An analysis of inter- and intra-provincial commercial vehicle activity chains

by

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Submitted in partial fulfilment of the requirements
for the degree of

BACHELORS OF INDUSTRIAL ENGINEERING

in the

FACULTY OF ENGINEERING, BUILT ENVIRONMENT
AND INFORMATION TECHNOLOGY

UNIVERSITY OF PRETORIA

October 2011

Executive Summary

The objective of this research is to contribute to the body of knowledge on commercial vehicle activity chain characteristics. To achieve this, the state-of-practice in freight modelling as well as contributions to the body of knowledge are reviewed, and opportunities to extend this knowledge are identified. Activity chains are extracted from the GPS logs of 41 711 commercial vehicles which all subscribe to *Digicore Fleet Management*'s tracking service. The extracted activity chains are analysed to determine whether structural, temporal and spatial differences exist. Inter-provincial traffic, also referred to as through-traffic, which is the focus of this research, is analysed in more detail to assess the impact that they have on the Gauteng road network and traffic congestion. The main findings are that the activity chain characteristics of through- and within-traffic are quite similar. They differ, however, quite extensively on different days of the week due to various factors as described in the research. The research is of value to any instance dealing with disaggregate commercial vehicle modelling. It could also be of benefit to, among others, government and businesses using commercial vehicles.

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List of abbreviations and acronyms

CRS	Coordinate Reference System
FSM	Four Step Model
GDP	Gross Domestic Product
GFIP	Gauteng Freeway Improvement Project
MATSim	Multi-Agent Transport Simulation
NDOT	National Department of Transport
O-D	Origin-Destination
ORT	Open Road Tolling
SANRAL	South African Roads Agency Limited
UML	Unified Modelling Language
WGS	World Geodetic System

Chapter 1

Introduction

Whenever one finds oneself at a particular place at a particular time, with a need to be at a different place thereafter, then there is a need for transport. Transport is a crucial part of our everyday life in one or more way such as a trip to school on a bicycle, the delivery of a take-away meal or other package, a businessman visiting a client, or a tourist who needs to travel from the airport to a hotel.

To be able to commute, commuters depend on a mode of transportation, a transport network, and transport infrastructure. Every commuter has an expectation to arrive at the intended destination on time, at an affordable cost, and safe. Therefore, the components, that form a dependable transport system, should be reliable, safe, and be capable of being used towards the long term goal of improving the country's economy.

Transportation is not only used for the movement of people, but also for the movement of commodities. While a transport system is used by both public and business organisations, it is the latter that have greater influence on the country's economy. Whereas a single private car usually conveys only a driver and a few passengers, a single truck usually transports commodities worth thousands of Rands. The economic impact of one commercial vehicle by far exceeds that of one private vehicle, yet there are many more private vehicles on roads than commercial vehicles. This is an indication of a disproportion in the ratio of the number of vehicles on the road, and the economic impact of such vehicles.

1.1 State of transportation in South Africa

In The Fifth Annual State Of Logistics Survey for South Africa (CSIR, 2008), it was noted that logistic costs for 2007 accounted for about 15.9% of the country's Gross Domestic Product (GDP). Of the 15.9%, the transport cost component is 53%. This is higher than the 39% world average. This higher percentage can be attributed to high fuel prices and long haul freight movements. Also, the split in market share for road and rail freight movements in South Africa is about 89/11 (CSIR, 2010) and since road transportation is more expensive than rail transportation, South Africa's road transport sector will have a greater than expected impact on the country's economy.

Transnet is investing R40.8 billion on the upgrading of freight rail transportation over the next five years (South Africa Online - Transport, 2011) in an effort to correct the imbalance. While this may reduce transportation costs of long haul freight movements, the question arises as to whether it would ease congestion on the roads. With the growing economy, an increase in the number of vehicles on the roads will still be experienced, but, as mentioned before, a greater number of freight movements are done by road. Accordingly, the question arises as to whether more effort should be put into the development of a better road network and road transport planning instead.

While all businesses aim to be competitive in an effort to improve the country's economy, there is a distinct problem when it comes to building time and place utility because all businesses need to compete to use the same road network. Furthermore, private vehicles and public transport use the same road network as commercial vehicles. To provide all stakeholders with an equal opportunity to commute and compete, a road network needs to be developed that can carry the required load. The network also has to be maintained and continually improved to keep in pace with the increasing demand of public and commercial vehicles making use of it.

The South African government realised the need for an improved road network and the National Department of Transport (NDOT) conducted a study to identify some key factors that need to be considered when planning for the future of road networks. The identified factors included, amongst others, changes to the needs of the disadvantaged, integration into the world economy, and changes deemed necessary because of global trends. These factors have been the catalysts of urbanisation.

The NDOT then developed a twenty year strategy plan titled *"Moving South Africa"*, in an attempt to respond to and adapt where necessary to these factors. The South African Roads Agency Limited (SANRAL) recently upgraded about 185km of freeways and many critical interchanges in the first phase of the Gauteng Freeway Improvement Project (GFIP). This serves as an example, amongst many others, of an effort towards the improvement of the road network. The NDOT further developed the *National Freight Logistics Strategy* to implement integrated transport mechanisms for long term freight transport development (Department of Transport, 2005).

However, with all these programs in place, traffic congestion on roads remains a problem in the country. This raises a number of questions as to how well the government in fact comprehends the transport issue, and the movement of vehicles, to be able to plan effectively? Furthermore, the question arises as to what role transport actually plays in planning and strategic decision making, and how can these plans and strategies be successfully maintained and achieved.

Development strategies are normally based on the consequences that different scenarios may have, often referred to as "what if" scenarios. "What if" the rate of urbanisation increased by 10% each year? "What if" the number of commuters on the roads doubles within half of the expected time? For strategies to be successful and for future strategies to be useful, appropriate vehicle movement models are required to test and validate different scenarios to determine the effect they will have on traffic congestion and the economy.

1.2 Vehicle movement modelling

In an attempt to model traffic behaviour, much emphasis has been placed on the modelling of private vehicle movement. While passenger and private vehicle models have been modelled with great success, the models are often inflated by a factor to reflect commercial traffic as background noise. These models reflect commercial vehicle behaviour to be similar to private vehicle behaviour.

This situation raises more serious questions, since commercial vehicle traffic has a much greater effect on the economy; making the modelling of commercial vehicle movement important, if not more important, than that of private vehicles. Commercial vehicles' movement differs quite distinctly from private vehicles' movement with regard to vehicle mix, motivations, and the number of activities during a trip (Hunt and Stefan, 2007). The question arises as to how commercial vehicles' movements can be accounted for by simply inflating private vehicle models.

To understand the differences between commercial vehicles and private vehicles that Hunt and Stefan (2007) identify, requires a disaggregate analysis of the behaviour of the vehicles. Liedtke and Schepperle (2004) argue that the current state-of-practice in freight modelling is still aggregate and based on GDP and economic sectors. Such models are useful if the models are developed to assess the economic impact of the commodities that are transported by the vehicles. However, to assess commercial vehicles' impact on road congestion, the average flow of vehicles is an inadequate measure to use. Little is known about the detailed movement of the individual vehicles, therefore there is a need to understand individual decision makers, and the decisions they make, to improve stategic decision making at such a level.

Disaggregate studies require disaggregate data. Many businesses have such data since they keep track of their vehicles, by using GPS devices, for security reasons. Businesses are however reluctant to share such information if it could jeopardise their competitive advantage. Yet there is an opportunity to improve their businesses, and decision making within their businesses, if accurate disaggregate models can be developed from their data.

Various studies (Tan et al., 2004; de Jong and Ben-Akiva, 2007) have since been conducted with the aim of improving the current "state-of-practice" freight movement model, but Figliozzi (2007) notes that commercial vehicles' activity chains are ignored in modelling approaches. This can be attributed to the fact that freight modelling was done using the principles, and models, of passenger modelling.

Joubert and Axhausen (2011) attempt to improve the understanding of freight vehicle movement at disaggregate level by considering the temporal and spatial characteristics of commercial vehicle activities. Their study includes the extraction of activity chains and analyses of the number of activities per chain, activity durations, chain durations, and the start time of chains. This is a giant leap in the direction of understanding commercial vehicle behaviour at a disaggregate level. Joubert et al. (2010) build on the findings of Joubert and Axhausen (2011) by generating intra-provincial traffic from the extracted activity chains and testing the model with the Multi-Agent Transport Simulation (MATSim) toolkit. The model includes both private and commercial vehicles and accurate time dependent results are obtained. They emphasise that inter-provincial activity chains still need to be fully understood, analysed and considered in freight modelling.

1.3 Research question

Freight vehicle modelling is becoming increasingly important as governments try to improve transport planning and strategic decision making. While proper private vehicle models exist, an appropriate disaggregate commercial vehicle model is still required. Various studies have been conducted to improve the understanding of commercial vehicles' movement at disaggregate level. In this project the aim is to focus on the understanding of commercial vehicle activity chains. In an attempt to add to existing literature, the aim is to answer the following research question:

> *What are the structural, spatial and temporal differences between inter- and intra-provincial commercial vehicle activity chains?*

1.4 Research design & methodology

This project aims to contribute to the body of knowledge on commercial vehicle activity chain characteristics. The main deliverables are: complete analyses that show the differences, if any exist, between the characteristics of inter- and intra-provincial commercial vehicle activity chains; and analyses that show the differences in these characteristics on different days of the week.

The research comprises three phases, with the first phase being the extraction of activity chains from raw GPS data. The method for the extraction is similar to the one that Joubert and Axhausen (2011) use.

In the second phase, the extracted activity chains are analysed to determine whether there are differences between activity chain characteristics on different days of the week, and between through- and within-vehicles.

The third phase involves extra detailed analyses specifically on through-traffic, since through-traffic has a few extra characteristics that within-traffic does not have: through-traffic contributes to gate activity at the edge of a study area, and enters and exits the area more frequently than within-traffic.

1.5 Document structure

The current state-of-practice freight movement model is reviewed in Chapter 2. Subsequent contributions to improve the understanding of commercial vehicles' movements at disaggregate level, and opportunities to extend this knowledge, are also reviewed in Chapter 2. A detailed description of activity chain extraction is given in Chapter 3. These extracted chains are then analysed to determine what the differences are between through- and within-traffic and the results are shown in Chapter 4. Chapter 5 has more depth on through-traffic characteristics and Chapter 6 concludes and sets a research agenda.

Chapter 2

Literature Review: Freight modelling

The world of transportation planning and modelling has evolved tremendously over the past few years as the need grows for improved transportation planning and strategic decision making.

The state-of-practice in freight modelling raised some serious concerns: it is to some extent outdated, still aggregate, and based on Gross Domestic Product (GDP) and economic sectors (Liedtke and Schepperle, 2004). It is also based on private vehicle models, mostly the traditional Four Step Model (FSM).

The FSM is a classic urban transportation planning model, with the four steps being trip generation, trip distribution, mode choice, and route assignment. The trip generation step involves the generation of production and attraction ends. Production ends are the start of trips from a specific zone, and attraction ends are the end of trips at a specific zone. The number of production ends from, and attraction ends at, a certain zone, is estimated from land use data or other socio-economic factors. In the trip distribution step, each production end is linked to an attraction end to form a complete trip. The number of trips between a specific origin and destination zone are determined and known as an Origin-Destination (O-D) set. The mode choice step uses the trips in each O-D set and assigns a mode of transportation to each trip. The final step then assigns a route to each of these sets and transportation modes. The aim of the FSM is to determine equilibrium flows in the network, which raises another concern, namely that equilibrium does not exist on road networks. This indicates that the current state-of-practice freight movement model is under serious debate in terms of the validity and accuracy of individual vehicles' movements.

2.1 Aggregate vs. disaggregate decision making

Most commercial vehicle studies focus on *commodity* movement and its impact on economic sectors, instead of *vehicle* movement and its impact on traffic congestion as well as the economy. As a result, commodity movement is transposed into vehicle movement. The movement of vehicles is solely based on the movement of commodities and is hence modelled as an aggregate flow of vehicles. There is space for commodity movement models if the objective of the model is solely to assess economic impact.

Unfortunately, commodity movement cannot be used to assess the impact that vehicles have on traffic congestion, since the individual vehicles' exact movement is unknown. Liedtke and Schepperle (2004) further emphasise the need to understand freight movement at micro level by stating that the different agents or "decision makers" should be analysed and understood, instead of merely inferring their behaviour from commodity movement.

To understand individual agents and their movements, disaggregate data is required. Obtaining this data is the main issue in attempts to do freight modelling. Organisations are reluctant to share any information that might reveal trade secrets or jeopardise their competitive advantage and this scarcity of data forces researchers to conduct surveys, which could be very time consuming and expensive.

2.2 Aggregate modelling

One of the first attempts at freight modelling is the truck traffic model of Marker Jr and Goulias (1998). They make use of a three step zonal approach consisting of trip generation, trip distribution and traffic assignment. The trip generation step was estimated by aggregating business employment to traffic analysis zones. The trip distribution step involved a gravity model, and user equilibrium accounted for the traffic assignment step.

According to Hunt and Stefan (2007), the most common, yet less satisfying, method to model commercial vehicles, is to use scale factors that adjust volumes in the private vehicle models. Commercial vehicles are then regarded as *background noise* in these models. Hunt and Stefan further add that urban commercial vehicle movements, the role of service delivery, and trip chaining would improve freight modelling. They divide their study into three main categories consisting of external-internal movements, fleet-allocator movements, and tour-based movements. The external-internal movements category consists of vehicles that had at least one trip that ended outside the area of interest. The fleet-allocator category consists of vehicles that were dispatched to conduct business over a certain area, as opposed to dealing with a specific shipment. The tour-based category, which represents the majority of the movements in the model, consists of individual shipments. These models form the components of a micro-simulation with the end result being a zone-to-zone trip table which is used in conjunction with the household travel model to find network equilibrium. The resulting travel times are fed back into the model and the model is repeated until travel times are consistent and system equilibrium is achieved. This, however, relates strongly to the four-step model which is used for private vehicle modelling. Although specific tours are being modelled, the tour generation is based on an aggregate trip generation model. Due to a lack of data, they collect information from about 3 100 business enterprises from which they eventually sample 64 000 trips to use in their study. This approach is based on individual shipments and not on commodity flows.

On the contrary, Tan et al. (2004) use commodity flows and transpose it into O-D data. This data are then used in a discrete event simulation model. This is a step in the direction of modelling commercial vehicle movements at micro level, but is still based on commodity flows.

De Jong and Ben-Akiva (2007) inspect the detailed movement of commercial vehicles and consider the frequency of activity chains, distribution centre use, and the mode of each of the activity legs in their study. Their work focuses more on activity chains while simultaneously taking management philosophies into account. The model takes commodity flows as input and converts these into disaggregate firm-to-firm flows. At this level, the logistic decisions such as shipment size or mode choice are simulated using micro-simulation. Although an effort is made to model different legs of a trip at a disaggregate level, there is still a lack of understanding of the explicit activity, and activity chain characteristics of commercial vehicles.

2.3 Disaggregate modelling

In an attempt to understand the activity- and chain-characteristics of commercial vehicles, Joubert and Axhausen (2011) analyse the temporal and spatial characteristics of disaggregated commercial vehicle activities. The study includes the extraction of detailed activity-chains from GPS logs of more than 31 000 commercial vehicles, over a six month period. These activity-chains are then analysed with regard to certain characteristics such as the number of activities per chain, activity durations, chain durations, and the start time of chains. The study is a great leap in the direction of understanding commercial vehicles' movements at disaggregate level. However, there is still room to explore the differences between intra- and inter-provincial activity chains. A vehicle passing through a study area may have a different travelling behaviour to that of a vehicle that is confined to the study area.

Joubert et al. (2010) build on the work of Joubert and Axhausen (2011) to test the modelling approach. They use an agent based approach to implement reconstructed commercial activity chains in conjunction with private vehicles. They generate intra-provincial traffic (within-traffic) by extracting vehicles that performed at least 90% of their activities in an activity-chain within the area of interest. With this study they show that detailed movements of commercial vehicles can be modelled accurately without having to model complex logistical functions. The model is tested using the Multi-Agent Transport Simulation (MATSim) toolkit and the results show that an activity based approach in the modelling of freight vehicles, and the impact thereof on private vehicle movement, can be done accurately. They state that the next step would be to generate through-traffic activity chains and compare those against actual traffic counts.

To be able to analyse through-traffic and activity chain characteristics, a set of activity chains is required. The extraction of activity chains will be discussed in the next chapter.

Chapter 3

Data Preparation

Digicore Fleet Management, a vehicle tracking service provider in South Africa, provided a dataset for this research project. The data contains the detailed GPS logs of 41 711 commercial vehicles for the period 1 January 2009 to 30 June 2009. Each vehicle has a tracking device installed that tracks certain "triggers" including temperature, opening and closing of doors, and ignition-on and ignition-off triggers. Whenever one of these triggers is received, a signal is sent to and logged by a server. If no trigger is received, a signal of the status of the vehicle is automatically sent every 5 minutes and also logged by the server. A vehicle, its activity-chains, and its activities, as well as the relationship between these aspects, should be defined before activity-chains can be extracted.

Before the activity-chains can be extracted, the relationship between a vehicle, activity-chains, and activities should be defined to understand how they fit together.

3.1 Connecting the concepts of vehicles, chains, and activities

Figure 3.1 depicts the relationship between vehicles, activity-chains, and activities, in the form of a high level class diagram using the Unified Modelling Language (UML). Since the data that will be used were obtained from *Digicore*, in this project the terms "vehicle", "activity-chain", and "activity", will be renamed to `Digicore Vehicle`, `Digicore Chain`, and `Digicore Activity` and presented in this font henceforth. Each of these terms will be discussed in detail:

`Digicore Activity` relates, in this research project, to the ignition activity in each of the vehicles. When an ignition-off trigger is received (the vehicle is switched off), an activity starts, and when an ignition-on trigger is received (the vehicle is switched on), the activity ends. A `Digicore Activity` therefore takes place when a vehicle

Figure 3.1: High level class diagram of the relationship between a `Digicore Vehicle`, `Digicore Chain`, `Digicore Activity`

is switched off. Joubert and Axhausen (2011) show that a threshold of 300 minutes is appropriate to distinguish between major and minor activities. Minor activities, which have a duration of less than 300 minutes, typically include short stops for deliveries or collections, or service activities. Major activities, which have a duration in excess of 300 minutes, typically include depot stops at the start and end of the activity chain. In this project, the same threshold of 300 minutes will be used to split the activities into major and minor activities.

