ASSESSMENT OF SCENARIOS FOR SUSTAINABLE TRANSPORTATION AT METU CAMPUS

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
MIDDLE EAST TECHNICAL UNIVERSITY

BY

ORUÇ ALTINTAŞI

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF THE MASTER OF SCIENCE
IN
CIVIL ENGINEERING

JANUARY 2013

Approval of the thesis:

ASSESSMENT OF SCENARIOS FOR SUSTAINABLE TRANSPORTATION AT METU CAMPUS

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ABSTRACT

ASSESSMENT OF SCENARIOS FOR SUSTAINABLE TRANSPORTATION AT METU CAMPUS

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January 2013, 123 pages

Sustainable transportation aims encouragement of non-motorized (pedestrian and bicyclist) and shared-ride transportation modes instead of car-dependent travels. This is important for university campuses, as they have better chance to implement such policies in a rather controlled traffic network, and can set an example to other communities. Most of sustainable campus transportation programs boil down to reduction of car-based emission cost of campus mobility, which is always the first step in developing more sustainable transportation policies.

Middle East Technical University (METU), Ankara has a large campus area and a population over 30,000 people. To develop sustainable campus transportation policies, it was important to quantify the current levels of mobility and vehicle emissions within the campus, which was the main motivation behind this study. This required determination of i) campus origin-destination matrix, ii) in-campus vehicle-km-travelled (vehicle-km), and iii) carbon emissions. Travel data obtained from different sources, including the gate entry with RFID systems enabled analysis of different user groups, such as academic and administrative personnel and students, separately.

The traffic simulations were prepared in PTV VISUM, which provided both speed and vehicle-km values for road segments, and could represent multi-user group demand matrices in a single traffic assignment. Based on the base case mobility and emission values, more sustainable campus transportation policies were simulated in PTV VISUM, and assessed in terms of carbon emission impacts. Discouraging of private car usage by students seemed the first and simplest action.

Keywords: Sustainable Campus Transportation, Sustainable Transportation, Network Traffic Assignment, VISUM, Carbon Emissions

ÖZ

ODTÜ YERLEŞKESİNDE SÜRDÜRÜLEBİLİR ULAŞIM SENARYOLARININ DEĞERLENDİRİLMESİ

ALTINTAŞI, Oruç
Yüksek Lisans, İnşaat Mühendisliği Bölümü
Tez Yöneticisi: Yrd. Doç. Dr. Hediye Tüydeş Yaman

Ocak 2013, 123 sayfa

Sürdürülebilir ulaşım, özel araca bağlı seyahat türünü desteklemek yerine motorize olmayan (yaya ve bisiklet) ve araç paylaşımı yapılan ulaşım türünü desteklemeyi hedefler. Bu hedef üniversiteler için de çok önemlidir; zira kampüslerdeki trafik ağlarının kontrollü olması ve topluma örnek oluşturmaları açısından bu tür politikaları uygulama imkanları yüksektir. Birçok sürdürülebilir kampüs ulaşım programları, özel araç emisyonun azaltılmasını her zaman sürdürülebilir ulaşım politikalarının geliştirilmesinde ilk aşama olarak görmektedir.

Orta Doğu Teknik Üniversitesi (ODTÜ) kampüsü 30,000 nüfusu ile geniş bir alana sahiptir. Sürdürülebilir kampüs ulaşımı politikasını geliştirmek için, öncelikle mevcut araç hareketliliği ve araç emisyon miktarını belirlemek gerekmektedir ki, bu çalışmanın ana konusu budur. Bunun için de i) araçların başlangıç-bitiş matrisinin, ii) kampüs içi taşıt km değerinin, iii) karbon emisyon değerinin belirlenmesi gerekmektedir. Seyahat verileri farklı kaynaklar kullanarak alınmıştır. Kapı giriş verileri Radyo Frekansı ile tanımla (RFID) yöntemiyle alınmış, bu sayede farklı seyahat grupları(akademik ve idari personel, öğrenci) için analiz yapma imkânı sağlamıştır.

Trafik simülasyonları PTV-VISUM yazılımı kullanılarak yapılmış, her bir yol kesimi üzerindeki hız ve taşıt-km değerleri bulunmuştur. Mevcut durumdaki hareketlilik ve emisyon değerlerine göre daha sürdürülebilir kampüs ulaşımı için politikalar geliştirilmiş, PTV-VISUM yazılımında simülasyonu yapılmıştır. Geliştirilen politikanın mevcut karbon emisyon değerine etkisi değerlendirilmiştir. Sonuç olarak, öğrencilerin özel araç kullanımın azaltılması birinci ve en basit eylem olarak görülmüştür.

Anahtar Kelimeler: Sürdürülebilir Kampüs Ulaşımı, Sürdürülebilir Ulaşım, Trafik Ataması, VISUM, Karbon Emisyon

To My Family

ACKNOWLEDGMENTS

I would like to express my sincere appreciation to my supervisor Asst. Prof. Dr. Hediye Tüydeş Yaman for her endless support, valuable guidance, and patience throughout this study.

I would like to express my sincere gratitude to PTV Company for providing license key during my study and supporting academic studies. I would especially thank to Adem Aslan for his supports and helps.

I would like to thank to my colleague Murat Özen for his supports during the study, especially coding in MATLAB and data collection part, and Mustafa Karcılı for his support in data collection part.

I would like to express my sincere thanks to my father, mother and my brother for their endless support during my life. Finally, I would like to thank to my wife for her patience and support.

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CHAPTER 1

INTRODUCTION

Sustainable campus transportation concept has been considered by many university campuses. As the goal of this concept can be summarized as increase in use of non-motorized and public transit modes with an expected reduction in use of private modes, carbon emissions are the direct measure of the sustainable transportation. Some universities developed quantified goals, such as a definite percentage carbon emissions reduction by a given year. However, some universities just worked on developing initiatives to support non-motorized transportation and public transit use to reduce private car usage in accessing campus. Additionally, there can be different policies for different campus users, students or personnel.

These policies gathered under the “Transportation Demand Management” aim to change the travel behavior of people from private car use to non-motorized transportation, such as walking, cycling. “Transportation Demand Management” has been defined as a planning strategy to influence the travel behavior of people in a way that the congestion is reduced (Meyer, 1997). The most widely implemented solutions are parking demand management, car-sharing/car-pooling programs, encouraging public transits, encouraging alternative fuel vehicles, and internet and video usage to provide online classes and transportation information (Markowitz and Estrella, 1998).

Middle East Technical University (METU) is one of the big campus universities in Turkey. METU campus is located on 20th km of former Ankara-Eskisehir highway, called Dumlupınar Boulevard today. All academic units are located in one settlement area of approximately 220 hectares (see Figure 1.1). Including the working population in the Technopolis part, which is an area reserved for small and medium enterprises dedicated on research and development, total campus population exceeds 30,000 people. The campus originally was designed as a pedestrian-friendly campus with strict separation of vehicular and pedestrian traffic, and there are access limitations at the entries.

Developing sustainable transportation policies is necessary for METU campus. However, any major policy change to increase sustainability in transportation, such as parking management and pricing, bike systems, pedestrian lanes and roads, is hard to implement without considering the potential impact on the vehicular traffic demand. Traditionally, travel demand analysis of a region depends on households surveys, which are costly and done mostly for long-term planning. Instead, this study utilizes available mobility data from various sources and combines them in a traffic simulation environment to calculate the traffic volumes on campus road segments and calculate the carbon emissions of in-campus private car mode.

