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Hemköp</td>
<td>22</td>
<td>0.19</td>
</tr>
<tr>
<td>2 ICA Maxi</td>
<td>90</td>
<td>0.78</td>
</tr>
<tr>
<td>3 Scandic</td>
<td>4</td>
<td>0.03</td>
</tr>
</tbody>
</table>

The data shows partially the cruising time, however, only 33% of tracks has a single positional within parking lots as can be seen in Figure 9, which shows different tracks in parking lots and that gives no sense about the driving behaviour.
However, Smartphone GPS data has 67% of tracks that have a maximum of two positional within the parking lots, as can be seen in Figure 10 where $F$ is the first positional at the parking lots entrance and $S$ is the second positional. But again this data does not depict a picture of the route the driver took or predict the final spot in the parking where the distance between $F$ and $S$ is 55 mater an there are many routes probabilities for vehicle ta take between those two points.

![Figure 9](image9.png)

**Figure 9.** A single positional recordings in parking lots with 15-second.

In figure 11, the time interval between $F$ an $S$ in is more than 15-second which means there are at least two point are missing between the firs and the last one. Furthermore the $F$ point was recorded outside the parking and after 56 seconds comes point $S$ in the parking lot as in parking spot. However, the device did not detect another points within the parking lots. It seems that the Smartphone encounter a technical problems that makes it less likely to be able to detect the driving behaviour in the parking lot. The signal might not be active all the time, and that may explain why the distance between each positioning point was too large, hence failed to demonstrate the driving route.

![Figure 10](image10.png)

**Figure 10.** Shows positional recordings in parking lots using 15-second Smartphone GPS data.
6. Discussion

The analyses that was based on the parking lots observation shows that the majority of the vehicles took longer routes rather than the optimal path while driving in the parking lots searching for parking space. This behaviour reflects in some cases specific intention the driver has. In such cases the driver may have a certain desire or requirement s/he needs to fulfil hence s/he sacrifices time and fuel for that. This behaviour account for 8% of inefficient driving behaviour in the parking lots. However the data that was collected during the observation indicates that considerable number of the observed vehicles showed inefficient driving behaviour where the driver failed to choose the optimal path towards a vacant parking spot.

Due to the lack of the guidance indicators in the parking lots, the driver enter the parking lot with no clue where the parking vacant or what direction to take towed it. Most of the observed vehicles took the most popular path when driving in the parking. The parking spots alongside the popular route are the first that they occupied most of the time. When the driver realizes that, the normal response is to go for searching in a less popular route. Sometimes it takes her/him a full lope or going to the farther area in the parking. The design of the parking in some cases intensifies this problem as in some parking lots the driver has limited option in choosing the driving routes and direction, however, the study does not consider this as inefficient driving when it is the only available option for the driver.

Figure 12 shows an observation outcome: in picture (a) a vehicle took 37 second to find a parking vacant using a long path derived on 200 meter rather than the taking the optimal one which is 59 meter and in picture (b) a vehicle took 105 seconds to find
a parking vacant using 305 meter long path rather than taking the optimal one which is 52 meter.

While figure 13 shows two observation outcomes in picture (a) which a vehicle took 107 seconds to find a parking vacant using a long path with 285 meter rather than the optimal one which is 90 meter, and in picture (b) which took using a parking with long path 215 meter with actual path while the optimal path is 87 meter.

The analysis also shows that the time interval in the collected GPS data is the critical factor in data validity. The time interval determines the ability of the data in evaluating the driving behaviour. The study shows clearly that the use of 30-second
time interval GPS data was not able to detect driving behaviour in parking lots. The data does not demonstrate driving routes in the parking lots effectively due to the large time interval. The 30-second time interval the data can only, capture a cruising time rather than driving behaviour.