`Digicore Chains` consist of two or more `Digicore Activity`(ies). A chain starts and ends with a major activity and can contain any number of minor activities between the two major activities. A chain can be one of two types: a chain consisting of only two major activities, containing no minor activities; or a chain starting with a major activity, containing a number of minor activities, and ending with a major activity. Whereas Joubert and Axhausen (2011) only consider chains with at least one minor activity, this project will consider these chains as well as chains that consist of only two major activities.

`Digicore Vehicles` may perform any number of activities. A sequence of these activities form `Digicore Chains`. A `Digicore Vehicle` therefore has a number of `Digicore Chains` and each chain has two or more `Digicore Activity`(ies). Each vehicle has a unique identification number (vehicle ID), which is used to distinguish it from other vehicles.

3.2 Extraction of activity chains

The method of activity-chain extraction is similar to the method used by Joubert and Axhausen (2011). The dataset is in the form of a single flat file, in excess of 30Gb in size. From this file, 41 711 vehicles were identified. It is therefore practical to split this single file into a number of smaller files, i.e. one file per vehicle, to simplify the extraction of `Digicore Chains`. These vehicles represent about 1.8% of the total light delivery vehicle and heavy vehicle population in South Africa (Live vehicle population statistics - eNaTIS, 2009). Since the activity chain characteristics of these 41 711 vehicles might not be representative of the total population, a possible selection bias is acknowledged, yet the dataset is invaluable in understanding commercial vehicle movement at a disaggregate level.

The process of extracting activity chains consists of three stages:

Splitting of the single file: The single file consists of data fields in the format: (1) a unique vehicle identification number which reveals no information about the customer; (2) a Unix time stamp (measured in seconds from the epoch, 1 January 1970); (3) a longitude value in World Geodetic System (WGS) 84 Coordinate Reference System (CRS) decimal degrees; (4) a latitude value in WGS 84 CRS decimal degrees; (5) a vehicle status identifier, which relates to one of the triggers mentioned in section 3.2; (6) the vehicle's speed. This file is split into 41 711 individual files, one for each vehicle, that have exactly the same data fields as the original single file.

Sorting of activities in files: Each vehicle file contains GPS records that are not necessarily sequenced chronologically. To simplify the extraction of the activity-chains, these records are sorted chronologically according to the time stamp field.

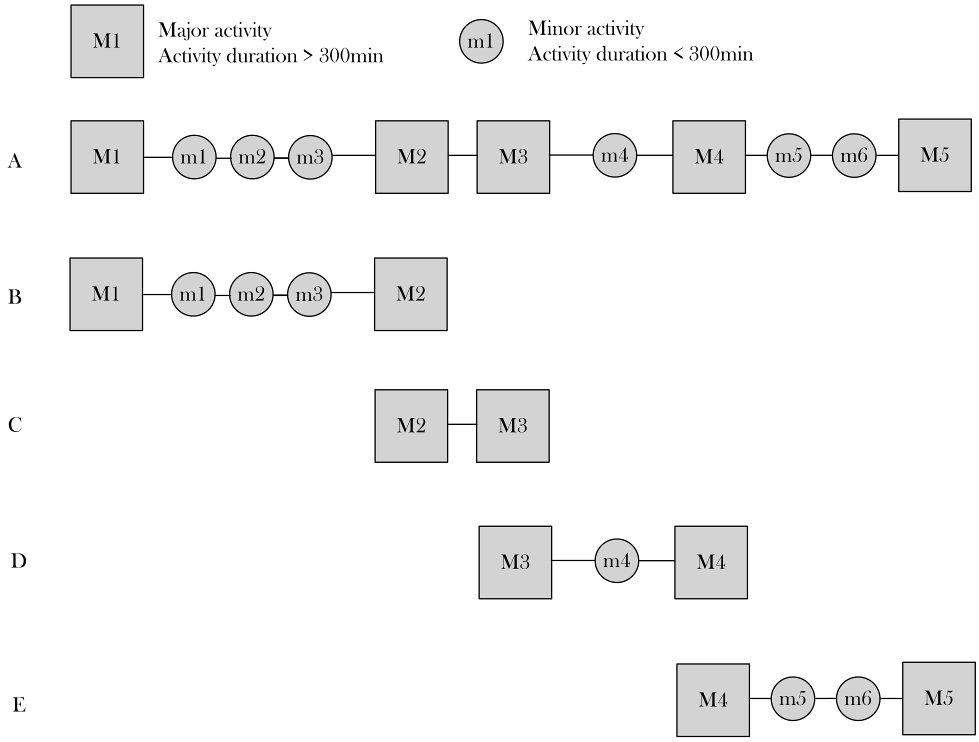


Figure 3.2: Extracting four `Digicore Chain`s from a sequence of `Digicore Activity`(ies)

Extraction of activity-chains: Each vehicle file is considered for activity-chain extraction. All initial minor activities are removed, until the first major activity in the file is identified, as these are not part of a complete `Digicore Chain`. As soon as the first major activity is identified, a new `Digicore Chain` is created, and the major activity added as the first activity of the chain. All subsequent minor activities, if any, are added to the chain until another major activity is identified, which ends the chain. Such a chain can be seen in row B of figure 3.2. The major activity that ends the chain, then also becomes the first major activity of the following chain. This is repeated until all completed chains are extracted. Whereas Joubert and Axhausen (2011) remove chains consisting of only two major activities, in this research project they are included. Such a chain can be seen in row C of figure 3.2. These extracted chains are stored in new files, one for each vehicle, which have a structure similar to the structure of `Digicore Vehicle`s.

Figure 3.2 depicts the extraction of four `Digicore Chain`s from a number of consecutive `Digicore Activity`(ies). Row A shows a series of activities of one `Digicore Vehicle`. The first complete extracted chain is shown in row B, consisting of the first major activity, three minor activities, and ending with the second major activity. In row B, the second major activity (last activity in the chain), becomes the first major activity of the chain in row C. There are no minor activities and the chain ends with the third major activity. This process continues until all possible chains are extracted.

These extracted `Digicore Chain`s form the foundation on which all analyses will be done in the next chapter. In the following chapters, whenever the term “activity” is used, it refers to a minor activity as described in section 3.1, unless specified otherwise. The term “chain” refers to a `Digicore Chain` and a “vehicle” refers to a `Digicore Vehicle`.

Chapter 4

Analysis of activity chains

To distinguish between inter- and intra-provincial traffic, also referred to as through- and within-traffic in this project, a suitable study area is required. In South Africa, Gauteng can be considered as the centre point for all major freight movements, imports, exports, and local distributions. Gauteng contributes almost 35.1% towards the country's Gross Domestic Product (GDP) (Gauteng Economic Development Agency, 2011). This is the reason why it is referred to as the "economic heart" of South Africa and whereas the road network that runs through it, is referred to as its "economic arteries" (South African National Roads Agency Limited, 2011).

Gauteng, the most active province in terms of commercial vehicle activity, is connected with other main centra in the country through corridors. These corridors are shown in figure 4.1, and where they cross the boundary of the province they create gateways into and out of Gauteng. The N3 links Gauteng with Durban, which has a good port infrastructure. The N12, along which various coal mines are situated, is a link to Mpumalanga. The N4 eastbound also passes through Mpumalanga and ultimately ends in Mozambique. The N4 westbound is the link to platinum rich North West province and the link to Botswana and Namibia. The N1 northbound is the link to the Limpopo province and Zimbabwe. The N14 and N12 westbound both link with Namibia and the industrial areas on the outside of Gauteng. The N1 southbound is the link with the Free State and, ultimately, Cape Town in the Western Cape where the country's second largest port is located. These major gateways are prominent links with neighbouring countries and offer opportunities for different types of commodities, people and services to flow in, out, and through Gauteng. Gauteng was identified as a suitable study area for this project.

4.1 Day-of-week analysis

During school holidays and public holidays, the private vehicle traffic volume reduces on the roads. The first question that comes to mind is whether this phenomenon also holds for commercial vehicles.

To determine if there are differences in commercial vehicle counts on different days of the week, the number of vehicles that travel on a given day had to be determined. An initial analysis was done to determine the number of commercial vehicles, with at least one activity in Gauteng, for each day of the week (Monday to Sunday). Figure 4.2a depicts a box plot of the `DigicoreVehicle` count for each day of the week.

There is a difference in proportion between weekdays and weekends, with weekdays each having almost double the number of vehicles than on Sundays. This lower count

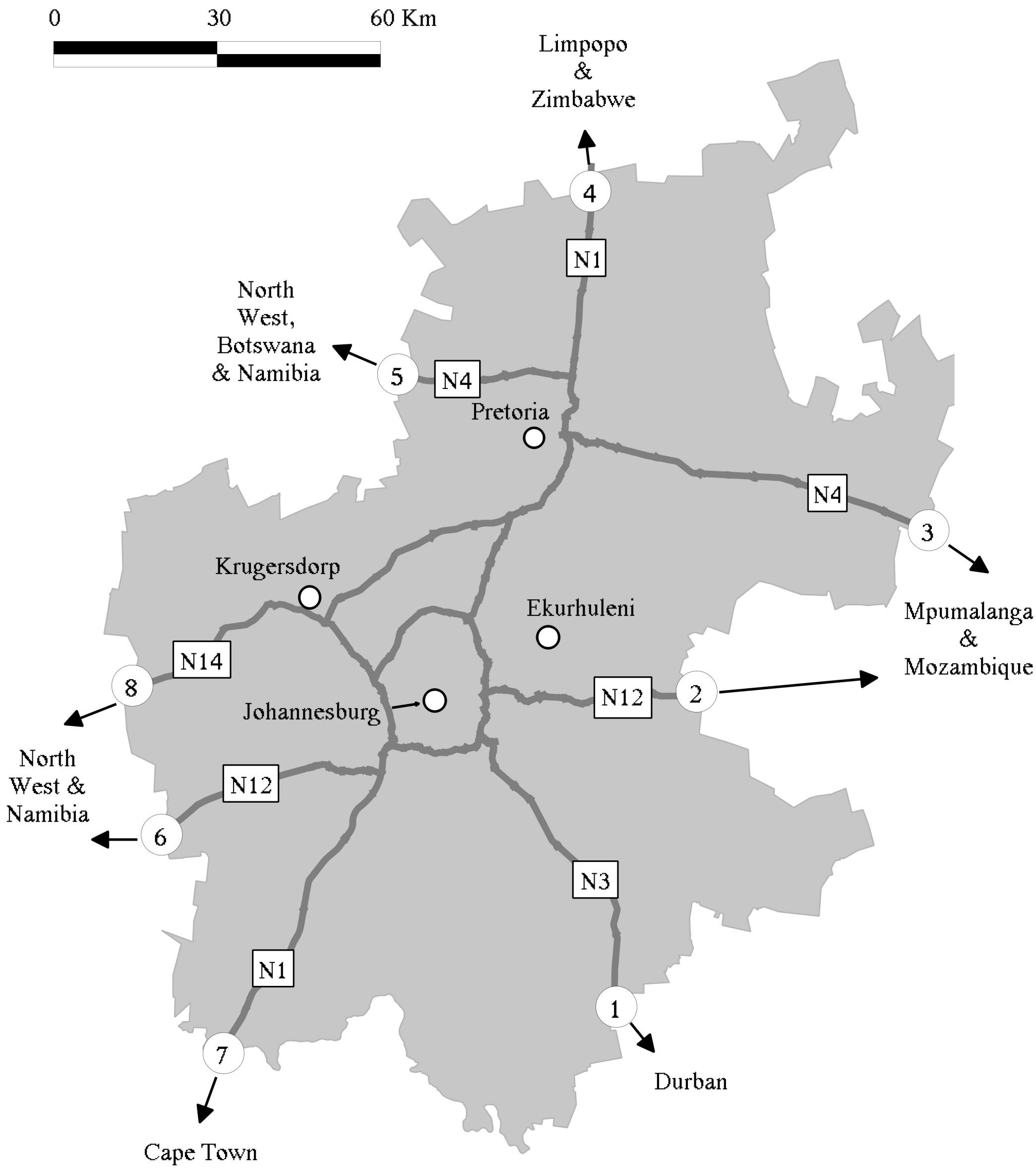
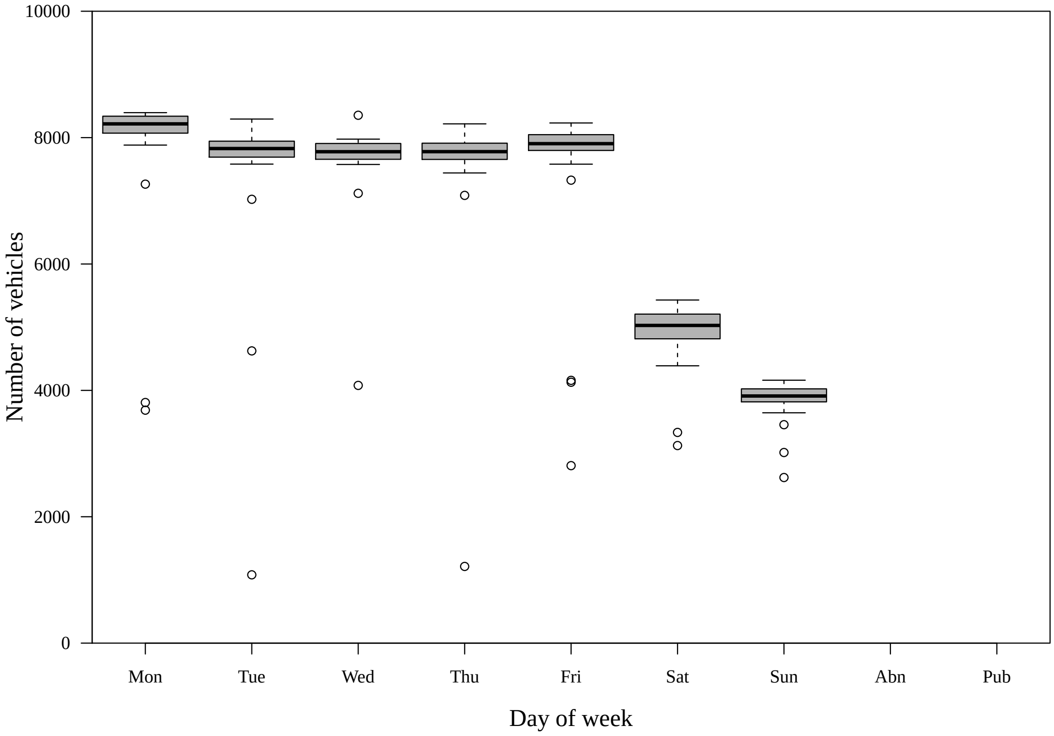
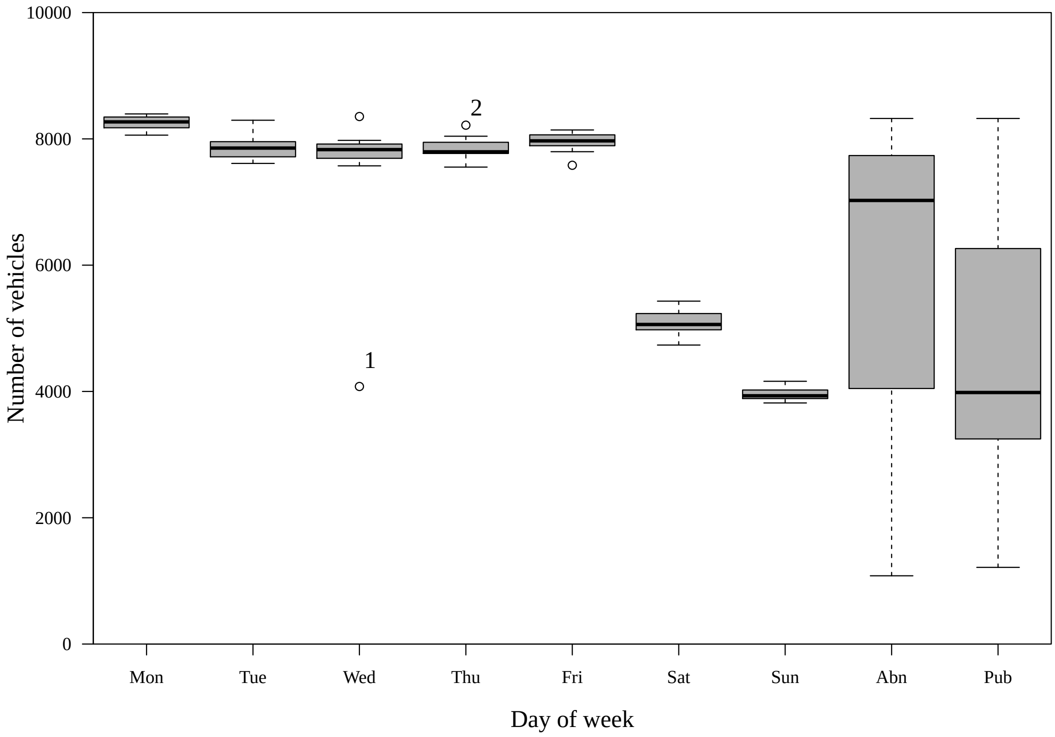


Figure 4.1: The main gateways in and out of Gauteng



(a) Only weekdays and weekend days



(b) Abnormal days and Public holidays extracted

Figure 4.2: Comparison of the number of vehicles with at least one activity in Gauteng

is a typical weekend inactivity of some vehicles. The outliers, indicated by circles on the box plot, represent values that do not fall inside the 25^{th} to 75^{th} percentiles. There are numerous outliers on both weekdays and weekends, suggesting that there might be underlying factors that influence some of the counts.