Earlier campus travel was studied by Gokbulut (2003). Traffic counts were manually collected during working hours (08:00 to 17:00) for different modes (*dolmus*, buses, services, private vehicles, and pedestrians). It was found that 41 % of passengers came to campus by using public transport, 39 % of them came by private car and 13 % of them preferred to use *dolmus* and 7% of them walked to the campus. The total number of vehicles entering the campus in working hours was calculated as 6491. Following the increase in automobile ownership and use in Ankara, the number of vehicles entering the METU campus nowadays exceeds 15000 per day (10492 vehicles during the work hours). This increase in the vehicular traffic has started to threaten walkability; Furthermore, METU campus was not designed for biking originally, which discourages the number of non-motorized trips.

Figure 1.1 The location of METU campus

Determining the currently existing vehicular demand and flow, more specifically private car, is the main motivation behind this research. This, first, requires calculation of characteristics of car-based travel in the campus; daily demand profile, campus stay times and vehicle-km (also called Vehicle-Km-Travelled). Emission calculations require the estimation of total system use through the vehicle-km values and the speed profiles on campus roads, which will be obtained by a traffic analysis and simulation tool, PTV VISUM software.

The layout of this thesis is as follows: In Chapter 2, the literature on sustainable campus transportation is summarized. Methodology for in-campus private car emissions is given in Chapter 3. METU campus travel data is presented in Chapter 4, and followed by the campus travel demand analysis in Chapter 5. Campus traffic assignment and carbon emission calculations are given in Chapter 6, and assessment of sustainable transportation scenarios are presented in Chapter 7. Finally, conclusion and further recommendations are presented in Chapter 8.

CHAPTER 2

SUSTAINABLE CAMPUS TRANSPORTATION

To propose sustainability policies for METU campus transportation, it is necessary to review the available literature on decade of sustainable development. Additionally, sustainable campus transportation implementations in different universities are presented in the following section. Finally, literature on vehicle emission calculations for university campuses is presented in the third section.

2.1 Decade of Sustainable Development

Sustainable development has been focus of many countries because of the decreasing of the national resources, increasing in carbon emissions and air pollution etc. Sustainable development can be defined as to balance environmental aims with a strong economy and an equitable society (Newman and Kenworthy, 1999; Roseland, 1998). Thus, sustainable development can be accomplished when social, economic and environmental objectives are in unison (MacDonald, 2000). These objectives can be defined as;

Social Sustainability: Social sustainability is defined as maintenance and improvement of happiness of the current and future generations (Chiu, 2003). Social sustainability has five major principles that are “equitable,” “diverse,” “connected,” “democratic” and “a good quality of life.”
Economic Sustainability: Macdonald (2000) explained the economic sustainability as “the production and distribution of wealth in a manner that provides goods and services for both present and future generations.” Economic sustainability includes the presence of diverse and consistent strong economic opportunities.
Environmental Sustainability: Environmental sustainability includes the cleaner air, waste reduction, resource conservation, and efficient environmental management systems. Sheltair (1998) stated that the characteristics of environmental sustainability contain efficiency, interdependence, resilience and adaptability, and self-sufficiency.

When investigating the evolution of the sustainable development, many declarations have been signed so far. The Stockholm Declaration (UNESCO, 1972) was the first declaration aiming at sustainability by implementing higher education and suggested many ways to achieve environmental sustainability. Later, the Brundtland Report (1987) focused on increasing of the economic development without damaging the natural resources and environment. In 1992, Earth Summit Report stated that human beings are the center of the sustainable development. The social, economic and environmental quality of the human settlements must be improved. Furthermore, promoting land use policies, and promoting sustainable energy and transportation systems are the focus of this declaration. The other protocol is the Kyoto (1998) that aims to reduce the current emissions in order to promote sustainable development. It aimed to enhance the energy efficiency of the national economy, increase and promote the use of renewable energy.

2.2 Sustainable Transportation

Sustainable transportation is one of the most important issues of future planning, focusing on preventing air pollution, generating maximum efficiency between transportation modes and land use planning. The most famous definition of sustainable transportation is “one that satisfies current transport and mobility needs without compromising the ability of future generations to meet their own" (Black, 1997; Richardson, 1999). The success of sustainable transportation depends on encouragement of non-motorized (pedestrian and bicyclist) and shared-ride transportation modes instead of car dependent travels.

The main objective of sustainable transportation is to "increase the level of accessibility without increasing individual mobility in private modes of transportation" (Guasch and Domene, 2010). According to the World Bank (1996), sustainable transportation has three dimensions, which are economic, environmental, and social. Economic dimension of sustainable transportation is to represents the minimum use of external resources, minimum congestion, and accident cost. The strategies to achieve economic sustainable transportation are using clean vehicle fuels and clean vehicle technologies, minimizing the traffic congestions, increasing the use of non-motorized transportation modes. Environmental dimension represents the use of renewable sources, and minimum air pollution, minimum greenhouse gas effect, traffic noise, etc. The strategies to achieve these actions are to encourage clean fuel and clean vehicle technologies, to minimize the road traffic congestion and to increase the sea and rail transportation, to minimize urban traffic by car and to encourage walking and biking. Finally, social dimension of the sustainable transportation provides safe and adequate service to all segments of society. The common strategies are improving public transportation, improving safety on public transportation for women, children and elderly people, and providing more access to low income regions

The actions of the sustainable transportation can be grouped into three main headings (see Figure 2.1). The first action is to achieve cleaner air. This can be achieved by encouraging non-motorized modes such as cycling and walking. Furthermore, encouraging transit use, implementing car-sharing programs, and using alternative fuel vehicles are the key strategies to achieve cleaner air. The second action is to provide more efficient land use policy. Efficient land use policy can be succeeded by implementing parking demand management strategies. For example, eliminating the free parking, increasing the parking charges according to time of the day, implementing parking permit programs for single occupancy vehicles are some of these kinds of strategies. The third action is to maximize the efficiency. Developing a strategic pedestrian improvement plan, implementing bicycle access planning, reducing tools for carpools are the strategies to maximize the efficiency of the region.

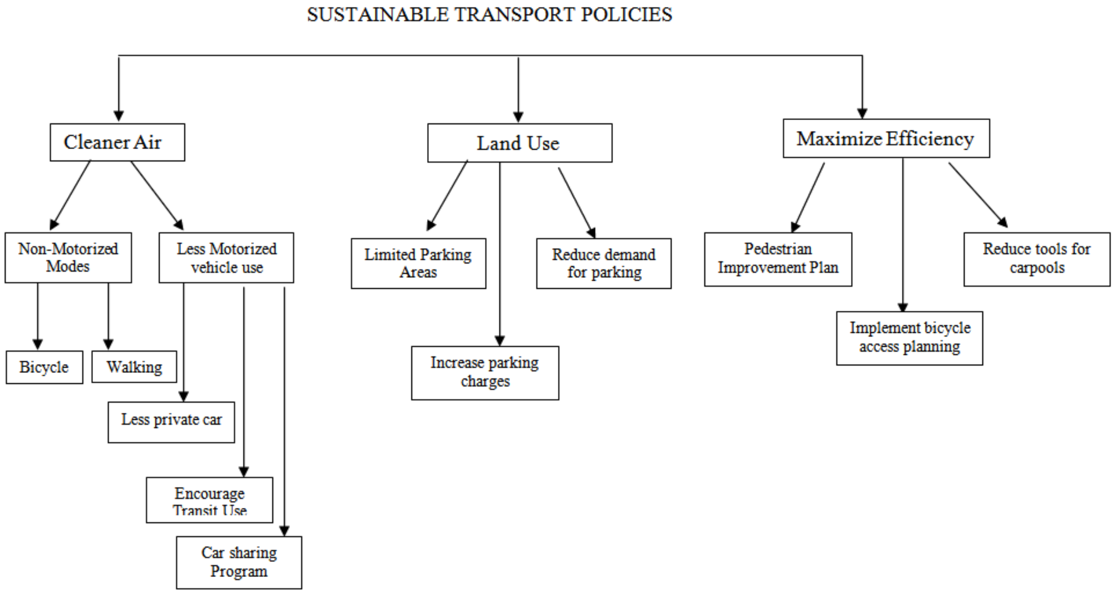


Figure 2.1 The aim and implementations of the sustainable transportation in a region

2.3 Sustainable Campus Transportation

Introducing sustainable transportation for university campuses is important for mainly many reasons: first, university campuses can be regarded as small cities, due to their high student population, increasing motorized traffic demand, different attraction-production zones (shopping, sport centers, teaching activities, etc.). On the other hand, they have relatively small and closed transportation systems, where different traffic and demand management options can be implemented easily. Secondly and more importantly, we can create a next generation with first-hand experience of sustainable transportation. The big youth population on campuses can take sustainable transportation concept with them to future and larger populations.