Meanwhile the use of the 5-second time interval GPS data demonstrates the ability to capture the driving behaviour even in a proportionate small size parking lots. The data shows several tracking points for every route in the parking relatively close to each other so there is no possibility that the vehicle took other rout that is not demonstrated by the GPS data in this regard. Therefore the route that the driver takes can be detected starting from the parking entrance till parking space. This means high possibility to compare the optimal route (shortest distance) to the parking space with the route that the driver took to approach the parking space and measure different aspects of driving behaviour. Figure 14, shows the track in parking lot that recorded using 5-seconds time interval GPS, where F is the first point in the parking lot entrance and S is the last point in the parking (parking spot).

![Figure 14](image)

Figure 14. Shows one route within parking lots using 5-second GPS.

In this case it is apparent that the S point is the final destination in the parking lot (parking spot) whereas the blue points shows the path outside parking lot. Since the driving rout was demonstrated clearly in this case, the driving behaviour can be easily detected. In addition the alternatives rout can be compared with the one that has been taken by the driver hence show the rationality of driving behaviour. When comparing Figure 14 with Figure 15 the different absolutely clear that the driving behaviour in former is more efficient than the later. Figure 15 shows the driver behaviour was not
efficient as s/he did not approach the parking spot using the optimal path (demonstrated by blue solid line with 78 meter whereas the distance between $F$ and $S$ in the actual driving path 119 metre).

Figure 152. Shows a driver in parking lot with 5-seconds.

The direct observation that was conducted during this study asserted the reality that the greatest, the time interval the GPS, the less the accuracy in identifying driving behaviour. For instance, the observation shows that the overwhelming majority of the observed vehicles took less than 36 second drive in the parking lot to reach their final parking spot. This would be demonstrated by the 30-second interval GPS data using only one positional recordings or two positional recording when using the 15-second interval GPS data. This does not give any sense about the driving behaviour in the parking lots as it was mentioned previously. However, the driving behaviour for the same number of those vehicles could be captured effectively when using the 5-second interval GPS data as each driving path would be demonstrated by several positional recordings all the way long.

It worth mentioning in this regard that the direct observation has proven that some of driving behaviour cannot be detected effectively by using the GPS mean. For instance inappropriate use of parking vacant or reckless driving in the parking. The type of the vehicle the driver posture and the design of the parking also have an important effect in parking lot. If the car has a big size the driver cruise for a convenient space to fit. Meanwhile the aisle between the parking areas are a critical factor that affect parking and exit time. Finally, the driver choose the parking space that accommodate her/his posture and this differ considerably amongst people according to their gender, age, distinction and other circumstances. In most of those behaviours the GPS could tell the symptoms but not able to give explanation of causes. These bring us to say that the
monitoring cameras still the best way to detect those kinds of problems as it can provide an accurate information similar to the observation role.

7. Conclusion

The study shows that driving behaviour in the parking lots varies significantly among parking users. The time variation was between 5-second and 180 second and the distance variation was between 25 and 416 meters. Most of the observed vehicles took unnecessary long time to complete their parking. The study describe 56% of the 430 observed vehicles as inefficient driving as they took long driving path rather than the optimal path (the shorter in meters and time). The study trace this to two factors, first, the absent of parking guidance in the parking lots and the second is the selectivity of the drivers.

The study also shows that the ability of GPS data to identify the driving behaviour in the parking lots varies based on the time interval and the type of the device that is being used. From that I draw three conclusions. First, the 30-second time interval GPS data was not able to demonstrate the vehicle movement in the parking lots due to large time interval. Only 11% of the data has two tracking points and that was in the largest parking whereas most of the data have only one tracking point. Therefore, this data was only able to capture a cruising time, but it gives no sense about the driving behaviour. Second, for the 5-second time interval GPS data, it clearly demonstrates the vehicle path starting from the parking entrance up till it reach the parking spot. Therefore, this data was able to detect driving behaviour even in a proportionate small size parking lots. Third, the Smartphone GPS data was not effective to detect the driving behaviour due to technical specifications continues loss of GPS signal.

This study aimed at evaluating the driving behaviour in the parking lots using direct observation and evaluate the ability of the GPS and to detect this behaviour. The study shows Smartphone limitation in capturing valid GPS data. This research area can be a subject for future study to enhance Smartphone compatibility and accuracy to capture GPS data exploiting its wide range of dissemination and extensive availability.
Reference:


Case studies for traffic solutions Modern concepts and technologies help improve efficiency, p8, siemens.com/mobility.