The initial feeling was that the outliers may be on days that fall within the school holidays or on a public holiday. To validate this assumption, the counts on school holidays and public holidays had to be extracted from the original data. Two files were obtained from SANRAL: one which contains the dates of days not considered "normal" days, such as school holidays in South Africa, and referred to as *abnormal days* henceforth; and one which contains the South African public holidays, and referred to as *public holidays* henceforth. The counts of these two types of days were extracted from the original data.

Figure 4.2b depicts a box plot of the number of vehicles with at least one activity in Gauteng, on each of the seven days of the week as well as abnormal days and public holidays. When the abnormal and public holidays were treated as separate day types, nearly all outliers from the initial box plot were accounted for. This confirms that the number of vehicles on abnormal days and public holidays do differ from those on normal weekdays and weekends. The spreads of the abnormal days and public holidays are large and little can be said about what a good representation of the number of vehicles on those days could be. The main focus in this project is on each of the 7 normal days of the week (weekdays and weekends), although some reference will be made to abnormal days and public holidays. Four outliers were still identified after the extraction of abnormal days and public holidays. The dates of the four outliers were determined and two of them were investigated further.

On figure 4.2b, outlier 1 has a count of 4 079 vehicles, which is almost half of the mean value on a Wednesday. The date of outlier 1 was found to be 22 April 2009, which was identified as the National Election day in 2009. Election day was not included in SANRAL's public holiday list since the list was generated before the president declared the day a public holiday, hence the outlier.

Outlier 2 has a count of 8 217 which lies above the upper quartile for a typical Thursday activity. The date of outlier 2 was found to be 23 April 2009, the day after the National elections on which outlier 1 was identified. This suggests that businesses increased the number of vehicles on the day following the election day to possibly make up for business lost on election day when the drivers were voting. These outliers are though not major concerns.

The difference in counts on different days of the week suggests that commercial vehicles' travelling patterns should differ on different days of the week. Some analyses, where relevant, will be evaluated on a day-of-week basis, to determine the extent to which vehicles' behaviour differs on different days of the week.

To be able to analyse through- and within-traffic and determine if the vehicles' behaviour differ, the vehicles had to be divided into through- and within-vehicles before any analysis could begin.

4.2 Through- and within-vehicles

Since Gauteng is the economic heart of South Africa, with various gateways that link it with the rest of South Africa, and even Africa, Gauteng will definitely have both through-traffic and within-traffic. Joubert and Axhausen (2011) determine that 60% of activities is a suitable threshold to distinguish between through- and within-vehicles. If more than

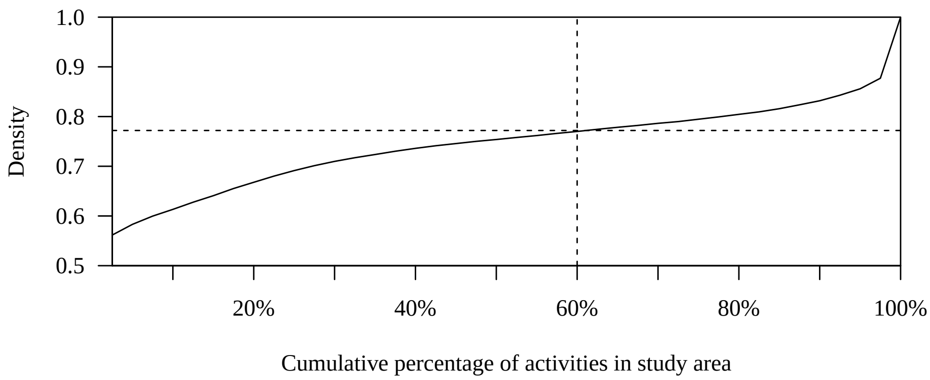


Figure 4.3: Density estimates to distinguish between through and within traffic in Gauteng

60% of a vehicle's activities are inside the study area, it is considered a within-vehicle. If less than 60% of a vehicle's activities are inside the study area, it is considered a through-vehicle.

The `Digicore Vehicle`s were analysed to determine if 60% is also a suitable threshold value for the current research project to distinguish between through- and within-traffic. Figure 4.3 depicts the cumulative percentage of activities in the study area for all vehicles. From this figure the curve flattens towards the 60% region, which suggests that 60% is indeed a suitable threshold. Furthermore, about 56% of `Digicore Vehicle`s did not enter Gauteng, which suggests that *Digicore* has enlarged its national footprint with tracking devices.

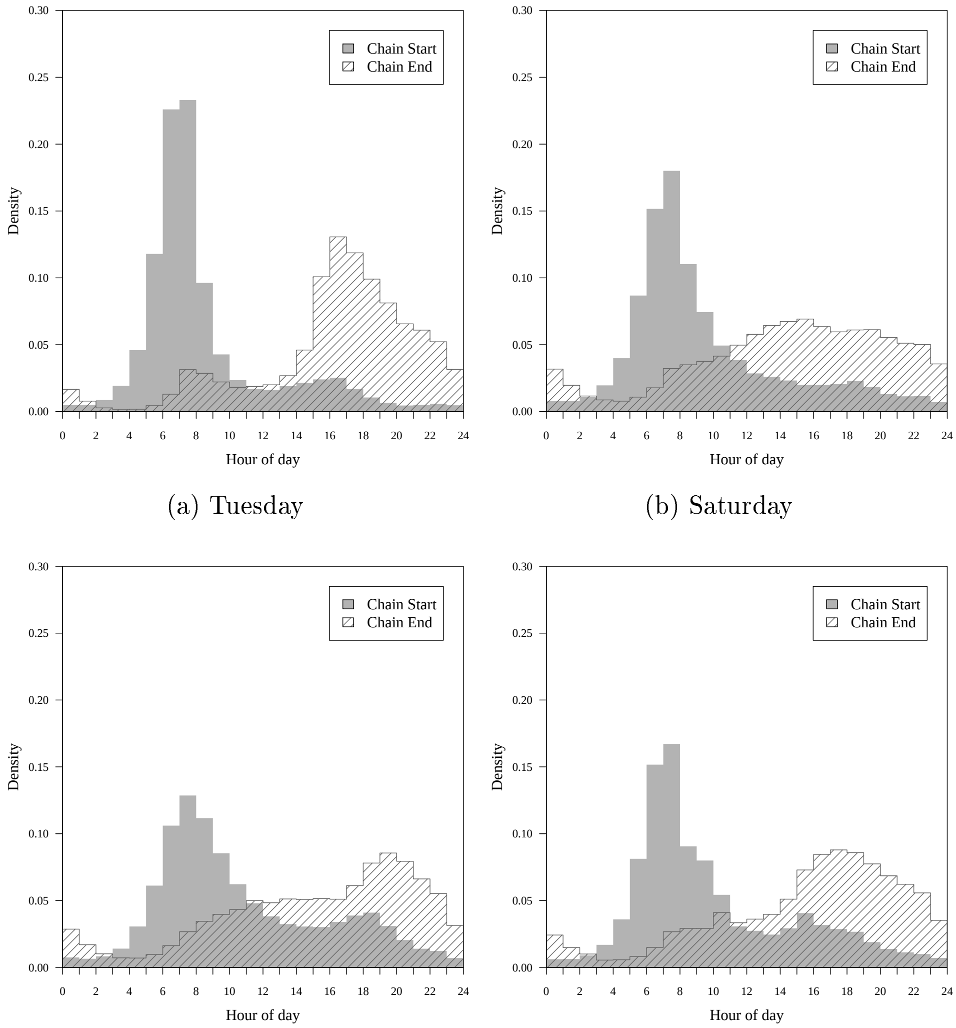
The 60% threshold to distinguish between through- and within-traffic was used to divide the 41 711 `Digicore Vehicle`s into through- and within-vehicles. Of the 41 711 `Digicore Vehicle`s, 31 982 or 76.68% were through-vehicles, and 9 729 or 23.32% were within-vehicles. The next step was to analyse chain characteristics to determine whether through- and within-vehicles' activity chain characteristics differ.

4.3 Chain characteristics

`Digicore Vehicle`s have different characteristics at different levels, some at chain level and some at activity level, and therefore analyses were carried out at both levels. The first analysis was done to determine when the vehicles' activity-chains start and end during the day. Through- and within-vehicles were split and for each hour of the day, the number of activity chains that started during that hour was determined. This was repeated for each day of the week.

Figure 4.4 depicts the density of chain start and end times of within vehicles for a weekday, weekend, and public holidays. As can be seen on the figure, the density distributions of the start times on the different days do not differ much. Only within vehicles are shown because through vehicles' chain start and end time characteristics were found to be very similar to those of within vehicles. Furthermore, only one weekday is shown because all weekdays' patterns are similar. It is important to note that although the patterns are similar, the actual volume of vehicles differ on the different weekdays.

On a Sunday, the chain start time density is slightly lower than on a weekday. This phenomenon similarly appears on a public holiday. Another similar feature is that on



(a) Tuesday (b) Saturday

(c) Sunday (d) Public holiday

Figure 4.4: Within vehicles' chain start and end times on different days of the week

weekdays, weekends and public holidays, the peak chain start times are between 06:00 and 08:00, namely peak hour traffic. Commercial vehicles move slower than other vehicles and thereby contribute to peak hour traffic congestion.

For chain end times, there is a peak in the late afternoon on weekdays, but on weekends the distribution is rather uniform towards the end of the day, with a slight peak between 18:00 and 20:00. Whereas Joubert and Axhausen (2011) find that 60% to 87% of chains have ended before the afternoon peak starts at 16:00, in this project only 35% to 52% of `Digicore Chain`s have ended before the afternoon peak. This means that the rest of the commercial vehicles will still be on the road during peak hour traffic and contribute to peak hour traffic congestion. The complete set of graphs in this regard can be seen in Appendix D.

The next step was to determine the duration of the activity chains. Through- and within-vehicles were analysed to determine the chain duration distribution of all chains on the different days of the week, and to determine if there are major differences between them. Table 4.1 contains the summary statistics for through- and within-vehicles' chain duration on the different days of the week.

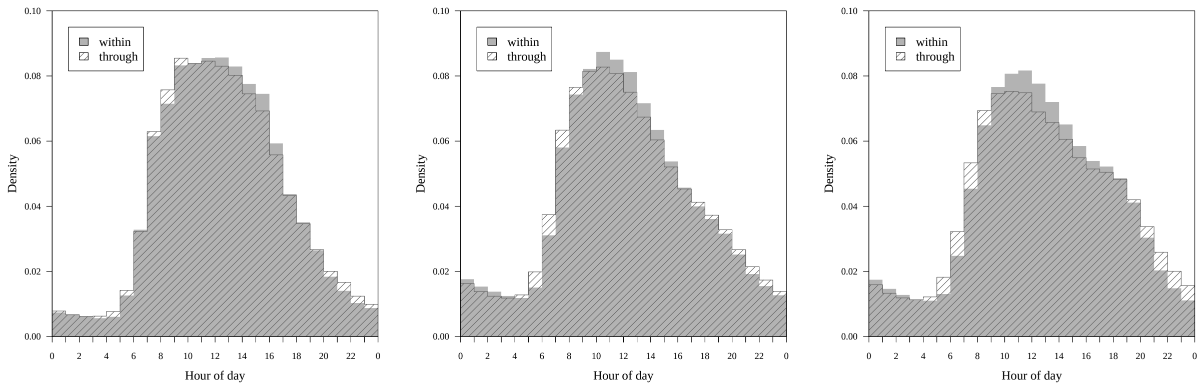
Table 4.1: Summary statistics of chain duration (in hours)

(a) Through Vehicles

			Percentile						Max
	Mean	**Std dev**	**25th**	**50th**	**75th**	**90th**	**95th**	**99th**	**(days)**
Monday	14.80	28.78	6.40	10.05	14.15	20.08	41.85	124.40	124
Tuesday	13.01	23.98	6.47	10.06	13.98	18.01	37.38	85.70	107
Wednesday	12.81	24.12	6.36	10.03	14.01	18.07	37.47	73.80	127
Thursday	12.51	24.13	6.36	9.98	13.94	17.93	36.06	64.39	127
Friday	11.78	24.75	6.11	9.53	13.57	17.50	26.84	58.82	149
Saturday	10.58	25.16	3.77	7.86	12.57	16.91	24.79	64.16	109
Sunday	12.45	27.15	3.08	7.52	12.76	19.73	39.00	124.12	86
Abnormal day	12.36	28.09	5.02	9.25	13.52	17.82	35.06	86.15	160
Public holiday	12.55	27.90	4.30	8.80	13.24	18.62	35.89	99.10	72

(b) Within Vehicles

			Percentile						Max
	Mean	**Std dev**	**25th**	**50th**	**75th**	**90th**	**95th**	**99th**	**(days)**
Monday	14.53	29.35	6.97	10.27	13.38	17.77	40.68	130.23	115
Tuesday	11.86	20.32	7.04	10.27	13.15	16.41	20.77	66.94	91
Wednesday	11.86	22.53	6.89	10.24	13.22	16.54	22.12	65.66	114
Thursday	11.74	24.37	7.02	10.24	13.26	16.52	21.46	56.22	139
Friday	11.06	19.49	6.48	9.87	12.98	16.38	19.30	44.62	133
Saturday	8.76	21.21	3.33	7.12	11.02	14.76	17.33	41.72	94
Sunday	9.19	26.94	2.41	5.90	10.33	14.13	18.63	87.84	122
Abnormal day	11.24	25.35	4.90	9.38	12.63	16.15	20.51	70.62	136
Public holiday	10.87	35.48	3.95	8.61	12.16	16.07	21.58	81.27	169



(a) Tuesday (b) Saturday (c) Sunday

Figure 4.5: Minor activity start times for weekdays and weekends

For both through- and within-vehicles, there is a slight drop in the mean chain duration as the week progresses. An interesting observation is that there is a longer mean chain duration of through-vehicles on a Sunday and that 95% of these vehicles have a chain duration of up to 39 hours. This could be vehicles that start their trips on a Sunday to deliver or pickup goods on the Monday when all business cycles are back to normal.

Within-vehicles' chain durations are slightly lower than those of through-vehicles. A possible reason for this is that through-vehicles are typically long haul vehicles that have longer activity chains, hence the longer chain durations than within-vehicles.

The extensive maximum durations seen on all days, could be attributed to a number of possible reasons: the vehicles are utilised exceptionally well, the vehicles are not serviced for very long periods of time, or wrong signals could have been sent. In future, the accuracy of the signals could be investigated and validated.

Another interesting observation was that 94.7% all through- and within-vehicles, have a chain duration of 24 hours or less. Some of the chains continue from one day over into the next day and for modeling purposes, in future research, these chains may need to be broken into independent chains such as in Joubert et al. (2010).

Since activity chains consist of activities, it would also be beneficial to know when the activities take place throughout the day. Figure 4.5 depicts the minor activity start times of both through- and within-vehicles, for a weekday and the weekend. Through- and within-vehicles were plotted on the same graph to determine whether differences between their minor activity start time distributions exist.

The minor activity start time distributions for through- and within- vehicles are similar for all weekdays where they tend to peak in the middle of the day. This confirmed the results of Hunt and Stefan (2007), that commercial vehicle activities concentrate towards the middle of the workday and not as much towards the morning and afternoon peaks. However, since minor activities are the typical drop off and collection activities, the activity chains had to start earlier than the start times of these minor activities. This means that vehicles could have started their trips during the morning rush hour. All other minor activity start time graphs can be seen in Appendix B.

Next, the activity duration of all vehicles was analysed. Since this project relies on ignition-related triggers that signal the start and end of an activity, there is a possibility of false start or stop signals; a vehicle's engine might fail, which triggers a false signal. To eliminate false starts or stops, a minimum activity duration threshold of 1 minute was

Table 4.2: Summary statistics of activity duration (in minutes)

(a) Through Vehicles

			Percentile						Max
	Mean	**Std dev**	**25^{th}**	**50^{th}**	**75^{th}**	**90^{th}**	**95^{th}**	**99^{th}**	**(days)**
Monday	101.00	733.69	4.35	11.75	38.35	159.32	608.60	1117.00	142
Tuesday	104.00	768.34	4.37	11.82	38.35	159.97	597.15	1156.85	134
Wednesday	101.40	746.30	4.37	11.73	37.85	157.58	584.01	1111.03	146
Thursday	112.60	862.94	4.35	11.65	37.62	157.61	590.12	1164.60	151
Friday	174.70	1015.63	4.32	11.58	37.65	158.45	695.03	3923.56	136
Saturday	161.70	762.97	4.53	12.92	48.13	294.50	932.72	2626.70	147
Sunday	126.10	578.95	4.83	14.40	59.37	389.95	740.73	1289.57	129
Abnormal Day	137.80	933.14	4.45	12.20	41.15	192.37	675.85	2510.67	166
Public Holiday	242.80	1719.72	4.58	13.12	49.90	397.69	925.32	4720.22	170

(b) Within Vehicles

			Percentile						Max
	Mean	**Std dev**	**25^{th}**	**50^{th}**	**75^{th}**	**90^{th}**	**95^{th}**	**99^{th}**	**(days)**
Monday	94.17	753.92	4.13	10.93	34.52	142.63	622.55	1014.60	120
Tuesday	95.22	711.86	4.22	11.22	35.20	144.42	605.45	1044.95	108
Wednesday	93.44	737.57	4.18	11.10	34.53	141.70	593.26	1012.78	115
Thursday	102.80	835.42	4.18	11.05	34.37	140.37	588.98	1038.82	150
Friday	163.30	937.44	4.15	10.97	34.45	144.30	695.47	3856.37	122
Saturday	180.70	787.06	4.47	12.68	47.40	328.44	1087.54	2719.93	141
Sunday	135.90	523.02	4.53	14.32	66.97	503.35	823.24	1294.43	85
Abnormal Day	134.60	976.94	4.27	11.60	38.28	179.80	694.28	2485.50	160
Public Holiday	249.50	1898.27	4.48	12.75	47.87	441.43	977.50	4808.59	172

applied. Table 4.2 contains the summary statistics for activity durations of through- and within-vehicles on the different days of the week.