Today, universities around the world are implementing many strategies to reduce car-dependent travels in campus. These strategies are gathered under the “Transportation Demand Management” concept. Transportation Demand Management has been defined as a planning strategy to influence the travel behavior of people in a way that the congestion is reduced (Meyer, 1997). The most widely implemented solutions are parking demand management, car-sharing/car-pooling programs, encouraging public transits, encouraging alternative fuel vehicles, and internet and video usage to provide online classes and transportation information (Markowitz and Estrella, 1998). Parking demand management policies provide more efficient land use to the campus community.

Car-sharing/car-pooling is the sharing of car travels so that more than one person travels in a car. Car-sharing is like low cost and short time car rental option. Any ride-sharing system decreases the travel cost of the each persons, provides less single vehicle occupancy, and decreases the carbon emissions. Encouraging public transportation is another way to reduce single occupancy vehicles. Alternative fuel vehicles provide less carbon emissions to the environment and provide cleaner air.

2.3.1 Sustainable Campus Initiatives

The sustainable campus initiatives of 38 universities in the USA and Canada have been displayed in a joint webpage (SC, 2012). Majority of the universities show effort to increase non-motorized modes (walking and bicycling), shared ride, and public transit. Most of the campuses are trying to reduce private car-trips or at least single-occupancy in travel. A summary of these plans are provided in Table 2.1. The analysis of sustainable campus transportation policies in these universities showed that 18 universities declared a definite emissions goal. The remaining 20 universities do not declare defined emission goals but they only mentioned emission reductions as a goal. While a more detailed review of the sustainable campus transportation initiatives are provided in Appendix A, a brief summary of most common initiatives are given below.

Table 2.1 Frequency of sustainable transportation initiatives implemented at university campuses

Policies	# of Universities
Biking	34
Walking	34
Public Transit	32
Ride-sharing (car-sharing/car-pooling)	30
Parking Management	12
Emission goals	18

Biking Initiatives:

Among 38 universities, 34 of them encourage biking systems by implementing several applications.
For example, Arizona State University biking program allows students, faculty members and staff to use bicycles for up to 10 days with no charge and bicyclist can buy high quality bicycle helmets, headlights and bike locks with a cheap price. Portland State University encourages biking by providing in campus bicycle repair and maintenance location, secure bike parking, bicycle maps showing the location of bike parking, bike storage rooms and they have detailed bicycle master plan.
University of Colorado stated that providing the bike lanes and improvement of the infrastructure resulted in the increase in bike usage from 20% to 31% in a year. University of California have bicycle network and campus bicycle plan for the campus community. Harvard University has a bike sharing system and strong bike commuting system. In summary, when checking the biking implementations of the sustainable campus universities, the followings are the key implementations to encourage university community to use bike.

- Improvement of bicycle paths, lanes and parking rocks and lockers
- Implement bike sharing system
- Provide bicycle storage rooms and shower facilities
- Establish linkages between different transportation modes
- Use appropriate signs and markings to create safety roads
- Provide campus bicycle map
- Provide campus bicycle shop

Walking Initiatives:

Pedestrian friendly campus is the one of the main focus of sustainable campus transportation actions. Among the 38 universities, 34 of them are trying to create pedestrian friendly environment by implementing many policies, such as providing more sidewalks, increasing of the use of pedestrian areas, improving the pedestrian network (removing the gaps and barriers), and minimizing the parking in the center of the campus increase the number of pedestrian travels. For example, Carleton University provided great infrastructure for person who likes walking.

Public Transit Initiatives:

Encouraging public transportation is another important strategy to become more sustainable campus transportation. Washington State University increased the use of public transit by improving the convenience of linkages, increasing frequency, areas of service, and funding. In addition, to increase the percentage of the students using public transportation, this university added more routes and provided weekend transportation. North Arizona State University improved the public transportation infrastructure to allow better access to the campus. For the University of North Carolina, implementing fare free transit system resulted in increasing of bus ridership from 3 million to 7.5 million trips in a year. Brown University provided subsidized transit pass to students and staff members. Cornell University defined "Omniride" that Cornell has offered its employees partially or fully subsidized transit to encourage the use of public transport. Also, OmniRiders have ten one-day parking permission for every six months, in case they occasionally need to bring a car to the campus.

Ride-sharing Initiatives: Car-sharing, Car-pooling:

Among 38 universities, 30 of them have implemented ride-sharing programs. For example, University of Kentucky provided car-sharing programs for students, academics, and their employees. Arizona State University have car-sharing programs that allowed its members to rent a low emission, fuel-efficient vehicle for an hourly fee, and this implementation resulted in 28.6 ton carbon emissions reduction in a year. In addition, Harvard University defined "Zimride" ride-sharing options that match Harvard friends, classmates, colleagues who are going the same way. To encourage car-sharing/car-pooling, many universities provide flexible parking permit options. Similarly, Cornell University implemented individual parking permits to increase the use of car-sharing. Emory University develops car-sharing program with a name of "ZipCar". It provides special and free fee parking lots to encourage this system.

Parking Management Initiatives:

Parking management program should be implemented to reduce the single occupancy vehicles and to encourage ride-sharing programs. Among 38 universities, 12 of them have parking management programs. These parking programs aimed at to

- reduce demand for parking through incentives for alternate travel modes,
- eliminate the lure of free parking,
- enhance parking enforcement,
- individual parking limits
- increase parking charges according to the time of day or implementing a permit parking program

For example, Cornell University applied individual parking permit to discourage the private car use and provide parking lots with low fee to encourage car-sharing. University of British Colombia reduced demand for parking to discourage the single occupancy vehicles. University of Virginia implemented parking permit program to increase the use of public transportation.

Emission goals:

Arizona State University aims to minimize 100% of its carbon emissions from transportation by 2035 by implementing "Transportation Demand Management" strategies. Michigan State University is planning to reduce their carbon footprint by using energy efficient transportation, and University of NC states a goal of 50% reduction in carbon emissions by 2020. Furthermore, UC Santa Barbara stated that 75 % of fleet purchases would be alternative fuel or ultra-efficient vehicles by 2011. University of British Colombia states that carbon emissions will be reduced 33% by 2015. Similarly, Washington State University aims at reducing carbon emissions 50% by 2020. Yale University targeted the 43% reduction in carbon emission by 2020 by investigating alternative fuel vehicles.

2.3.2 Review of Sustainable Campus Studies

In-campus travel demand and management has been the focus of more detailed studies. Balsas (2003) studied eight bike and pedestrian friendly campuses (Cornell; U of Wisconsin, Madison; U of Colorado, Boulder; UC Santa Barbara and UC David; Stanford University; U of Oregon, Eugene; U of Washington, Seattle) to understand the reasons behind the success of non-motorized modes. It was found that improving the infrastructure of biking and discouraging private car use by implementing "Transportation Demand Management" strategies are the key elements to achieve sustainable campus transportation. As an evaluation of parking management on Beijing University of Aeronautics and Astronautics, China, Huayan et al. (2007) obtained inflow and outflow of vehicles during the day and calculated the average parking stay time of vehicles. Showing that the existing parking lot capacity did not satisfy the demand and resulted in increasing on-street parking, the study concluded that pedestrian safety was threatened.