Oliveti, M., van der Spek, S., Quak, W., Sarjakoski, T., Santos, M. Y., & Sarjakoski, L. T. Assessing people travel behavior using GPS and open data to validate neighbourhoods characteristics. AGILE.


UN. World urbanization prospects 2014.


Appendix A

### Table A1: Displayed the positional recordings as shape file.

<table>
<thead>
<tr>
<th>№</th>
<th>Shape</th>
<th>TP ID</th>
<th>TRAID</th>
<th>USER</th>
<th>Y COORDINA</th>
<th>X COORDINA</th>
<th>TIME</th>
<th>SPEED</th>
<th>Heigt</th>
<th>SMA TIMES</th>
<th>LNM MAV</th>
<th>FZ</th>
<th>WSN &amp; ID</th>
<th>WS &amp; ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Part 1</td>
<td>1</td>
<td>Street1</td>
<td>1</td>
<td>1229676</td>
<td>9434215687</td>
<td>2025</td>
<td>12817</td>
<td>1334</td>
<td>989</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>Part 2</td>
<td>2</td>
<td>Street2</td>
<td>2</td>
<td>1239676</td>
<td>9434215697</td>
<td>2025</td>
<td>12817</td>
<td>1334</td>
<td>989</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>Part 3</td>
<td>3</td>
<td>Street3</td>
<td>3</td>
<td>1249676</td>
<td>9434215697</td>
<td>2025</td>
<td>12817</td>
<td>1334</td>
<td>989</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>Part 4</td>
<td>4</td>
<td>Street4</td>
<td>4</td>
<td>1259676</td>
<td>9434215697</td>
<td>2025</td>
<td>12817</td>
<td>1334</td>
<td>989</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>Part 5</td>
<td>5</td>
<td>Street5</td>
<td>5</td>
<td>1269676</td>
<td>9434215697</td>
<td>2025</td>
<td>12817</td>
<td>1334</td>
<td>989</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>6</td>
<td>Part 6</td>
<td>6</td>
<td>Street6</td>
<td>6</td>
<td>1279676</td>
<td>9434215697</td>
<td>2025</td>
<td>12817</td>
<td>1334</td>
<td>989</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>7</td>
<td>Part 7</td>
<td>7</td>
<td>Street7</td>
<td>7</td>
<td>1289676</td>
<td>9434215697</td>
<td>2025</td>
<td>12817</td>
<td>1334</td>
<td>989</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>8</td>
<td>Part 8</td>
<td>8</td>
<td>Street8</td>
<td>8</td>
<td>1299676</td>
<td>9434215697</td>
<td>2025</td>
<td>12817</td>
<td>1334</td>
<td>989</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

#### Table A2: Shows the number of valid GPS and smartphone data tracks which were filtering and pre-processing from the volunteer movements within ten parking lots in two cities Borlänge and Falun.

<table>
<thead>
<tr>
<th>Location</th>
<th>Parking lots</th>
<th>Valid GPS data tracks with 30 second</th>
<th>Valid Smartphone data tracks with 15 second</th>
</tr>
</thead>
<tbody>
<tr>
<td>Borlänge</td>
<td>32</td>
<td>273</td>
<td>9</td>
</tr>
<tr>
<td>Falun</td>
<td>54</td>
<td>52</td>
<td>88</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>City</th>
<th>Parking lots</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Borlänge</td>
<td>830</td>
<td></td>
</tr>
<tr>
<td>Falun</td>
<td>8</td>
<td>8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Location</th>
<th>Parking lots</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hemköp</td>
<td>22</td>
<td></td>
</tr>
<tr>
<td>ICA Maxi</td>
<td>90</td>
<td></td>
</tr>
<tr>
<td>Scandic</td>
<td>4</td>
<td>116</td>
</tr>
</tbody>
</table>