An interesting observation from table 4.2 is that the 90^{th} percentile of activity durations on Saturdays, Sundays, and Public holidays, exceeds 300 minutes (the threshold to distinguish between major and minor activities). This means that there are more major activities on weekends and public holidays than on weekdays and abnormal days. These major activities could suggest vehicle inactivity over weekends and on public holidays. On the contrary, on abnormal days the activity duration is similar to that of weekdays, suggesting that during school holidays, commercial vehicle activity is similar to that of weekdays.

Furthermore, activity duration increased towards the end of the week. This could suggest that bigger loads are being moved on Fridays to provide for the weekend demands, and increasing the loading time.

Within-vehicles have lower average activity duration than through-vehicles, which could mean more effective warehousing and centres in Gauteng than in the surrounding areas outside Gauteng. The warehouses or distribution centres in Gauteng have more competition and turnaround times, thereby encouraging managers to streamline the warehouses for competitive advantage and hence shorter loading and unloading times.

The longer activity durations on weekends, for both through- and within-vehicles, could be due to less staff being available for loading and unloading on weekends.

Table 4.3: Summary statistics of the number of activities per chain

(a) Through Vehicles

			Percentile						
	Mean	**Std dev**	**25th**	**50th**	**75th**	**90th**	**95th**	**99th**	**Max**
Monday	13.74	27.99	3	9	17	27	38	101	4811
Tuesday	12.22	23.14	3	9	16	25	32	68	4486
Wednesday	12.14	19.39	3	9	16	25	33	64	2575
Thursday	11.95	19.17	3	9	16	25	32	60	3768
Friday	11.53	21.11	3	9	16	24	30	54	2815
Saturday	8.66	26.63	1	5	11	19	26	51	4903
Sunday	8.91	26.81	1	4	10	19	29	79	2936
Abnormal Day	11.05	23.55	2	7	15	23	31	66	4663
Public Holiday	10.42	31.62	1	6	13	22	30	73	3159

(b) Within Vehicles

			Percentile						
	Mean	**Std dev**	**25th**	**50th**	**75th**	**90th**	**95th**	**99th**	**Max**
Monday	15.24	32.64	3	10	18	27	40	66	3467
Tuesday	12.29	18.98	3	9	17	25	31	73	2279
Wednesday	12.46	25.93	3	10	17	25	32	66	7288
Thursday	12.36	20.64	3	10	17	25	31	147	2844
Friday	11.82	21.01	3	9	17	24	30	68	3237
Saturday	7.89	21.48	1	5	11	18	24	41	2734
Sunday	7.63	28.20	1	3	9	16	23	66	2808
Abnormal Day	11.28	25.43	2	7	15	23	30	69	3591
Public Holiday	9.95	32.24	1	5	13	21	28	63	2897

The next step was to analyse the number of activities per chain. Table 4.3 shows the summary statistics for through- and within-vehicles with regard to the chain length (number of activities per chain).

For both through- and within-vehicles, the chain length decreases as the week progresses from Monday to Friday. Weekends tend to have shorter chains than the rest of the week or abnormal days and public holidays. A possible explanation could be that many businesses are closed on weekends or only open for a part of the day, limiting the actual activity that could take place.

The chain lengths of through- and within-vehicles were found to be very similar. At first glance this could be rather counter intuitive, since it is expected that through-vehicles, which are associated with long haul vehicles, should have much less activities per chain than within-vehicles. However, these vehicles also have possibilities of collecting and distributing, only over longer distances. It is possible that more businesses have started using load consolidation as a means of reducing expenses. A possible cause could be warehouse inefficiencies in and around Gauteng. Long haul vehicles could waste time at inefficient distribution centres unloading or loading and relocating; which typically increases the number of minor activities per chain. Another interesting analysis could be to determine what the activity chain characteristics look like closer to the month end.

The excessively long maximum chain lengths suggest again that some vehicles might not be serviced for very long periods, or that some signals might not be accurate. These cases can be investigated in future to validate and ascertain why some chains have that many activities.

In both the Joubert and Axhausen (2011) and Joubert et al. (2010) studies, the emphasis was on within-traffic. With 76.68% of `DigicoreVehicle`s being through-vehicles (calculated in section 4.2), it is imperative to continue to analyse through-traffic to obtain a more detailed understanding of its behaviour and impact on Gauteng.

Chapter 5

Through-traffic

Through-vehicles, also referred to as inter-provincial vehicles, are identified in this project as vehicles with less than 60% of their activities inside Gauteng. Before through-traffic characteristics could be analysed, specific gates into and out of Gauteng needed to be identified. Eight gates were identified on the major routes linking Gauteng to the rest of the country, as was explained in Chapter 4. These gates are located along the boundary of Gauteng, and are numbered as can be seen in figure 4.1.

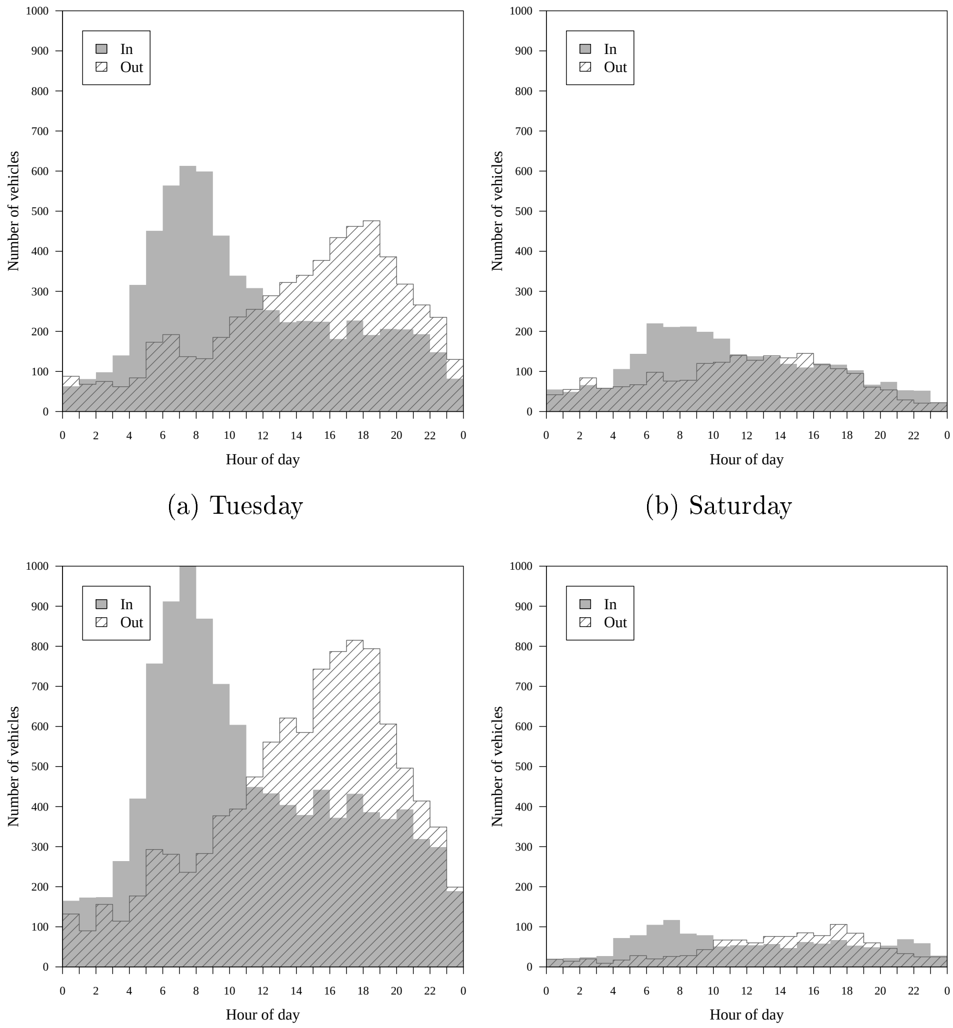
5.1 Gate activity

Through-vehicles were analysed to obtain a temporal distribution of the number of vehicles that enter and exit at a specific gate. Figures 5.1 and 5.2 depict the the number of vehicles that enter and exit at gates 1 and 7 on different days of the week. The numbers were calculated as the average number of vehicles on a specific day of the week over the 182-day period from 1 January 2009 to 30 June 2009.

Gates 1 and 7 had the highest traffic volumes of all gates. At all gates, the number of vehicles that entered and exited the study area on a weekday, exceeded the number of vehicles on weekends. It is however noted that abnormal days had a significantly higher activity than weekdays, specifically at gates 1,2, and 7, which suggested that organisations continue with, and even increase, their business during the school holidays. A possible explanation could be that less private vehicles use the road network during school holidays and therefore the commercial vehicles can take advantage of this situation to increase their activity. On public holidays, however, a much lower count was noted than on any other day of the week. This pattern on different days of the week is evident at all gates.

On weekdays and abnormal days, there is a distinct peak of inflowing traffic during the early morning hours and an outflowing peak during the late afternoon hours. Since the order of magnitude of the morning and afternoon peaks are the same, it suggests that vehicles tend to exit through the same gate at which they entered. It is furthermore noted that gate 2, as can be seen in figure 5.2, does not have the morning and afternoon peaks, but instead has a constant inflow and outflow of vehicles. This could be vehicles that exit at gate 2 on the N12 eastbound, performing activities all the way to the N4, and returning to Gauteng via the N4 and gate 3. The route in the opposite direction is also a valid option. This will be confirmed in section 5.3 where vehicles are analysed to see whether they enter and exit through the same gate.

Gates 1, 2, and 7 have high volumes of vehicles, as is the case in Joubert and Axhausen (2011)'s study. The high volumes at gate 1 were expected as Gauteng is connected,



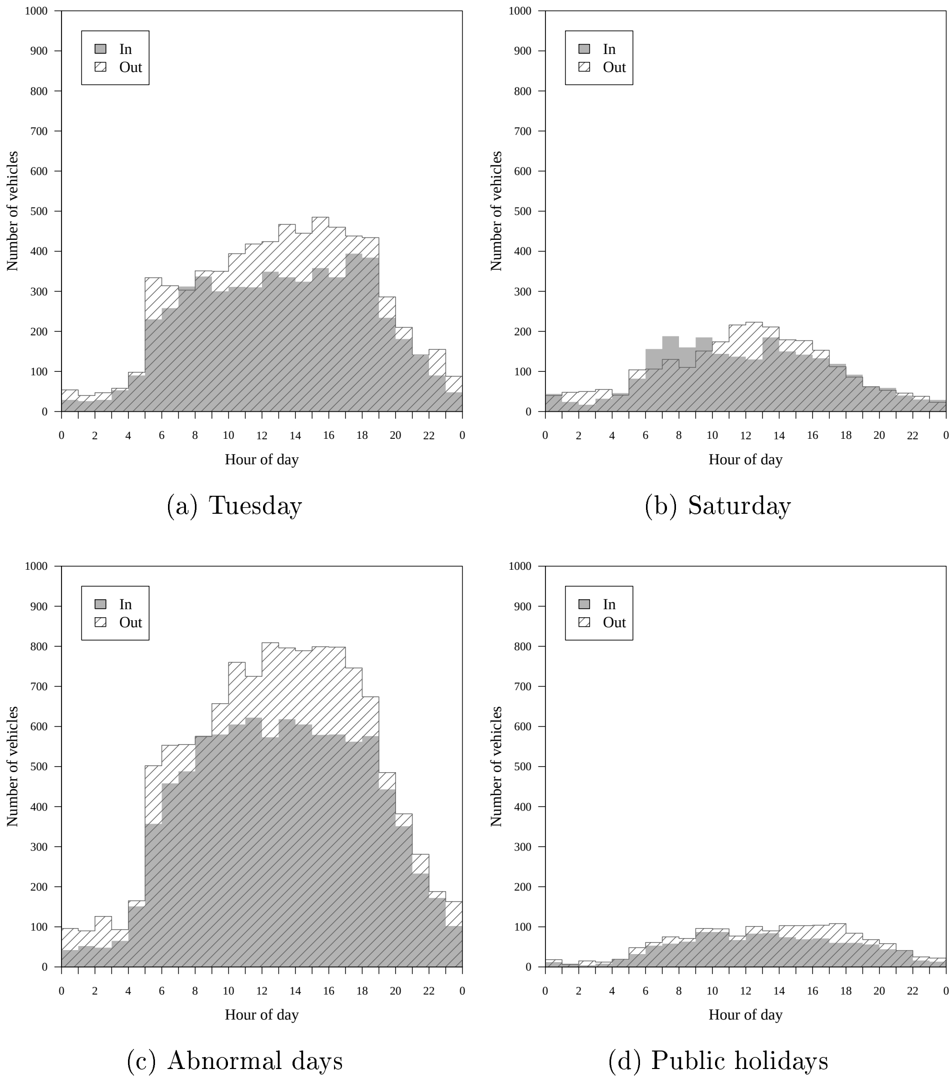
(a) Tuesday

(b) Saturday

(c) Abnormal days

(d) Public holidays

Figure 5.1: Gate activity on different days of the week at gate 1



(a) Tuesday

(b) Saturday

(c) Abnormal days

(d) Public holidays

Figure 5.2: Gate activity on different days of the week at gate 2

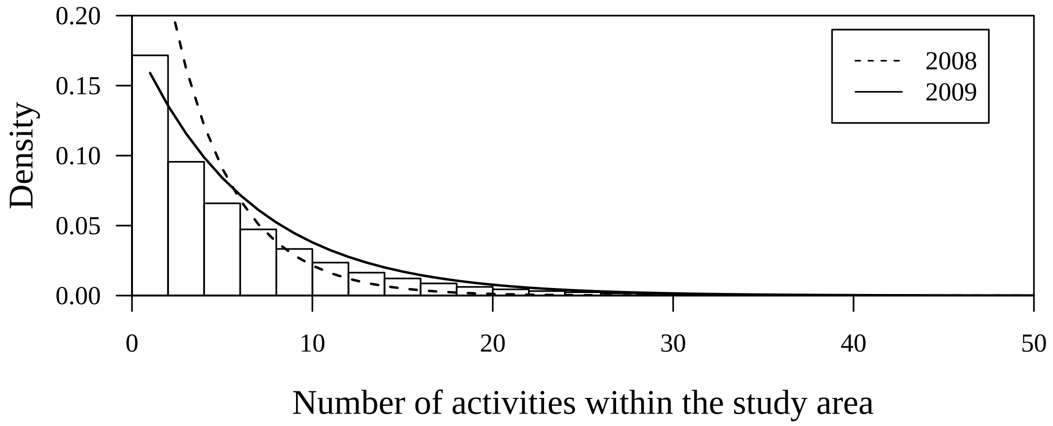


Figure 5.3: Number of activities within the study area before the vehicles leave

through this gate, to Durban via the N3. The gate activity at gate 2, however, is higher than expected. One possible explanation could be a misallocation of vehicles to gates since gates 2 and 3 are in close proximity. Since gate 2 is associated with the N12 and gate 3 with the N4, it was expected that more vehicles would prefer the better, yet tolled, N4 toll road. Furthermore, there is a large number of coal mines on the N12 towards Witbank. The more plausible explanation would be that the industrial areas in Gauteng are mainly situated in the southern parts of the province, and vehicles rather use the N12 as a shorter alternative to the N4. The N12 and N4 eventually converge near Witbank and the road continues as the N4 in Mpumalanga towards Mozambique.

Joubert and Axhausen (2011) identify gate 7, which is associated with the N1 towards Cape Town, as another gate with a high volume of vehicles, and gate 8, which is associated with the N14, as a gate with a lower volume of vehicles. From this research project, it can be confirmed that the gate activity at these two gates is similar to that of Joubert and Axhausen's study. It was expected that gate 7, which is associated with the N1 towards Cape Town, would have a high gate activity since Cape Town has the country's second largest port accounting for many freight movements to and from Cape Town.

Gate 4 was expected to have a high volume of vehicles as it links Gauteng with Limpopo province as well as the rest of Southern Africa. However, contrary to this expectation, gate 4 had a very low activity. The possible selection bias, which was acknowledged in section 3.2, could be the reason for this phenomenon. It is possible that very few of *Digicore*'s subscribers are cross-border carriers, or conduct only a few of their activities in the Limpopo province. This again correlates with the findings of Joubert and Axhausen (2011).

5.2 Number of activities in study area

Knowing where vehicles entered and exited the study area raised the question as to how many activities through-vehicles have within the study area before eventually leaving. Figure 5.3 depicts a histogram of the results from this analysis.

An exponential distribution was fitted to the data and yielded a probability density function $\lambda e^{-\lambda x}$ with a rate parameter λ of 0.1591 and estimated standard error of 0.0004. This exponential probability function, as well as the function that Joubert and Axhausen

(2011) determine in their study, were plotted over the histogram in figure 5.3. Whereas Joubert and Axhausen (2011) find that 90% of vehicles have 4 activities or less within the study area, the findings in this project reveal that only 50% of vehicles perform 4 activities or less in the study area. Also, 90% of vehicles performed an increased number of 14 activities or less within the area. There was an increase, between 2008 and 2009, in the number of activities that vehicles have within the study area before departing from it.

A possible explanation could be that long haul vehicles spend a lot of time at distribution or consolidation centres when parking and waiting for loading or unloading, then relocate within the centre, and wait for the next loading or unloading activity. Another possible explanation could be that this project didn't make use of a density based clustering approach to cluster activities. If activities are clustered, chains consist of fewer activities, and therefore this could be a valid cause leading to the longer activity chains in this project. Yet another reason could be due to the economic recession in South Africa during the first quarter of 2009. Businesses tried to cut on expenses and this could have lead to more organisations consolidating on loads to save on costs. This could mean that vehicles would perform more activities per chain as they will carry more load due to the consolidations.

5.3 Returning chains

The gate activity at each gate was determined in section 5.1 whereafter the number of activities that a vehicle had within the study area before leaving, was determined in section 5.2. The next question that came to mind was: do chains enter and exit through the same gate?