Limanond et al. (2011) studied travel behavior of 130 students who live on campus in a rural university. Average daily trip generation was found for weekdays and weekends. Daily travel time and average daily distance traveled were determined. The results showed that males and females had similar travel pattern. Students owning a car preferred driving and non-car owners preferred riding with a friend and bus. Miralles-Guasch and Domene (2010) determined the travel pattern and transportation challenges of Autonomous University of Barcelona through an online survey with 5525 participants. The results showed that the lack of adequate infrastructure, the marginal role of walking and cycling and longer time involved using public transport were the main barriers to shift travel mode from private vehicle to non-motorized modes.

2.4 Campus Transportation Carbon Emissions

Many universities, especially in the USA, used "Clean Air-Cool Planet's University Carbon Calculator" programs to calculate carbon emissions of the university campuses. This is a Microsoft Excel-based program that it enables to calculate future emissions trends and analyzes the potential carbon footprint annually (Ferraro, 2008). Furthermore, it does not only measure transportation carbon footprint, but also carbon emissions, which accounts for waste and energy. Using this tool, Miami University calculated its carbon emissions by dividing their transportation systems into three sub-sectors (vehicle fleet, commuter travel, and air travel) and estimated the corresponding carbon emissions, separately. For such a campus wide analysis, vehicle fleet fuel usage data were collected from their University Garage, Miami Metro and departments with personally owned vehicles. Secondly, commuter travel was determined by conducting travel survey and finally air travel carbon emissions were measured separately. Miami University found their total carbon emissions from transportation as 25,320 $MTeCO_2$ in 2008 (36 % is commuter travel, 26% is vehicle fleet, 38% is air travel). A MTeCO2 stands for the metric tons of CO_2 equivalent that it is an international unit of CO_2

emissions as an equivalent unit of tone. Also, Ferraro (2008) stated that University of Wisconsin Madison was calculated commuter travel carbon emissions as 9,032 MTeCO_2 in 2008.

CHAPTER 3

METHODOLOGY FOR IN-CAMPUS PRIVATE CAR EMISSION ESTIMATION

3.1 Proposed approach

The main steps of the proposed methodology used to assess sustainable campus transportation policies for METU is summarized in Figure 3.1. The proposed methodology is composed of two major phases. The first phase is base case calculations that various types of data were collected in Step 1 and used to determine campus travel demand characteristics of METU (Step 2). This led to calculation of the O-D matrix for the current demand levels in the campus and used in the campus network assignment in Step 3. As a results of the assignment provided the vehicle-km values and speed profiles in the network, which were later used in the estimation of carbon emissions for METU campus in Step 4.

Based on the emissions, it was possible to develop policy scenarios for more sustainable transportation, which were studied in the second phase, named as scenario analysis. Campus travel demand analysis were used to create scenarios (Step 5), which either proposed a change in the demand or the road network usage, and assigned to the network again to get the vehicle-km and emissions. Finally, vehicle-km and carbon emissions changes were evaluated in Step 6. The change in the emissions provided insights about the prioritization of the developed sustainable campus transportation scenarios.

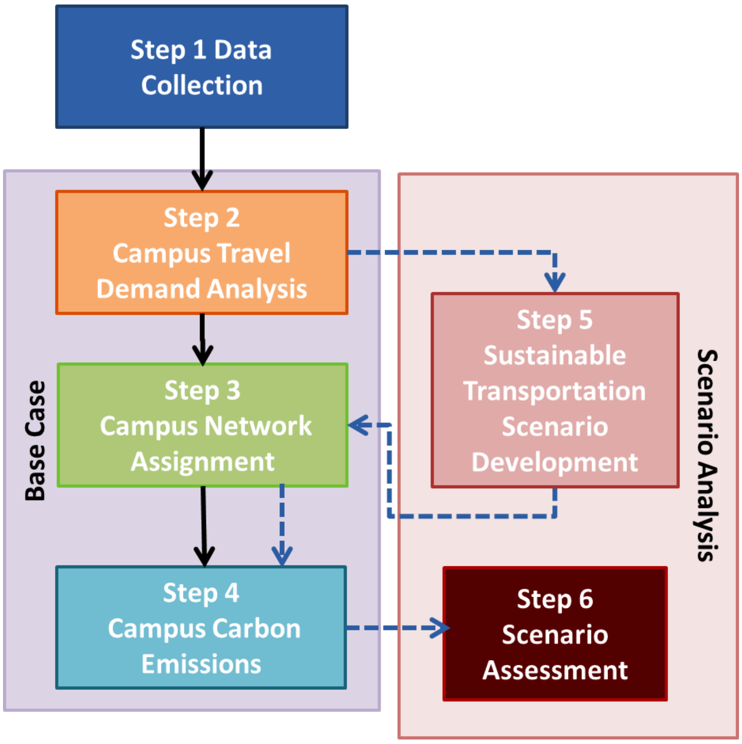


Figure 3.1 Proposed simulation-based methodology for sustainable campus scenario assessment

Among these steps, the most crucial and the challenging ones are the first two steps: because, if the data collection process does not include all the demand and O-D pairs, it is not possible to estimate the total travel demand. Also, if the data are not detailed enough to provide travel and traveler characteristics, it is not possible to create time-dependent and/or traveler-type based O-D matrices, which are fundamental to create and study different transportation demand management policies.

3.2 Origin Destination (O-D) Estimation

In this section, first O-D estimation methods in the literature will be mentioned and secondly, proposed O-D estimation method for this study will be presented.

3.2.1 Review of O-D Estimation Methods

O-D matrix of a region can be determined by using different techniques. The first one is the data surveys; household survey, roadside interview survey, and license plate journey survey (Doblas, 2005). Household and roadside surveys are the traditional survey types whereas license plate journeys are the new surveying type over the decade. Household survey gives reliable and more accurate results, but it requires too much time and work force (expensive interviewing, data validation and so on). Roadside interview survey is just used for roughly estimations; drivers are stopped at the side of the road and asked questions to capture their origin and destination of the trips and travel purposes. Slinn et al. (2005) states that this kind of traffic survey is difficult to implement in congested urban roads, it is hard to stop driver in congested traffic so; it should be repeated on the same day of the following week to improve the accuracy of the results. The third one is the most frequently used over the past twenty-five years because it gives a more accurate result and decreases the cost of the survey and saves time. Data are collected automatically and does not need to be calibrated (Doblas, 2005).

O-D estimation has been focus of many studies. Lu (2008) studied the O-D estimation of bus passengers using automated data collection technologies. The research aimed to compare the on-board surveys, which are traditional method to estimate bus passenger O-D, and boarding and alighting counts for each bus stop using Automatic Passenger Counting (APC) system. It was found that all the methods gave similar estimated O-D, but using APC saves time and less labor intensive. Another research conducted by Cools et al. (2009) studied to assess the quality of O-D matrices obtained from household surveys. The travel information of 10,296,350 residents were used, and randomly 2000 stratified samples were selected, and origin and destination matrices were observed in three levels (municipality level, district level and provincial level) for each sample. It was found that accurate O-D matrix could not be directly obtained by travel surveys; it must be supported with roadside interview surveys.

Another technique to estimate O-D is via traffic counts. If there are not any travel surveys of a region, but just have an inflow/outflow values of a major locations or link volumes are known, then O-D estimation can be determined by various developed methods and traditional methods such as; trip distribution model (gravity model) or using simulation based traffic assignments. Yang and Zhou (1998) conducted a research to find optimal traffic counting location defining four basic rules to obtain accurate O-D estimation. These rules are; O-D covering rule, maximal flow fraction rule, flow intercepting rule, and link independence rule. Linear programming was developed to formulate them. O-D covering and independence rules were defined as constraints and total network is formulated as objective function. Two different situations were searched; first, path flow information is existence or not. Second, turning probabilities at nodes is high or not. It was found that their developed methodology for appropriate for practical applications.

Bustillos et al. (2011) studied the O-D estimation of University of Texas at El Paso at morning peak period. The traffic data were collected on selected links and intersections (according to the directionality of the traffic at morning) and O-D estimation was formulated as assignment-based linear optimization problem in which the objective function is to minimize the one-norm of link count deviations. In addition, they performed the pedestrian counts with boarding and alighting time at all bus stops to estimate the O-D of transit users. Finally, they were simulated in a simulation environment to see the impacts of transit vehicles on the current traffic.

3.2.2 Proposed O-D Estimation Method

Majority of the effort was spent to obtain detailed O-D matrices from various available traffic data. Campus travel data were collected from gates by using Radio Frequency Identification System (RFID) data and gate videos, which were examined under "Gate Activity Data" (see Figure 3.2). With the help of the RFID system, we can get all of information about a vehicle with its license plate, sticker type; group type, entry and exit time, and 24-hour continuous data can be obtained for a full week or a longer period automatically. An example RFID data is shown in Table 3.1.

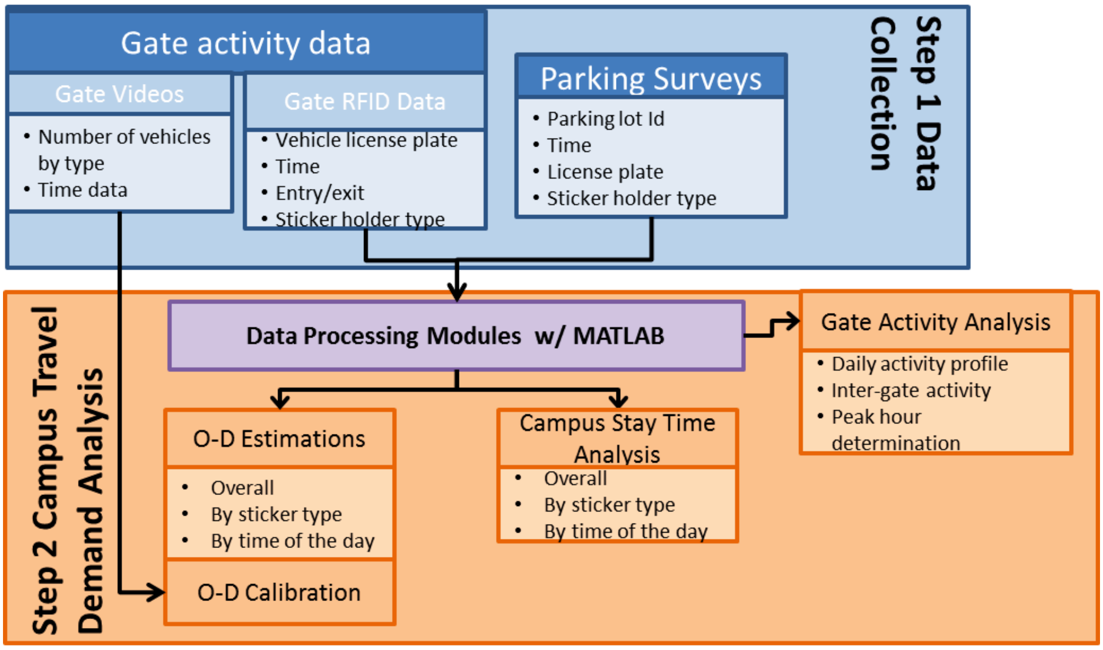


Figure 3.2 Proposed methodology for estimation of O-D matrix of the METU campus

Table 3.1 An example RFID data profile

License Plate	Gate	Sticker Type	Group	Time	Movement
01HJ361	A1	Academic	Academic (permanently)	07:54	Entry
01HJ361	A4	Academic	Academic (permanently)	12:00	Exit
01ZM025	A4	Student	Local (2011)	15:05	Entry
01ZM025	A4	Student	Local (2011)	19:49	Exit
01ZM025	A4	Student	Local (2011)	21:26	Entry
06AC1277	A4	Admin.	Admin.	08:56	Entry
06AC1277	A1	Admin.	Admin.	16:15	Entry
06AC1277	A4	Admin.	Admin.	20:34	Exit
01BJ651	A1	Student	Local (2011)	14:30	Exit

In addition to the RFID data, parking lot surveys were performed in different times in a day to find the in-campus origin or the destination of a trip. In these surveys, license plates of the vehicles were collected in defined parking lots. An example parking survey data is shown in Table 3.2.

Table 3.2 An example parking survey data

License Plate	Survey Time	Location (Parking Lot ID)	License Plate	Survey Time	Location (Parking Lot ID)
…	…	…	…	…	…
01HJ361	08:30-09:30	70	06AC1277	16:30-17:30	26
01HJ361	10:30-11:30	18	01BJ651	08:30-09:30	26
01ZM025	15:30-16:30	30	01BJ651	10:30-11:30	29
06AC1277	10:30-11:30	25	01BJ651	12:30-13:30	26
…	…	…	…	…	…

Using the RFID and the parking lot survey data, the total trips by private cars were studied to create a daily O-D matrix for campus traffic. Data processing was performed by using MATLAB program (see Figure 3.2). An example analyzed data is illustrated in Table 3.3. In this table, "first time" indicates the time which a vehicle enters to campus; "source" column indicates whether the information was taken from the gates (if source=1) or from parking lot (if source=0). "Gate" column shows the used gate"; Movement" column indicates the type of vehicle movement if it is "1," the movement is entry; if it is "2," the movement is exit. If it is "0" then information is taken from parking lot. "Second time" indicates the time, which a vehicle is captured at parking lots or at the gate. Finally, stay time shows the stay time of vehicle for each sequence pairs. For the license plate of "01HJ361"; the origin and the destination of this vehicle is; 07:54 entry to campus at A1 and seen at 08:30-09:30 parking lot survey time; so, the origin of the trip is A1, and the destination of the trip is 70th id number of parking lot and the travel time start at 07.54. Furthermore, some movements have missing entry or missing exit. If a vehicle have a recorded entry but not have recorded exit, artificial exits have been defined (see Table 3.3). O-D estimation was performed for all different sticker types for peak hours and off-peak hours, separately. After the created O-D matrix, O-D calibration was done according to the gate camera records. Finally, in-campus private car O-D matrix was estimated, which will be explained in Section 5.3 in detail.

Table 3.3 Combination of gate RFID data and parking survey data

License Plate	First Time	Source	Gate	Mov.	Second Time	Source	Gate	Mov.	Stay Time (min)
01HJ361	07:54	1	A1	1	08.30	0	70	0	36
01HJ361	08.30	0	70	0	10:30	0	18	0	120
01HJ361	10:30	0	18	0	12:00	1	A4	2	90
01ZM025	15:05	1	A4	1	15:30	0	30	0	25
01ZM025	15:30	0	30	0	19:49	1	A4	2	199
01ZM025	21:26	1	A4	1	**00:00**	**1**	**0**	**2**	**164**
06AC1277	08:56	1	A4	1	10:30	0	25	0	94
06AC1277	16:15	1	A1	1	16:30	0	26	0	15
06AC1277	16:30	0	26	0	20:34	1	A4	2	244
01BJ651	**00:00**	**1**	**0**	**1**	08:30	0	26	0	510
01BJ651	08:30	0	26	0	10:30	0	29	0	120
01BJ651	10:30	0	29	0	14:30	1	A1	2	240

3.3 Network Traffic Assignment

In this section, first, available literature on simulation based traffic assignment by PTV-VISUM/ VISSIM will be presented and secondly, proposed network assignment will be mentioned for this study.