To answer this question, consecutive activities were paired and referred to as (a, b). If both a and b were inside or outside Gauteng, the pair was ignored. If activity a was inside Gauteng and activity b was outside Gauteng, an exit was noted. The point of exit was determined by connecting point a with point b by means of a straight line. The point where the line intersected the border of Gauteng was noted as point c. The nearest gate to point c was considered to be the exit gate.

Similarly, an entry was registered whenever a was outside and b was inside Gauteng. The nearest gate to point c was considered to be the entry gate.

From the activity chains it is possible to determine the activity start and end times. The time at which the entry or exit occurred was estimated by calculating the fraction f, which is the straight line distance between a and the point of entry or exit, c, divided by the straight line distance between a and b. From the activity chains, the duration d was determined as the time that elapsed from the end of activity a, denoted as a^{end}, to the beginning of activity b. The duration d was denoted as $d = b^{\text{begin}} - a^{\text{end}}$. The estimated time of entry or exit, denoted as e, was then determined using both the duration and fraction measures, as $e = a^{\text{end}} + fd$.

During the analysis of activity pairs, entries and exits, as well as the times associated with them, were registered, irrespective of where the chains started or ended. From this data, two types of chains were identified:

In-out chains start outside Gauteng, perform a number of activities inside the province, and return and end outside Gauteng. In-out therefore means that the vehicle starts outside Gauteng, enters, and eventually exits Gauteng again.

Out-in chains start inside Gauteng, perform a number of activities outside the province, and return and end inside Gauteng. Out-in therefore means that the vehicle starts inside Gauteng, exits, and eventually re-enters Gauteng.

From these two types of chains, two types of gate pairs are defined:

In-out pairs are the gate pairs associated with in-out chains. Since an in-out chain starts outside Gauteng, enters, and eventually exits Gauteng again, an in-out gate pair is the combination of gates through which the vehicle enters (in) and then exits (out).

Out-in pairs are the gate pairs associated with out-in chains. Since an out-in chain starts inside Gauteng, exits, and eventually re-enters Gauteng, an out-in gate pair is the combination of gates through which the vehicle exits (out) and then re-enters (in).

Tabel 5.1 shows the fraction of gate activities on a Tuesday for all the activity pairs that were defined as in-out and out-in pairs. The results captured in table 5.1a show fraction of vehicles that entered at a specific gate (from), and then exited at specific gates (to). The results in table 5.1b show the fraction of vehicles that exited the study area at a specific gate (from), and then re-entered at specific gates (to). The total number of entries and exits for each gate pair, and chain type, are also shown. Fractions below 5% are omitted from the table. To ease the interpretation of the table, the cells are colour coded according to the weight of the fraction in the cell. The higher the fraction, the darker the shade of grey.

From table 5.1b the darker diagonal is much more pronounced than in table 5.1a. Out-in chains are therefore much more likely to exit and enter at the same gate than in-out chains. The prominent diagonal feature in in-out pairs correlate well with figure 5.1a and confirms the morning and afternoon peaks at the same gate, especially for gates 1 and 7.

For out-in chains that exit through gate 3, 70.2% return through gate 3, but 20.9% return through gate 2. One possibility could be that gates were misalocated to entries and exits. Another possibility is that once vehicles exit Gauteng, they make use of the road network on the outside of Gauteng and eventually re-enter Gauteng through gate 2 or vice versa. Figure 5.4 depicts such a chain.

Overall, out-in vehicles tend to enter the study area through the same gate they exited. In-out vehicles showed the same pattern except that they also tend to exit at other gates than where they entered the study area. A possible explanation could be that the road network inside Gauteng is better than outside, or that pickups and deliveries take place throughout Gauteng, leading to the vehicles considering other routes to exit Gauteng.

Table 5.1: Fractions of gate activities on a Tuesday

(a) In-out pairs

	To								Total
From	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**entries**
1	0.565	0.137	–	0.053	0.052	–	0.110	–	3483
2	0.079	0.658	–	–	–	–	0.118	–	2946
3	–	0.378	0.396	–	0.074	–	–	–	1246
4	0.185	0.105	–	0.360	0.089	–	0.176	–	930
5	0.073	0.062	0.063	0.056	0.664	–	–	–	1405
6	0.065	0.106	–	–	–	0.516	0.169	0.080	872
7	0.083	0.122	–	–	–	–	0.631	–	2987
8	0.092	0.089	–	–	0.126	0.110	0.137	0.405	1115
Total exits	2924	3626	919	923	1595	940	3169	888	**18 210**

(b) Out-in pairs

	To								Total
From	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**entries**
1	0.855	0.087	–	–	–	–	–	–	595
2	–	0.769	0.176	–	–	–	–	–	1475
3	–	0.209	0.702	0.072	–	–	–	–	608
4	–	–	0.074	0.851	–	–	–	–	525
5	–	–	–	–	0.802	–	–	0.139	1037
6	–	–	–	–	–	0.767	0.079	0.127	417
7	0.067	–	–	–	–	–	0.862	–	979
8	–	–	–	–	0.241	0.063	–	0.644	477
total exits	646	1364	732	531	992	390	927	531	**7 444**

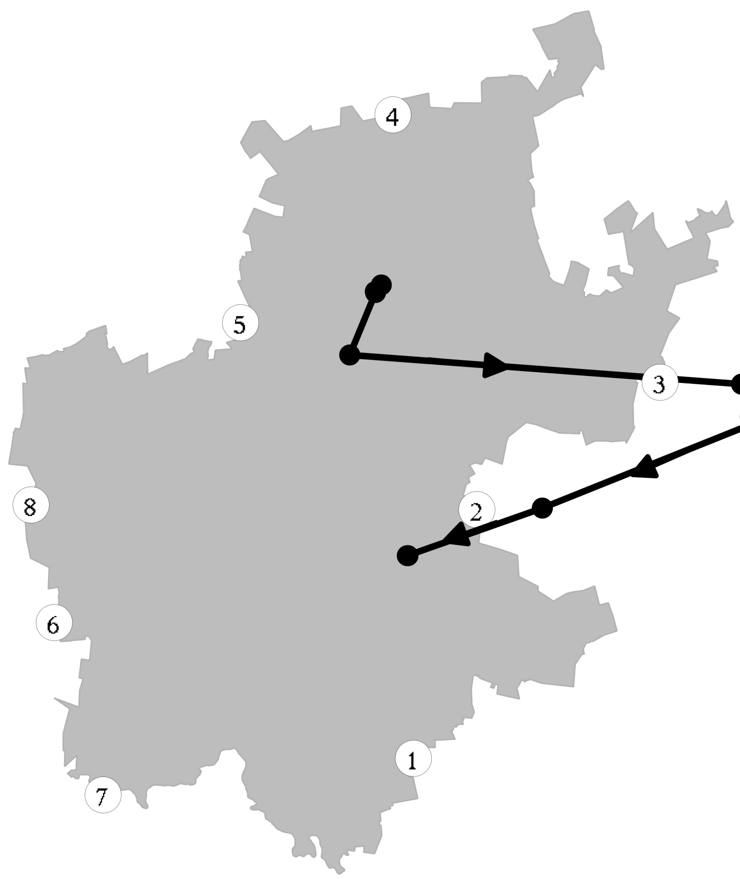


Figure 5.4: An out-in chain with gates 3 and 2 as gate-pair

Chapter 6

Conclusion

The world of freight modelling has seen attempts on aggregate and disaggregate level. The literature review analysed some of the models used and identified opportunities for this research project to extend and focus on.

6.1 Outcome of research

The results of this project extend the body of knowledge on commercial vehicle activity chain characteristics. While some of the statements from Joubert and Axhausen (2011) were validated and used in some of the analyses done in this research project, the emphasis of this project was placed on through-vehicles and their impact on Gauteng. This was done by comparing the chain characteristics of through- and within-vehicles on different days of the week, followed by an in-depth analysis of through-vehicles' entry and exit behaviour in the study area.

Figure 4.2 proved to be invaluable in the quest to determine whether activity chain characteristics differ on different days of the week. It was determined that chain characteristics should be modelled separately for weekdays, weekends, abnormal days, and public holidays. Activity chain characteristics on abnormal days tend to be similar to that of weekdays, but public holidays differ from all other days. There is, however, some variability in the activity chain characteristics on abnormal and public holidays, which is confirmed by the wide spread of the box plots for these two types of days in figure 4.2b.

This project also determined that through- and within-vehicles' activity chain characteristics are very similar. The main difference, however, in through- and within-vehicles is the proportion of through-vehicles to within-vehicles. Of all `Digicore Vehicles`, 76.68% was through-vehicles, suggesting that the emphasis should be placed on through-vehicles and their behaviour.

Through-vehicles were analysed in more depth and it was determined that the number of activities that vehicles perform in the study area after entering it, increased from 2008 to 2009. A possible reason for this is that vehicles spend a lot of time at distribution centres, waiting for loading or unloading activities, relocating within the centre, and loading or unloading again. It could also be due to inefficient distribution warehouses.

Finally, gate activity at the eight major gateways in Gauteng was analysed and confirmed that there is a difference in the volumes of traffic on different days of the week. The activity patterns at the various gates correlated with that of Joubert and Axhausen (2011) and it was also confirmed that more vehicles start from outside Gauteng, enter, and exit again, as opposed to starting in Gauteng, exiting, and re-entering. This suggested that more distribution centres and carriers are located outside Gauteng, which is encouraging in the quest to increase decentralisation and reduce urbanisation.

The analyses in this project can be used for future research which will be discussed in section 6.2.2.

6.2 Future research

Although this research project has analysed commercial vehicle activity chains in depth, some opportunities for future work were identified.

6.2.1 Density based clustering

Density based clustering is a method in which consecutive data points within a certain distance threshold are clustered or grouped. Whereas Joubert and Axhausen (2011) use the density based clustering approach in their study, in this project it wasn't implemented. By not clustering activities within a certain threshold distance of each other, activity chains tend to increase in length.

The problem with density based clustering is that possible inefficiencies at distribution centres may be clustered away. A vehicle could arrive at a distribution centre and park and wait for unloading whereafter the vehicle relocates within the distribution centre and parks and waits for another offloading activity. If these activities are short and close to each other, they will be clustered together when using density based clustering. A series of minor activities in close proximity of one another could signal a form of inefficiency much clearer than a single clustered activity of all these activities.

In this project it was found that some vehicles tend to have extremely long activity chains in both duration and the number of activities per chain. Possible causes were mentioned and it was said that the causes could be investigated in future to validate the accuracy of signals that trigger the start and end of activities.

There is an opportunity to validate the density based clustering approach used by Joubert and Axhausen (2011) by determining what impact the distance threshold has on the characteristics of activity chains.

6.2.2 Generation of a synthetic population

The next step after the analyses of commercial vehicle activity chains is to set up a synthetic population from the data. A set of conditional probability matrices should be set up for both through- and within-vehicles and for different days of the week. Joubert et al. (2010) successfully modelled within-vehicles in conjunction with private vehicles. From this project, through-traffic can also be modelled and a complete commercial vehicle population can then be sampled from the conditional probability matrices. The model can be tested and validated in a simulation package such as the Multi-Agent Transport Simulation (MATSim) toolkit.

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Appendix A

In-out and out-in pairs

Table A.1: Fractions of gate activities on a Sunday

(a) In-out pairs

	To								Total
From	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**entries**
1	0.310	0.150	–	0.237	0.062	–	0.143	–	565
2	0.066	0.466	–	–	–	–	0.328	–	564
3	–	0.338	0.484	–	0.069	–	–	–	320
4	0.180	0.090	0.056	0.271	–	–	0.323	–	266
5	0.176	0.067	0.073	0.067	0.570	–	–	–	386
6	0.058	0.175	–	0.100	–	0.325	0.258	–	120
7	0.054	0.155	–	0.108	–	–	0.589	–	1073
8	0.197	0.086	–	–	0.086	–	0.232	0.318	198
Total exits	447	710	240	382	353	106	1084	170	**3 492**

(b) Out-in pairs

	To								Total
From	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**entries**
1	0.829	0.060	–	–	–	–	0.111	–	117
2	0.054	0.778	0.149	–	–	–	–	–	221
3	–	0.176	0.765	–	–	–	–	–	68
4	–	–	0.105	0.895	–	–	–	–	105
5	–	–	–	–	0.849	–	–	0.108	212
6	–	–	–	–	–	0.639	0.194	0.167	36
7	–	–	–	–	–	–	0.912	–	376
8	–	0.078	–	–	0.188	0.094	–	0.609	64
total exits	128	200	96	103	194	38	370	70	**1 199**

Table A.2: Fractions of gate activities on a Monday

(a) In-out pairs

From	To 1	2	3	4	5	6	7	8	Total entries
1	0.640	0.125	–	–	–	–	0.094	–	2648
2	0.087	0.704	–	–	–	–	0.092	–	2288
3	–	0.384	0.413	–	0.082	–	–	–	1056
4	0.115	0.109	–	0.427	0.113	–	0.144	–	576
5	0.055	0.062	0.069	0.055	0.671	–	–	–	1136
6	0.067	0.116	–	–	–	0.458	0.211	0.073	855
7	0.077	0.126	–	–	–	–	0.638	–	2874
8	0.105	0.091	–	–	0.154	0.097	0.123	0.385	889
Total exits	2436	3022	781	646	1298	720	2724	695	**12 322**

(b) Out-in pairs

From	To 1	2	3	4	5	6	7	8	Total entries
1	0.851	0.081	–	–	–	–	0.052	–	383
2	–	0.804	0.153	–	–	–	–	–	1406
3	–	0.113	0.790	0.079	–	–	–	–	391
4	–	–	0.089	0.879	–	–	–	–	315
5	–	–	–	–	0.807	–	–	0.131	888
6	–	–	–	–	–	0.803	0.072	0.101	345
7	0.057	–	–	–	–	–	0.891	–	754
8	–	–	–	–	0.199	0.053	–	0.701	412
total exits	425	1229	560	354	814	325	736	451	**4 511**

Table A.3: Fractions of gate activities on a Tuesday

(a) In-out pairs

From	To 1	2	3	4	5	6	7	8	Total entries
1	0.565	0.137	–	0.053	0.052	–	0.110	–	3483
2	0.079	0.658	–	–	–	–	0.118	–	2946
3	–	0.378	0.396	–	0.074	–	–	–	1246
4	0.185	0.105	–	0.360	0.089	–	0.176	–	930
5	0.073	0.062	0.063	0.056	0.664	–	–	–	1405
6	0.065	0.106	–	–	–	0.516	0.169	0.080	872
7	0.083	0.122	–	–	–	–	0.631	–	2987
8	0.092	0.089	–	–	0.126	0.110	0.137	0.405	1115
Total exits	2924	3626	919	923	1595	940	3169	888	**14 984**

(b) Out-in pairs

From	To 1	2	3	4	5	6	7	8	Total entries
1	0.855	0.087	–	–	–	–	–	–	595
2	–	0.769	0.176	–	–	–	–	–	1475
3	–	0.209	0.702	0.072	–	–	–	–	608
4	–	–	0.074	0.851	–	–	–	–	525
5	–	–	–	–	0.802	–	–	0.139	1037
6	–	–	–	–	–	0.767	0.079	0.127	417
7	0.067	–	–	–	–	–	0.862	–	979
8	–	–	–	–	0.241	0.063	–	0.644	477
total exits	646	1364	732	531	992	390	927	531	**6 113**

Table A.4: Fractions of gate activities on a Wednesday

(a) In-out pairs

	To								Total
From	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**entries**
1	0.569	0.115	–	0.054	–	–	0.139	–	4024
2	0.074	0.659	–	–	–	–	0.121	–	3202
3	–	0.365	0.428	–	0.075	–	–	–	1279
4	0.203	0.093	–	0.357	0.097	–	0.174	–	940
5	0.089	0.074	0.075	0.051	0.623	–	–	–	1559
6	0.063	0.124	–	–	–	0.471	0.194	0.060	1122
7	0.088	0.119	–	–	–	–	0.629	–	3758
8	0.115	0.082	–	–	0.148	0.101	0.101	0.396	1274
Total exits	3451	3935	1041	1009	1720	1107	3910	985	**17 158**

(b) Out-in pairs

	To								Total
From	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**entries**
1	0.887	0.050	–	–	–	–	–	–	951
2	0.053	0.746	0.182	–	–	–	–	–	1710
3	–	0.234	0.673	0.064	–	–	–	–	640
4	–	–	0.060	0.869	–	–	–	–	503
5	–	–	–	–	0.797	–	–	0.129	987
6	–	–	–	–	–	0.822	0.071	0.086	477
7	0.072	–	–	–	–	–	0.876	–	1228
8	–	–	–	–	0.247	0.070	–	0.615	473
total exits	1048	1521	792	536	935	480	1183	474	**6 969**

Table A.5: Fractions of gate activities on a Thursday

(a) In-out pairs

	To								Total
From	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**entries**
1	0.573	0.118	–	0.058	–	–	0.114	–	4194
2	0.088	0.656	–	–	–	–	0.119	–	3466
3	0.053	0.333	0.407	–	0.089	–	–	–	1424
4	0.183	0.085	–	0.382	0.095	–	0.172	–	1094
5	0.098	0.068	0.056	0.061	0.643	–	–	–	1700
6	0.051	0.114	–	–	–	0.509	0.172	0.056	1149
7	0.084	0.126	–	0.052	–	0.051	0.616	–	3876
8	0.102	0.096	–	–	0.138	0.121	0.128	0.379	1307
Total exits	3669	4192	1075	1182	1959	1221	3933	979	**14 016**

(b) Out-in pairs

	To								Total
From	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**entries**
1	0.895	–	–	–	–	–	–	–	1022
2	–	0.751	0.181	–	–	–	–	–	1782
3	–	0.200	0.721	0.055	–	–	–	–	616
4	–	–	0.081	0.851	–	–	–	–	606
5	–	–	–	–	0.815	–	–	0.123	1080
6	–	–	–	–	–	0.752	0.085	0.129	505
7	0.078	–	–	–	–	–	0.848	–	1339
8	–	–	–	–	0.223	0.051	–	0.650	494
total exits	1140	1561	835	606	1038	478	1248	538	**7 444**

Table A.6: Fractions of gate activities on a Friday

(a) In-out pairs

	To								Total
From	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**entries**
1	0.595	0.120	–	–	–	–	0.110	–	3125
2	0.075	0.661	–	–	–	–	0.124	–	2584
3	0.053	0.352	0.416	–	0.065	–	0.059	–	1093
4	0.166	0.117	–	0.361	0.103	–	0.173	–	797
5	0.081	0.062	0.062		0.662	–	–	–	1250
6	0.052	0.136	–	–	–	0.498	0.184	0.056	890
7	0.061	0.131	–	–	–	–	0.652	–	2966
8	0.113	0.107	–	–	0.131	0.113	0.140	0.365	1035
Total exits	2690	3260	849	750	1384	866	3139	802	**13 740**

(b) Out-in pairs

	To								Total
From	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**entries**
1	0.882	0.050	–	–	–	–	–	–	756
2	–	0.757	0.180	–	–	–	–	–	1389
3	–	0.196	0.697	0.084	–	–	–	–	429
4	–	–	0.087	0.847	–	–	–	–	425
5	–	–	–	–	0.790	–	–	0.149	787
6	–	–	–	–	–	0.803	0.077	0.093	441
7	0.073	–	–	–	–	–	0.855	–	1016
8	–	–	–	–	0.234	0.051	–	0.649	376
Total exits	826	1208	603	433	735	433	961	420	**5 619**

Table A.7: Fractions of gate activities on a Saturday

(a) In-out pairs

	To								Total
From	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**entries**
1	0.428	0.163	–	0.088	0.072	–	0.145	0.068	1106
2	0.090	0.574	–	–	–	–	0.208	–	1257
3	0.058	0.326	0.368	0.058	0.084	–	0.079	–	571
4	0.178	0.088	–	0.341	0.086	–	0.236	–	590
5	0.115	0.073	0.073	0.076	0.586	–	–	–	590
6	0.062	0.118	–	–	–	0.462	0.207	0.074	338
7	0.054	0.132	–	0.066	–	–	0.646	–	1693
8	0.167	0.082	–	–	0.111	0.054	0.201	0.360	389
Total exits	969	1479	351	550	642	326	1864	353	**6 534**

(b) Out-in pairs

	To								Total
From	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**entries**
1	0.867	0.050	–	–	–	–	0.067	–	360
2	0.065	0.728	0.163	–	–	–	–	–	478
3	–	0.116	0.809	0.060	–	–	–	–	199
4	–	–	–	0.883	–	–	–	–	196
5	–	–	–	–	0.850	–	–	0.076	406
6	–	–	–	–	–	0.727	0.105	0.119	143
7	0.064	–	–	–	–	–	0.876	–	627
8	–	–	–	–	0.186		–	0.692	172
Total exits	398	413	250	212	319	131	603	183	**2 221**

Table A.8: Fractions of gate activities on an 'Abnormal day'

(a) In-out pairs

	To								Total
From	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**entries**
1	0.586	0.121	–	0.055	–	–	0.112	–	5485
2	0.078	0.663	–	–	–	–	0.132	–	4823
3	0.058	0.351	0.386	–	0.077	–	–	–	2178
4	0.156	0.078	–	0.374	0.095	–	0.212	–	1631
5	0.075	0.057	0.078	0.054	0.652	–	–	–	2373
6	0.072	0.115	–	–	–	0.475	0.167	0.070	1576
7	0.072	0.112	–	0.061	–	–	0.639	–	5967
8	0.075	0.104	–	–	0.141	0.083	0.154	0.399	1921
Total exits	4838	5937	1515	1727	2710	1542	6147	1538	**25 954**

(b) Out-in pairs

	To								Total
From	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**entries**
1	0.861	0.058	–	–	–	–	0.062	–	1256
2	–	0.771	0.157	–	–	–	–	–	2538
3	–	0.136	0.791	–	–	–	–	–	925
4	–	–	0.063	0.883	–	–	–	–	891
5	–	–	–	–	0.848	–	–	0.101	1758
6	–	–	–	–	–	0.781	0.080	0.110	872
7	0.066	–	–	–	–	–	0.862	–	1935
8	–	–	–	–	0.208	0.074	–	0.658	780
Total exits	1353	2240	1201	910	1710	833	1876	832	**10 955**

Table A.9: Fractions of gate activities on a Public Holiday

(a) In-out pairs

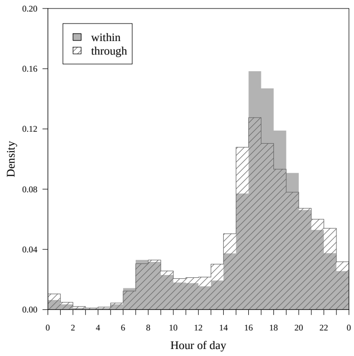
	To								Total
From	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**entries**
1	0.580	0.149	–	–	–	–	0.111	–	569
2	0.097	0.664	–	–	–	–	0.129	–	596
3	–	0.369	0.442	–	0.077	–	–	–	260
4	0.189	0.063	–	0.316	0.131	–	0.248	–	206
5	0.052	0.056	0.059	0.066	0.677	–	0.054	–	288
6	–	0.095	–	0.082	–	0.538	0.171	–	158
7	0.074	0.138	–	0.089	–	–	0.580	–	716
8	0.071	0.081	–	0.051	0.111	0.086	0.207	0.379	198
Total exits	520	736	197	217	316	164	694	147	**2 991**

(b) Out-in pairs

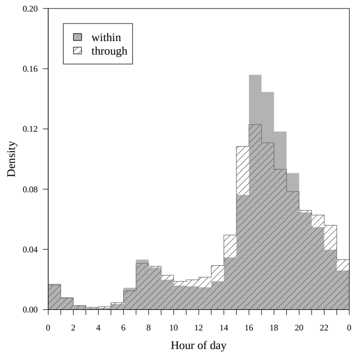
	To								Total
From	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**entries**
1	0.858	0.071	–	–	–	–	–	–	127
2	–	0.799	0.130	–	–	–	–	–	299
3	–	0.267	0.640	–	–	–	–	–	86
4	–	–	0.125	0.852	–	–	–	–	88
5	–	–	–	0.052	0.865	–	–	0.057	193
6	–	–	–	–	–	0.721	–	0.186	86
7	–	–	–	–	–	–	0.934	–	213
8	–	–	–	–	0.230	–	–	0.667	87
Total exits	133	280	106	95	192	74	211	88	**1 179**

Appendix B

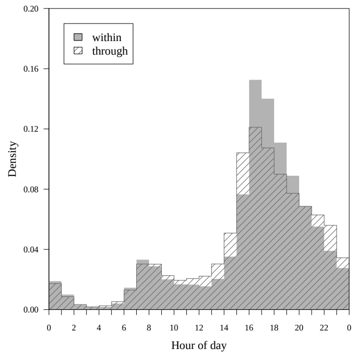
Activity start times



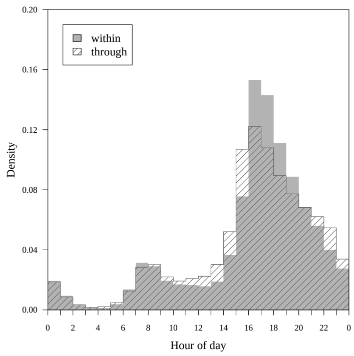
(a) Monday



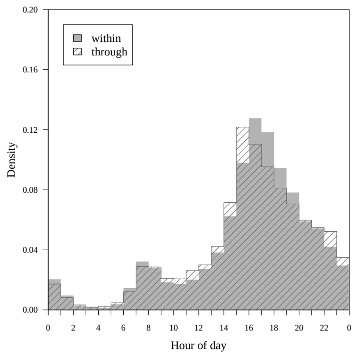
(b) Tuesday



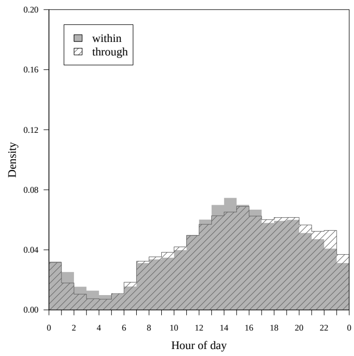
(c) Wednesday



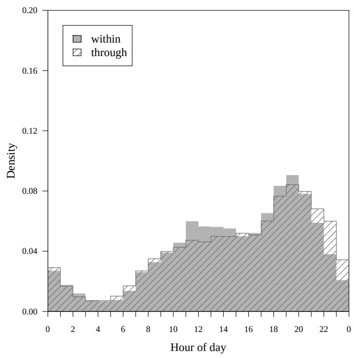
(d) Thursday



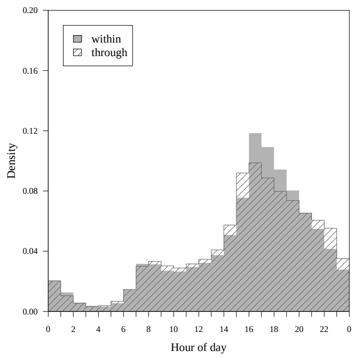
(e) Friday



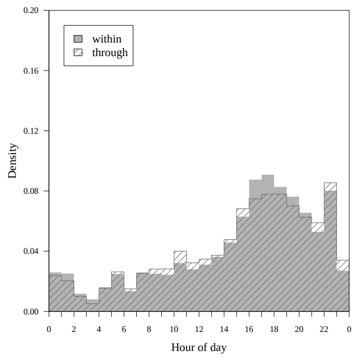
(f) Saturday



(g) Sunday

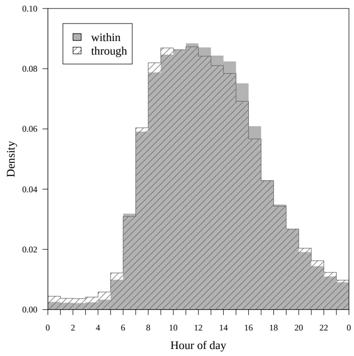


(h) Abnormal day

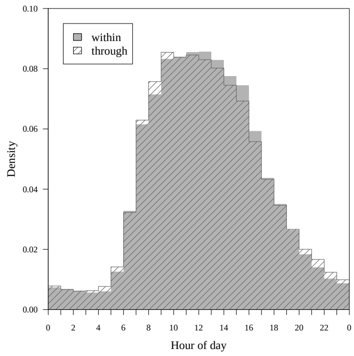


(i) Public holiday

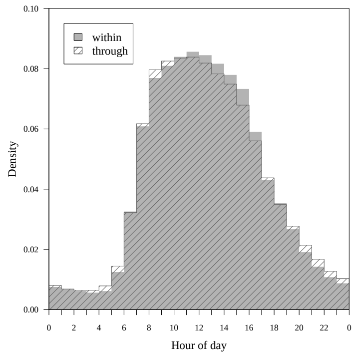
Figure B.1: Major activity start times on the different days of the week



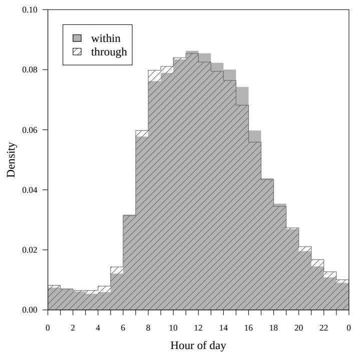
(a) Monday



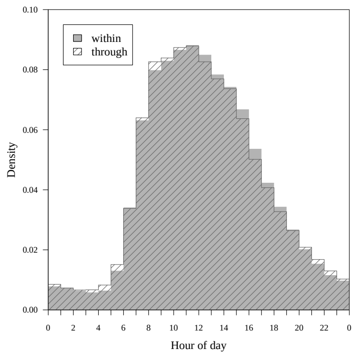
(b) Tuesday



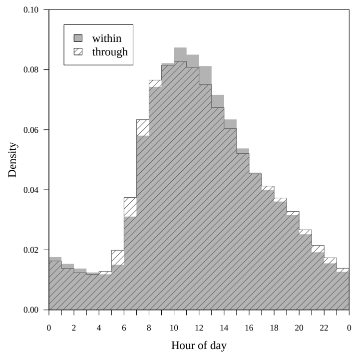
(c) Wednesday



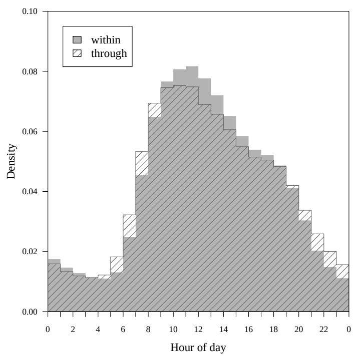
(d) Thursday



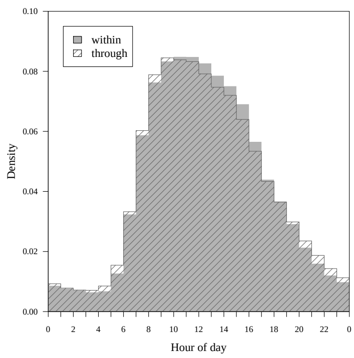
(e) Friday



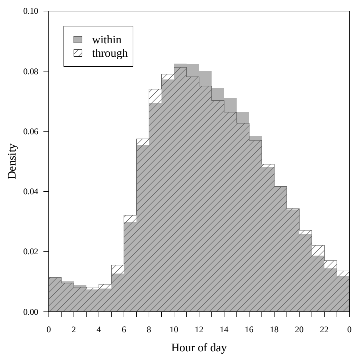
(f) Saturday



(g) Sunday



(h) Abnormal day

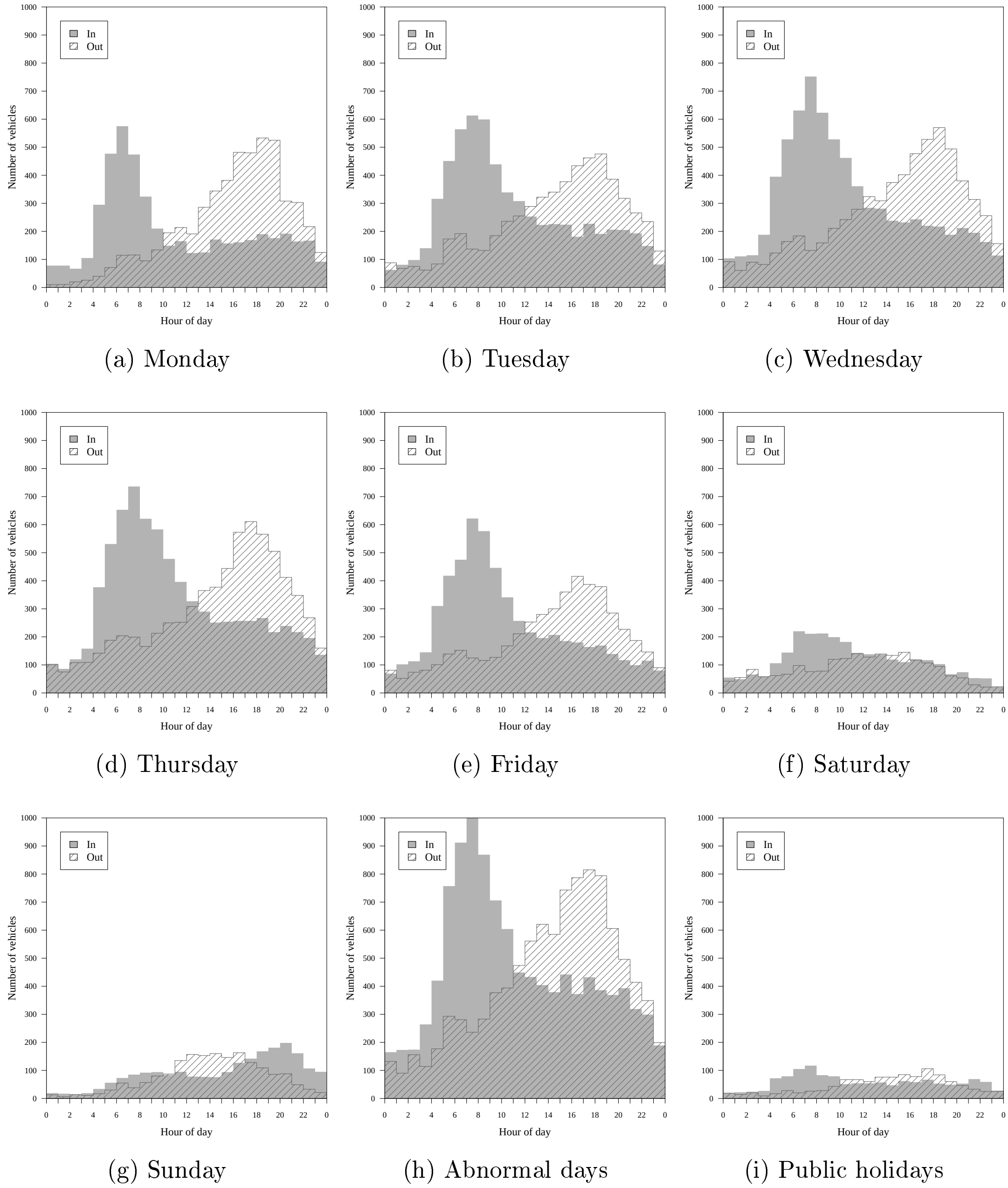


(i) Public holiday

Figure B.2: Minor activity start times on the different days of the week

Appendix C

Gate activity

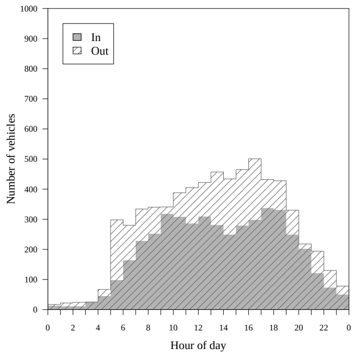


(a) Monday (b) Tuesday (c) Wednesday

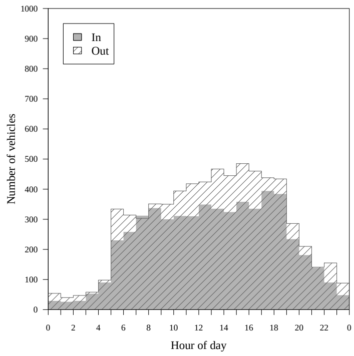
(d) Thursday (e) Friday (f) Saturday

(g) Sunday (h) Abnormal days (i) Public holidays

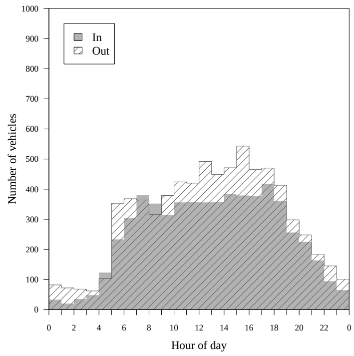
Figure C.1: Gate activity on the different days of the week at gate 1