3.3.1 Traffic Assignment by PTV-VISUM/VISSIM

VISUM is a comprehensive transportation planning software program that analyzes the transportation system macroscopically. The behavior of every vehicle is not important in macroscopic simulation; the main important point is the flows in the whole network. The network is defined as traffic nodes, links, and zones; and various assignment procedures (user equilibrium, stochastic, dynamic assignment, and so on) are included to perform traffic flow analysis. Furthermore, various types of transportation modes can be defined in single assignment (*VISUM Basics*, 2009). For the micro traffic simulation, PTV-VISUM is supported by PTV-VISSIM, which analyzes private and public transport operations under the certain constraints such as, traffic composition, traffic signals, lane configurations (*VISSIM Basics*, 2009). Every vehicle in microscopic model is simulated. Furthermore, PTV Company provides PTV-Viswalk to simulate the pedestrians. Social Force Model is used to represent the human walking behavior. This program is generally used when pedestrian flows are important and need to be analyzed.

There are different studies conducted by using VISUM. Hui et al. (2010) developed a methodology to estimate time varying O-D matrix by using floating car data (FCA) and remote traffic microwave sensors (RTMS) data in Western 3rd Ring-Road corridor network in Beijing, China. The defined network was formed by using VISUM to get static O-D demand. Another study conducted by Wong and Yu (2011) aimed to determine the O-D matrix of Macau Grant Prix. The data were collected at the morning peak of normal day and during GP event. Data collection was performed in 36 intersections and 26 road segments, the network consisted of 443 nodes, 1344 links, and 23 zones, which were defined in VISUM, and traffic assignment was performed to get flows on links for normal days and GP day. Finally, most critical links, trip lengths, and travel times were evaluated.

Bustillos et al. (2011) used to VISSIM to simulate the campus traffic dynamically. Parking surveys were done for a total 80faculty and staff to determine their destination trips. The network was created in VISSIM with 20 zones and data collection points were located at different points in a network. Counts were classified for students, faculty, and staff separately. Finally, O-D matrix, parking information, and transit services (is mentioned in O-D estimation method section) were assigned to the VISSIM with dynamic assignment procedure to evaluate of the traffic performance.

Fries et al. (2011) was also studied to evaluate the mobility impact of relocating parking of the Clemson University campus in South Carolina using dynamic traffic assignment by VISSIM. The network consists of 742 nodes and 20000 links and traffic control devices were located with 12 different locations. The traffic data were collected by manual counts and video footage. The created 44x44 O-D matrix was assigned to the 11 different traveler types (commuter student, faculty and staff, university service cars and so on). The model was simulated 4h midday period at which it is difficult to find any empty parking lot. They suggested that if the parking lots was removed in the core campus, where high probability of vehicle-pedestrian conflicts occurred, the travel time of vehicles in a campus were decreased but the travel time of pedestrians were increased as expected. They found that there was no significant change in total network delay.

3.3.2 Proposed Network Assignment using PTV VISUM

The calibrated O-D matrix was assigned to the traffic simulation environment by using PTV-VISUM. First, the road network was drawn in VISUM in terms of links, nodes and zones. The daily O-D matrix was divided into three sub-groups, which are morning, evening and off-peak, and then assigned to the traffic network to get the link volumes, speeds and the vehicle-km (see Figure 3.3). At the end of the assignment, total vehicle-km values for different travelers, speed profile of campus at the morning, evening, and the off-peak hours were obtained, which were later use to estimate carbon emissions of the campus.

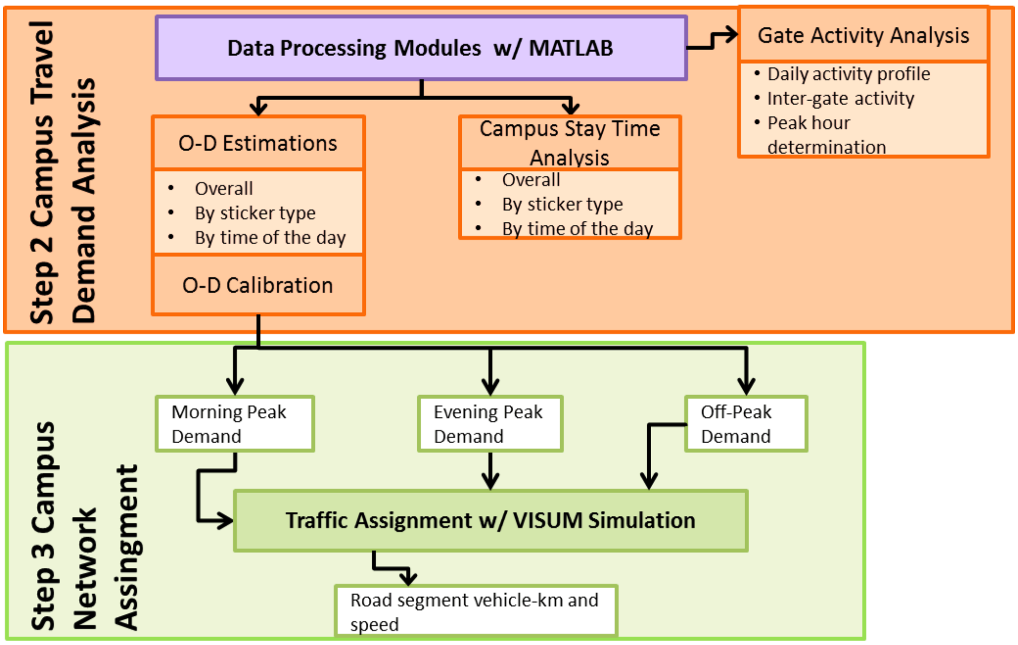


Figure 3.3 Proposed methodology for campus traffic network assignment

3.4 Carbon Emissions Calculation

Vehicle emission calculation programs and the relation between the speed and carbon emissions will be mentioned in the first section. The method to calculate the carbon emissions for this study will be presented in the second section.

3.4.1 Background for Private Car Emission Calculations

"Researchers and policy-makers around the world have produced many carbon "calculators" in attempts to estimate the emissions of all activities of an individual, city or university in units of metric tons of CO_2 equivalent per unit time ($MTeCO_2$)" (Padgett et al. 2008; Sinha and Cass 2007). Furthermore, COPERT 4 and MOBILE 6 are also used to measure vehicle emissions for large road networks, such as city or whole country networks. These programs are mainly used to determine national or regional emission purposes.

Emissions are generally associated with the vehicle engine types, fuel types, and average speed of vehicles. To understand the relationship between vehicle speed and corresponding CO_2 amount, Barth and Boriboonsomsin (2009) conducted a survey which finally showed that CO_2 emissions was higher, if the speed was low (0-10mph), and optimal emissions was reached between 35 mph and 60 mph (see Figure 3.4). Similarly, speed and corresponding CO value was determined by the CO-speed diagram (*VISUM Basics*, 2009). The graph was prepared for different reference years, which indicate the quality of fuel type that vehicles use. Again, lower speeds resulted in higher CO emissions, and if speed increases, CO emissions decrease (see Figure 3.5). These speed-carbon emission relations will be used in the estimation of the campus emissions for METU. Car 2000 reference year values were taken to calculate CO emissions.