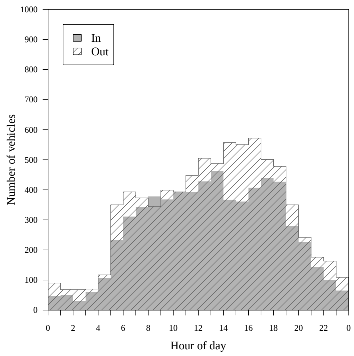
(a) Monday



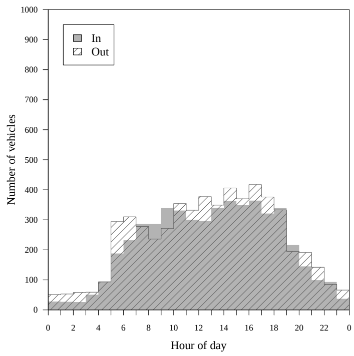
(b) Tuesday



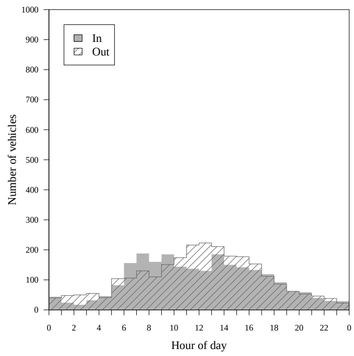
(c) Wednesday



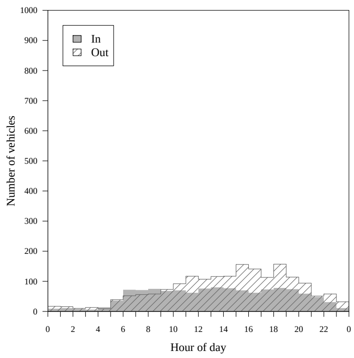
(d) Thursday



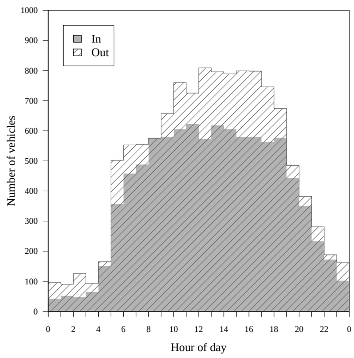
(e) Friday



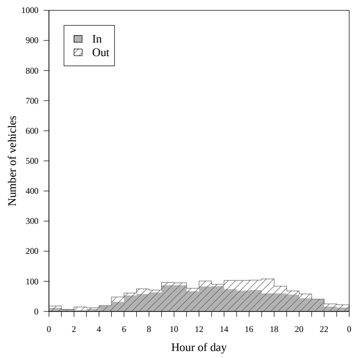
(f) Saturday



(g) Sunday

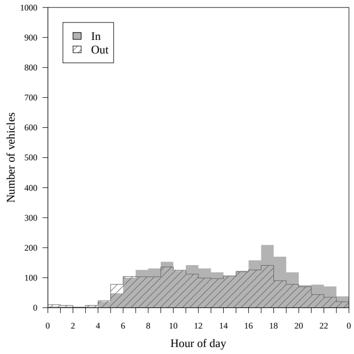


(h) Abnormal days

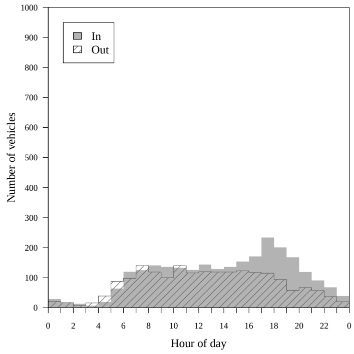


(i) Public holidays

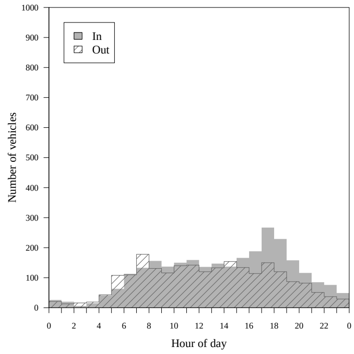
Figure C.2: Gate activity on the different days of the week at gate 2



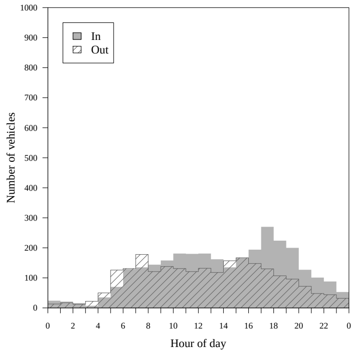
(a) Monday



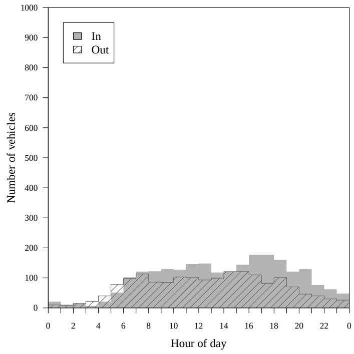
(b) Tuesday



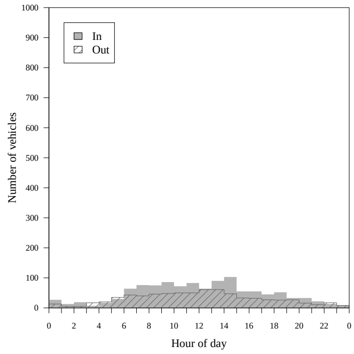
(c) Wednesday



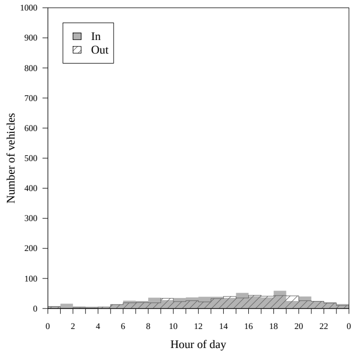
(d) Thursday



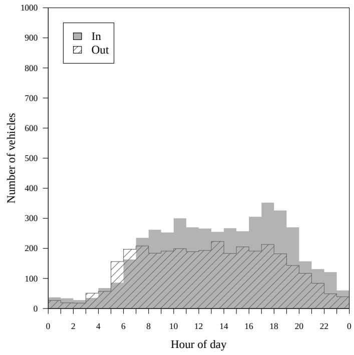
(e) Friday



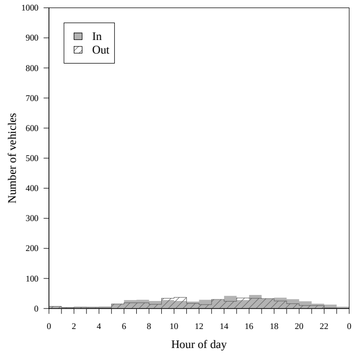
(f) Saturday



(g) Sunday

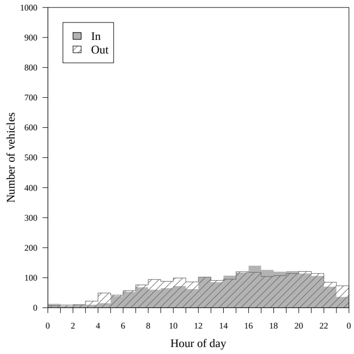


(h) Abnormal days

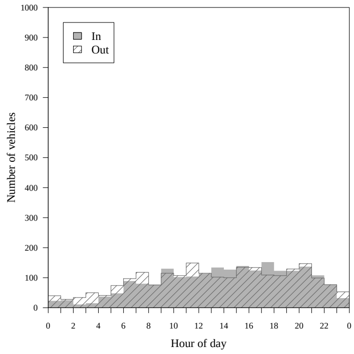


(i) Public holidays

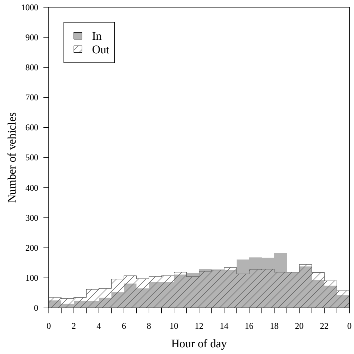
Figure C.3: Gate activity on the different days of the week at gate 3



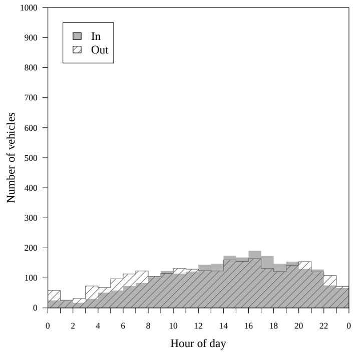
(a) Monday



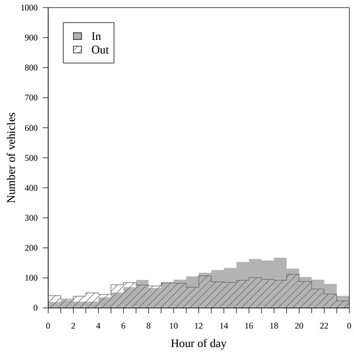
(b) Tuesday



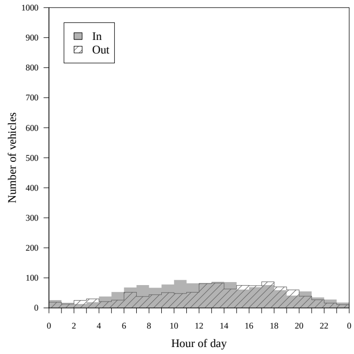
(c) Wednesday



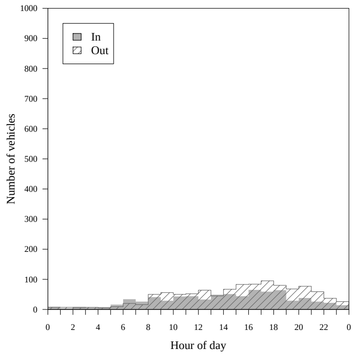
(d) Thursday



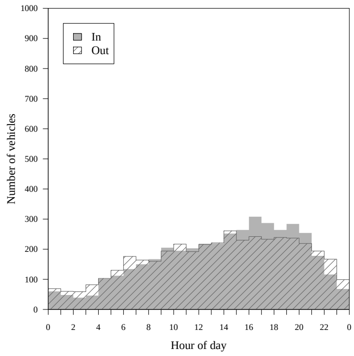
(e) Friday



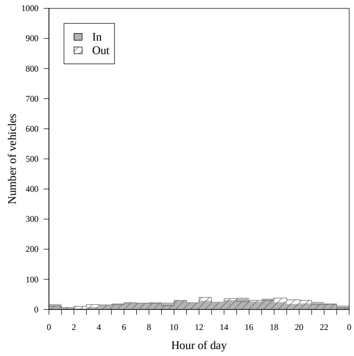
(f) Saturday



(g) Sunday

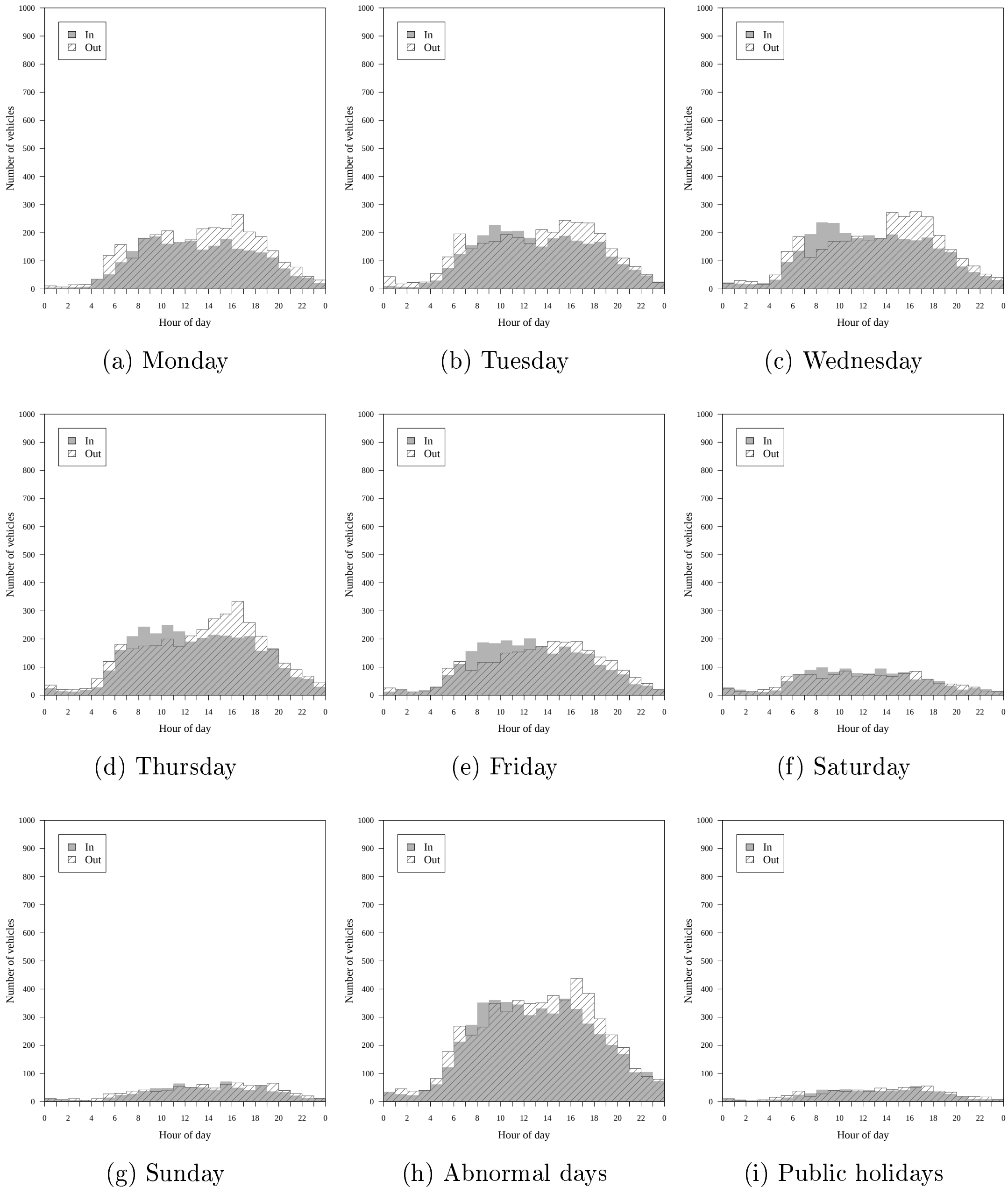


(h) Abnormal days



(i) Public holidays

Figure C.4: Gate activity on the different days of the week at gate 4

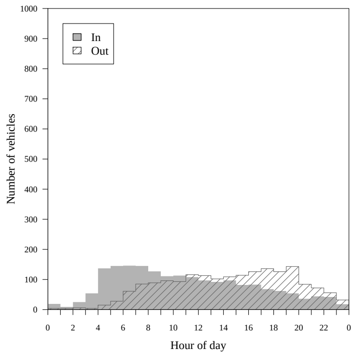


(a) Monday (b) Tuesday (c) Wednesday

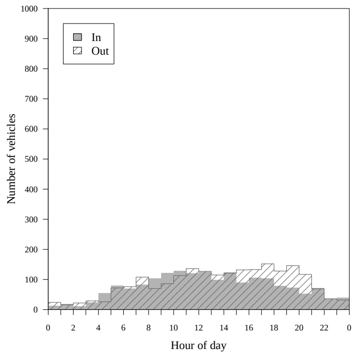
(d) Thursday (e) Friday (f) Saturday

(g) Sunday (h) Abnormal days (i) Public holidays

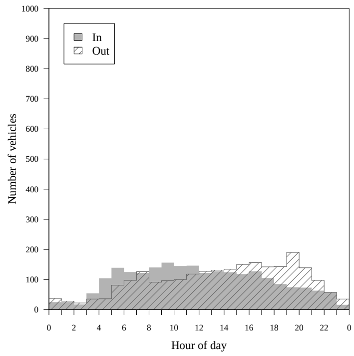
Figure C.5: Gate activity on the different days of the week at gate 5