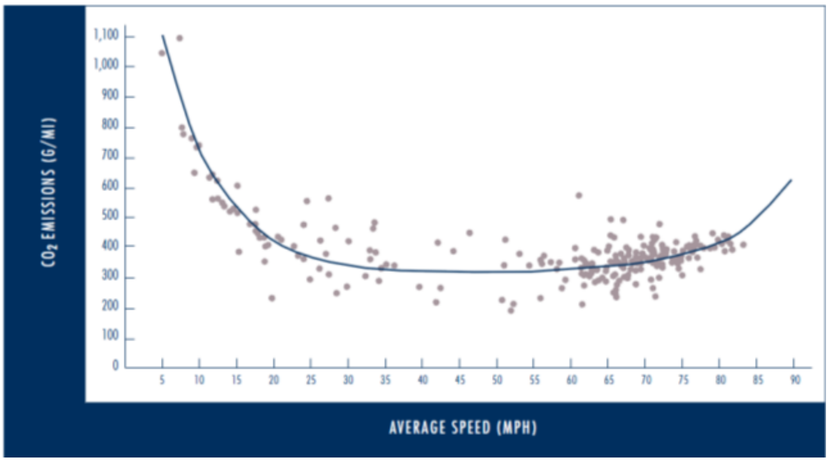


Figure 3.4 The relation speed and CO_2 emissions (Barth and Boriboonsomsin, 2009)

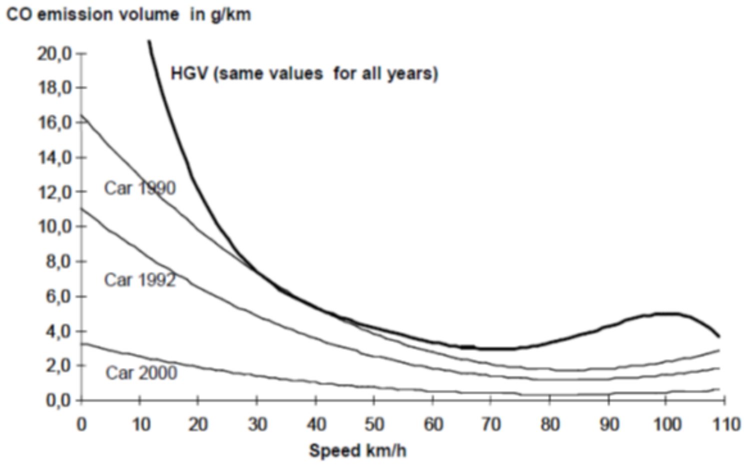


Figure 3.5 The relation between speed and CO (*VISUM Basics*, 2009)

3.4.2 Proposed Carbon Emissions Calculation Method

Figure 3.6 represents the proposed methodology for estimating the carbon emissions. As a result of the traffic assignment, link speeds and vehicle-km were determined. The link speeds were grouped into four categories as 0-5 km/h, 5-15 km/h, 15-30 km/h, and 30-50 km/h. Average unit carbon emissions values (g/km) were selected from speed-CO_2 diagram in Figure 3.4 and speed-CO diagram in Figure 3.5 as shown in Table 3.4. Network links were grouped based on the selected categories, and their vehicle-km values were multiplied by the unit values to get the corresponding carbon emissions. Carbon emissions by traveler groups were calculated for the morning, evening and off-peak hours, separately.

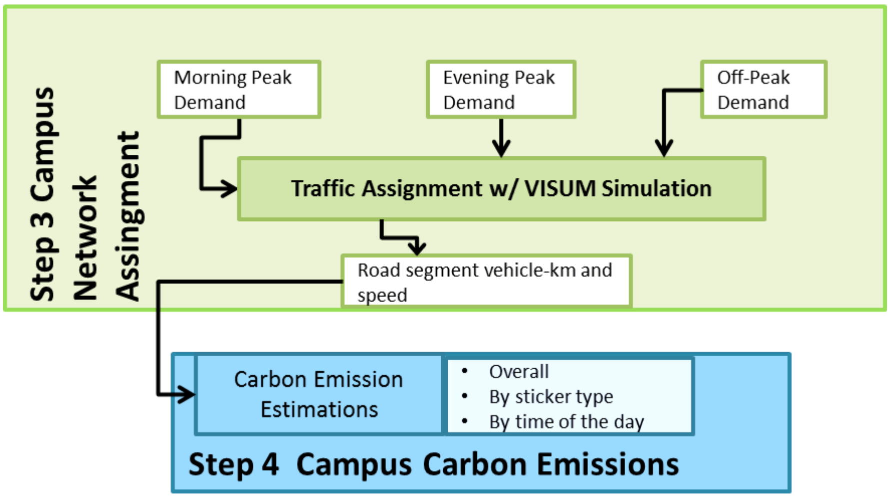


Figure 3.6 The proposed methodology for estimating the campus carbon emissions

Table 3.4 Speed and corresponding carbon emissions value in g/km

Speed km/h	Unit CO_2 (g/km)	Unit CO (g/km)
0-5	683	2.4
5-15	323	2.2
15-30	218	2.1
30-50	204	1.8

3.5 Campus Travel Demand Analysis

Processing of RFID data with the help of MATLAB program provided the daily activity profile which means hourly entry-exit profile of individual gates in a day, and provided the peak hours of morning and evening times, which will be studied under “Gate Activity Analysis” (see Figure 3.2). Table 3.5 represents the output of the analysis of gate RFID data. The movements for the same license plate were matched. For example, the vehicle with 01ZM025 license plate had a student sticker type and entered to campus at 15:05 from A4, and leaved the campus at 19:49 from A4. At 21:26, it entered to campus again. Moreover, it enabled us to calculate the stay time of each vehicle in a day, and stay time of each different traveler from this analysis. Thus, the travel characteristics of different travelers can be determined. In this part was studied under “Campus Stay Time Analysis,” which will be used to develop sustainable campus transportation scenarios.

Table 3.5 Analysis result from gate activity data

License Plate	Sticker Type	Group	Time	Loc.	M_ type	Time	Loc.	M_ type	Time	Loc.	M_ type
01HJ361	Academic	Academic (Perm.)	07:54	A1	Entry	12:00	A4	Exit	---	---	---
01ZM025	Student	Local (2011)	15:05	A4	Entry	19:49	A4	Exit	21:26	A4	Entry
06AC1277	Admin.	Admin.	08:56	A4	Entry	16:15	A1	Entry	20:34	A4	Exit
01BJ651	Student	Local (2011)	14:30	A1	Exit	---	---	---	---	---	---

3.6 Assessment of Sustainable Campus Transportation Scenarios

As included in many campus policies, it is important to encourage walking and biking, and shared-ride options, while it is equally important to discourage private car usage (especially single occupancy case). Based on base case conditions on METU Campus, a set of selected following policies are analyzed in terms of emission impacts:

a) Introducing bike lanes on campus roads,
b) Reduction of in-campus private car use by students by implementing transport demand management implementations,
c) Peak-hour policies to reduce short-stay trips during peak hours,
d) Directing Technopolis workers to A7 gate totally,
e) Modal shift after the metro station opening

While the first policy is totally focusing on encouragement of a non-motorized mode, the remaining ones are aimed to reduce private car carbon emissions. The whole methodology for sustainable campus scenario assessment is presented in Figure 3.7. The developed scenario was first assigned to the traffic network for the peak and off-peak hours separately (Step 3), and the speed profile of the road segments and vehicle-km were determined. According to the speed and vehicle-km values, corresponding emissions were calculated (Step 4). In Step 6, the change in vehicle-km and reduction in carbon emissions were examined and assessed.