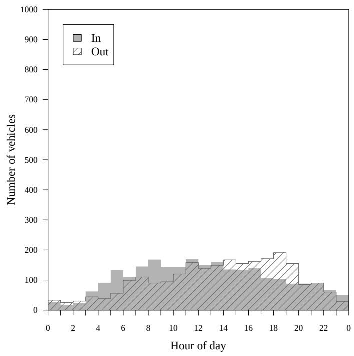
(a) Monday



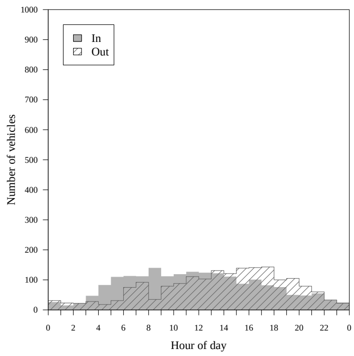
(b) Tuesday



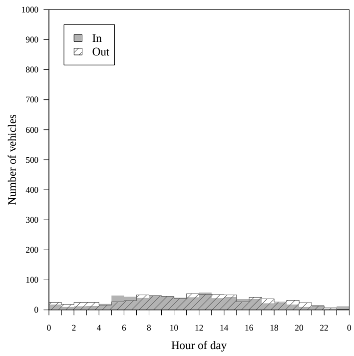
(c) Wednesday



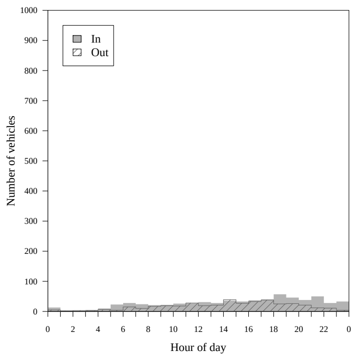
(d) Thursday



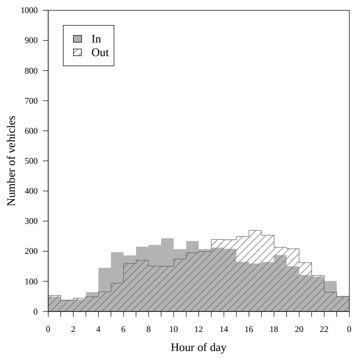
(e) Friday



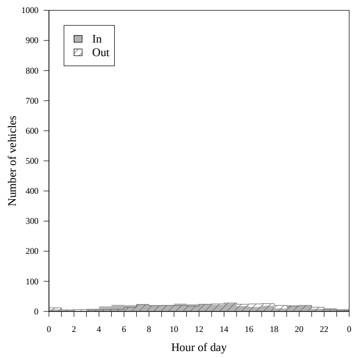
(f) Saturday



(g) Sunday

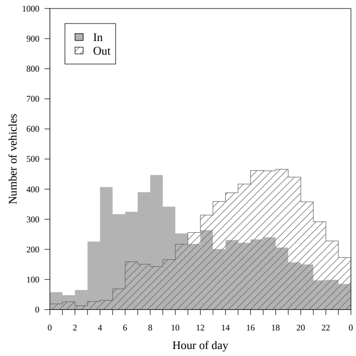


(h) Abnormal days

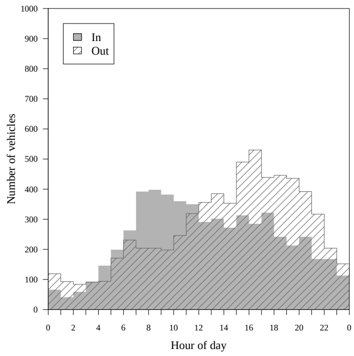


(i) Public holidays

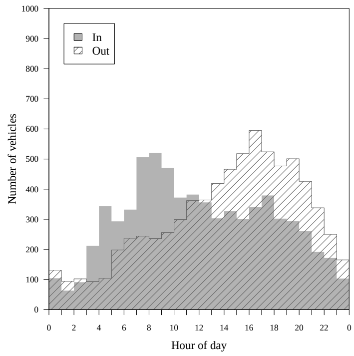
Figure C.6: Gate activity on the different days of the week at gate 6



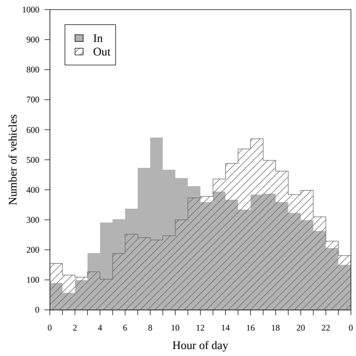
(a) Monday



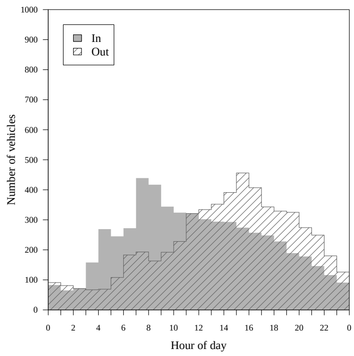
(b) Tuesday



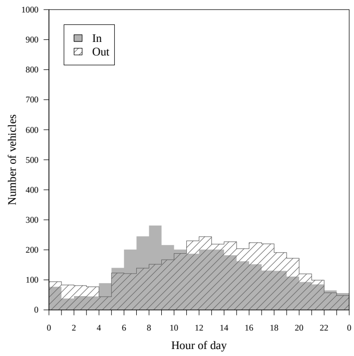
(c) Wednesday



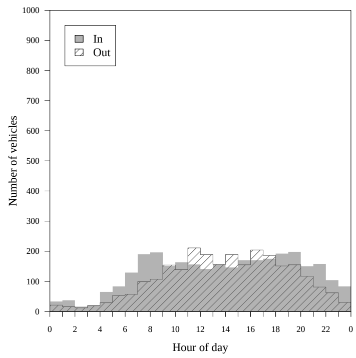
(d) Thursday



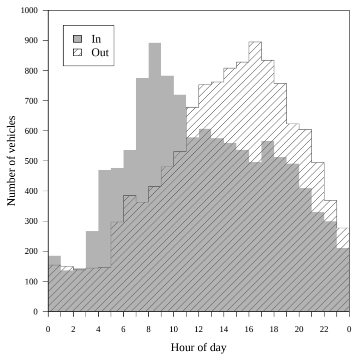
(e) Friday



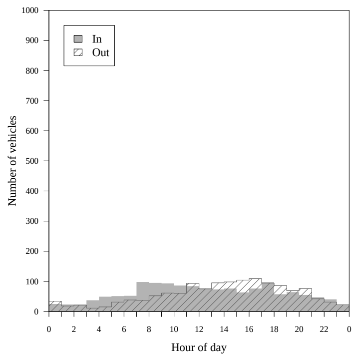
(f) Saturday



(g) Sunday

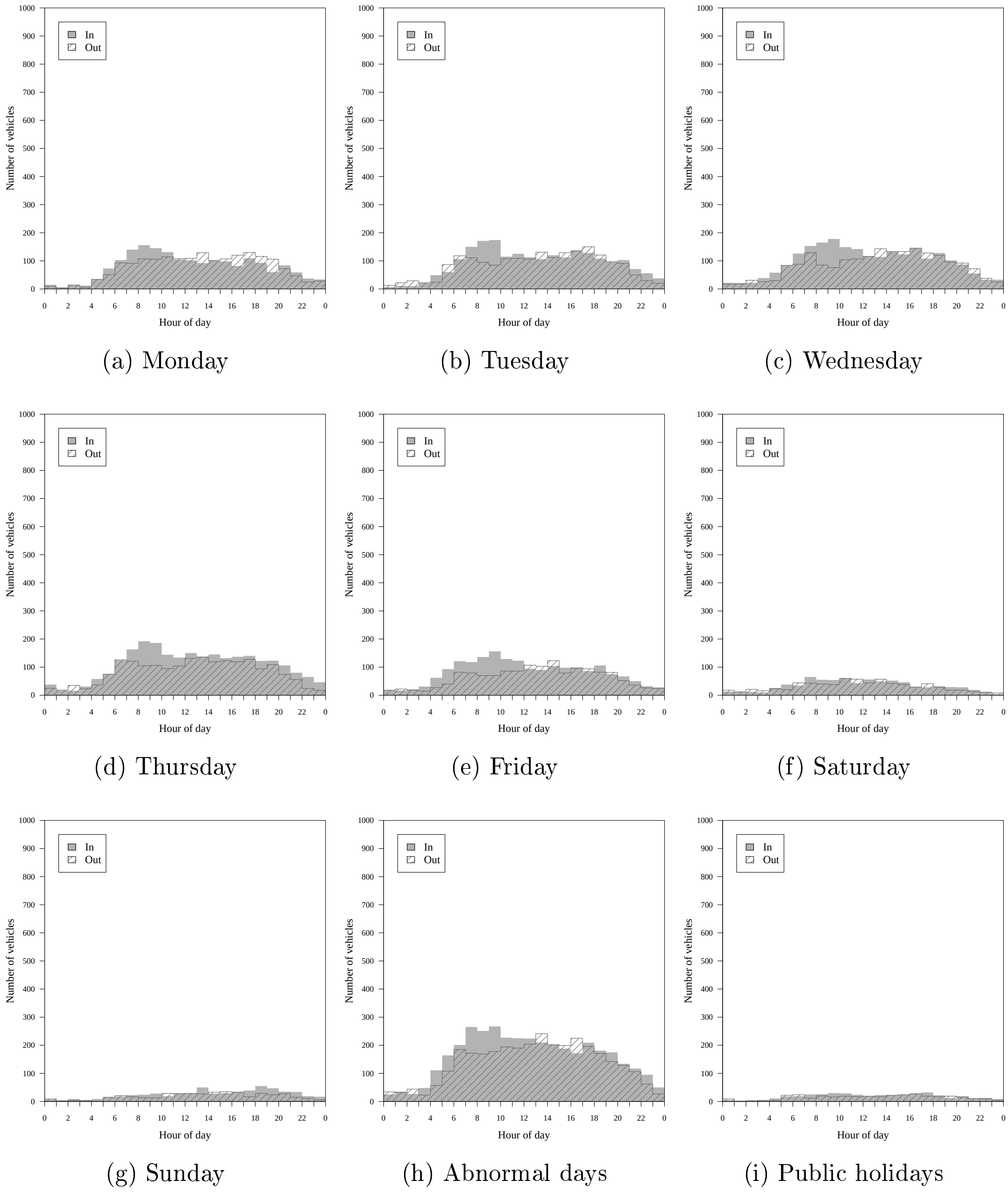


(h) Abnormal days



(i) Public holidays

Figure C.7: Gate activity on the different days of the week at gate 7



(a) Monday (b) Tuesday (c) Wednesday

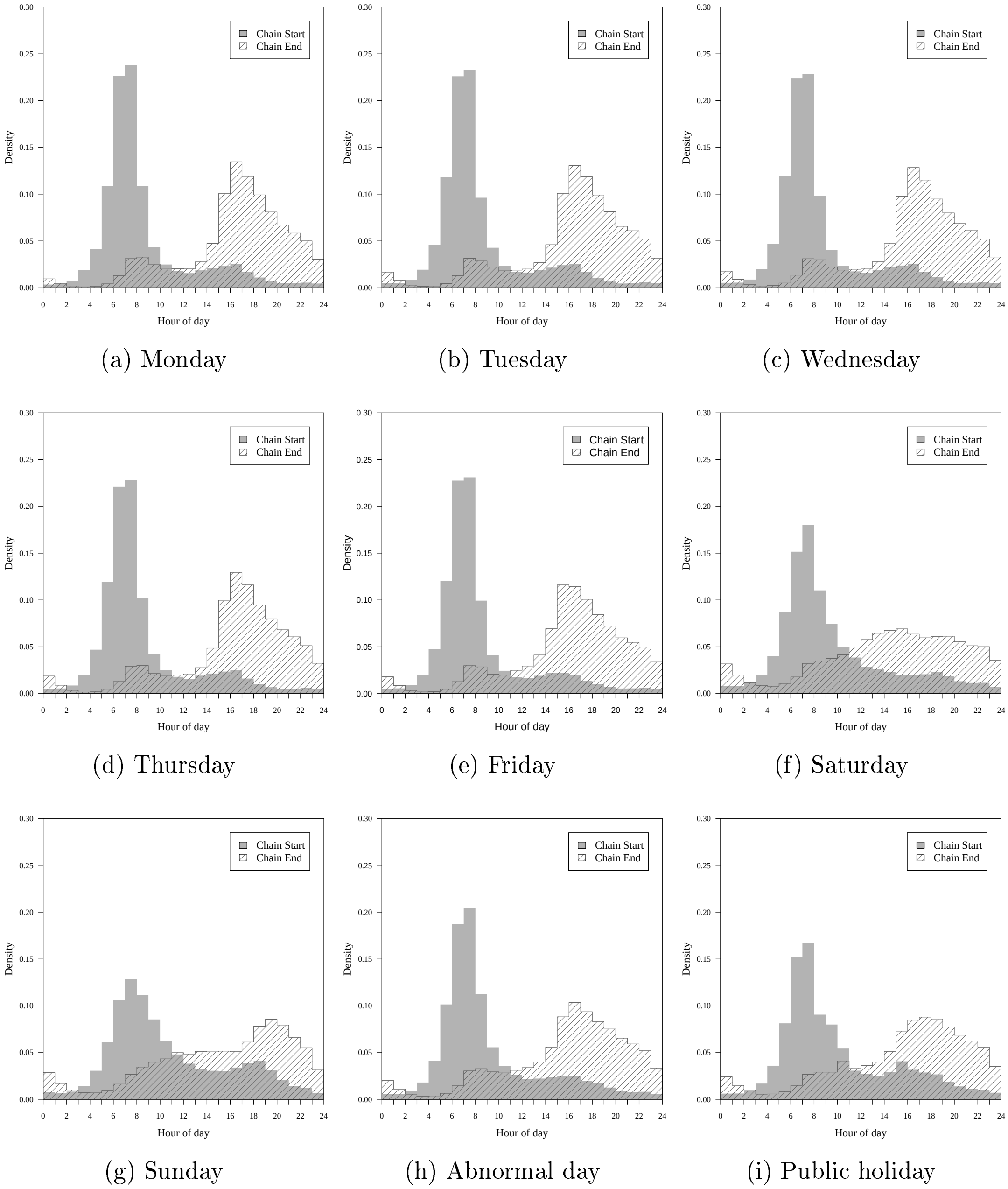
(d) Thursday (e) Friday (f) Saturday

(g) Sunday (h) Abnormal days (i) Public holidays

Figure C.8: Gate activity on the different days of the week at gate 8

Appendix D

Chain start and end times

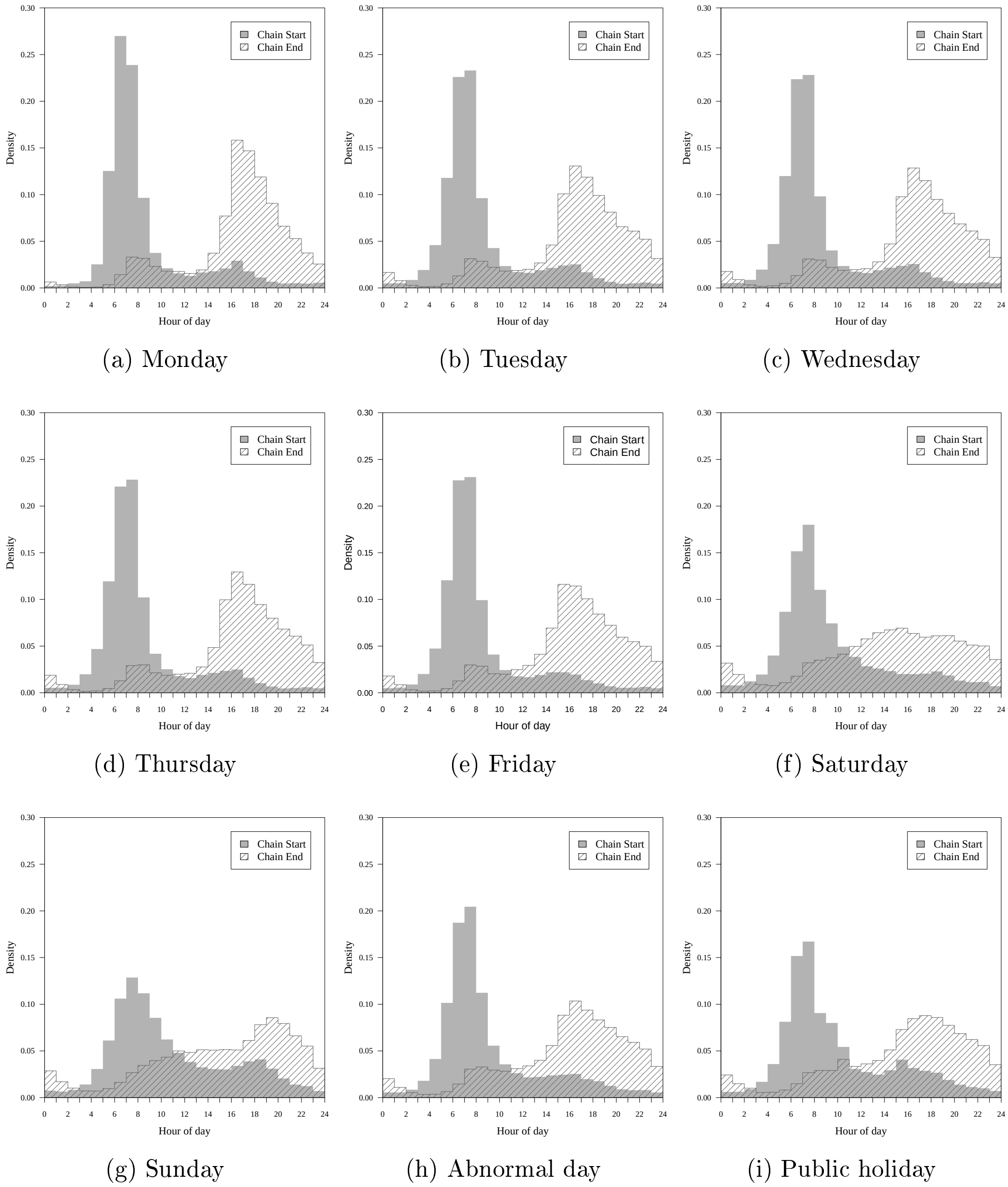


(a) Monday (b) Tuesday (c) Wednesday

(d) Thursday (e) Friday (f) Saturday

(g) Sunday (h) Abnormal day (i) Public holiday

Figure D.1: Through vehicles' chain start and end times on different days of the week



(a) Monday (b) Tuesday (c) Wednesday

(d) Thursday (e) Friday (f) Saturday

(g) Sunday (h) Abnormal day (i) Public holiday

Figure D.2: Within vehicles' chain start and end times on different days of the week