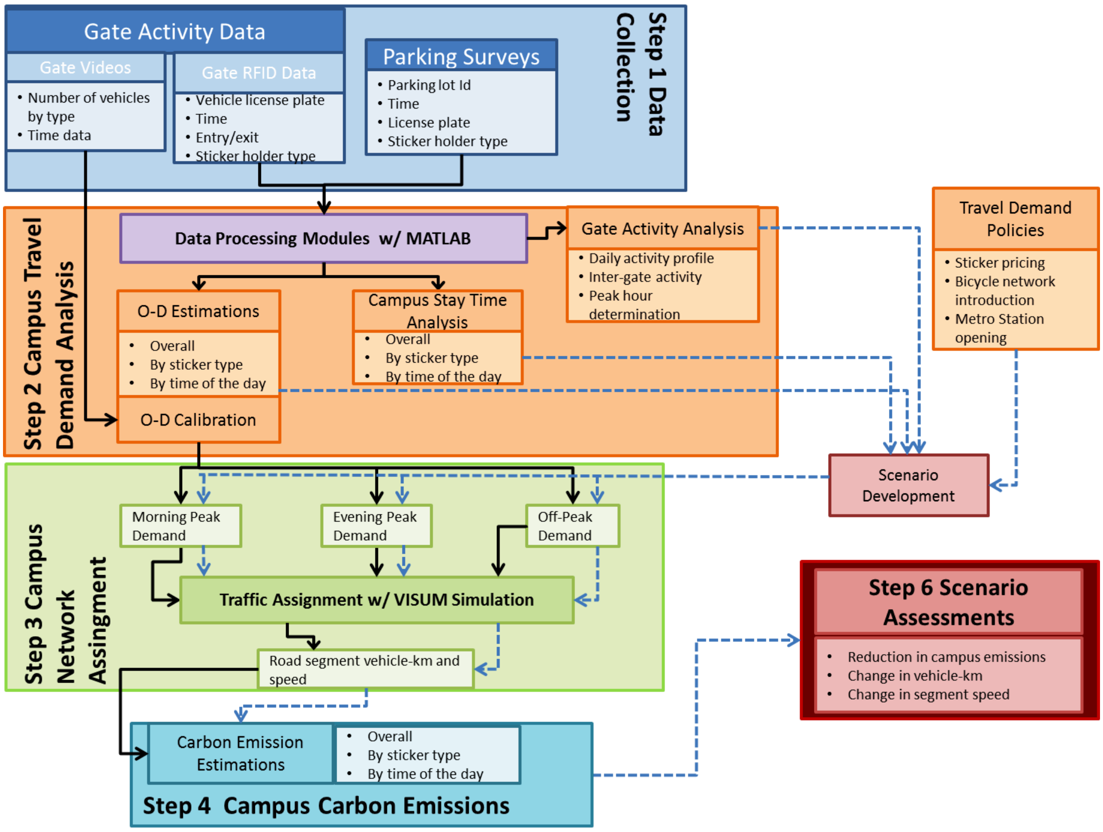


Figure 3.7 Details of proposed simulation-based methodology for sustainable campus policy assessment

CHAPTER 4

METU CAMPUS TRAVEL DATA

4.1 Campus Traffic Analysis Zones (C_TAZ)

METU has five campus entry locations (called gates) actively used. Three main gates are A1, A4 and A7 (see Figure 1). The remaining two are the gates used by people working in Technopolis (A8 and A7_Tech). The location of A7_Tech gate is independent from main campus gates and does not contribute any traffic to campus; thus is not included in any analysis in this study. However, A8 gate is in inside the campus and vehicles that use this gate, must use one of three main gates. Therefore, it is assumed as an internal control gate as shown in Figure 4.1.

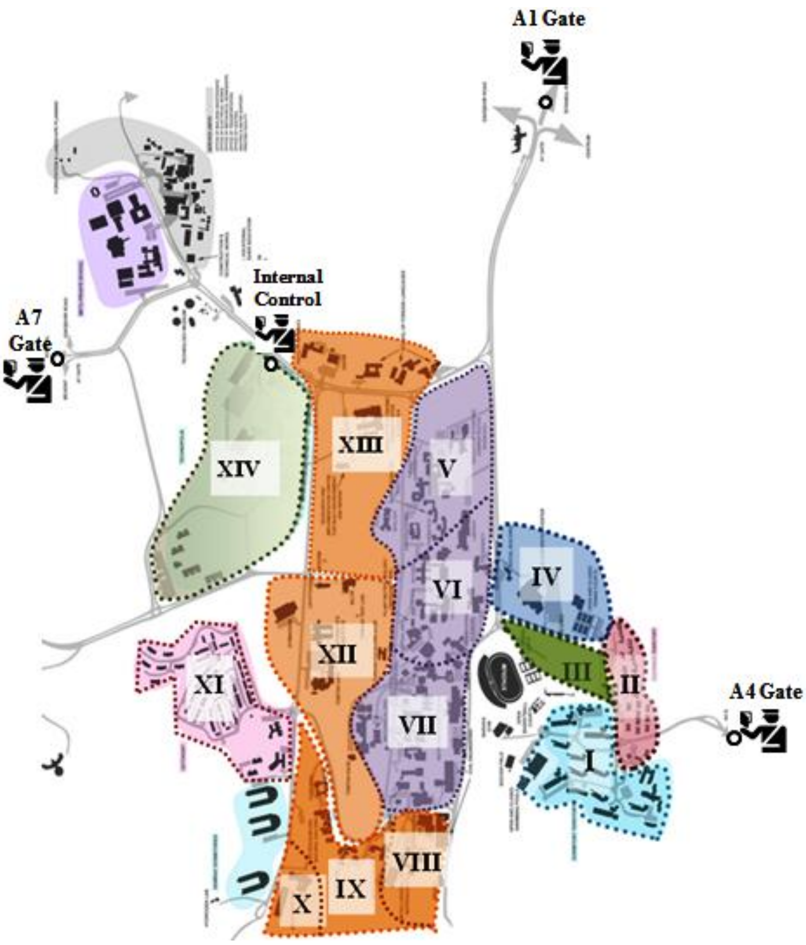


Figure 4.1 The layout of METU campus with CTAZ

Land use of the campus settlement area has changed greatly, especially over the last decade. To describe the change in land use the campus area is divided into 14 traffic analysis zones, called "campus traffic analysis zones (CTAZ)". Originally, the campus was developed as a big loop of academic units (core campus regions V, VI and VII in Figure 4.1), with an undivided two-lane road around it. CTAZ VIII is developed over time mostly as a part of Civil Engineering Department.

The student population is approximately 24,500 with an in-campus dormitory with a capacity up to 6000 students, in Region I and Demiray Dormitories near Region XI. Housing for faculty and administrative staff members is available for approximately 250 families, in Region II and Region XI. In addition, social building , cultural and conventional center, shopping areas, banks, post office, eating places, sport centers (including gymnasiums, tennis courts, basketball and football fields, jogging trails, indoor and outdoor swimming pools) are available in METU campus (in Region III and IV).

More recently, a second loop (new campus regions of XII and XIII) is developed with a two lane undivided road. Besides these two big loops, the south part of campus was defined as extended campus area which was divided into three traffic analysis zones (Regions VIII, IX and X). Additionally, due to the increased private car use to access the Technopolis region, traffic to this region was encouraged to use A7 gate; and an internal gate (A8) which controls the movements between Technopolis and the rest of the campus. As this minor gate is not a campus main entry location, but merely a destination, it will only be shown to represent Technopolis in Region XIV. As the traffic in METU College and administrative units in the northeastern were not included in this study, these CTAZs were not numbered. CTAZs with designated areas are shown in Table 4.1.

Table 4.1 CTAZ with designated areas for METU campus

CTAZ	CTAZ Label	Designated Areas
I	Dormitory Territory	Dormitories (1-9, Parlar Vakfı, Samir Kırdar), Guesthouses (Osman Yazıcı, Faik Hızıroğlu, EBI, Sami Kırdar), Medical Center, Swimming pools, Gymnasiums (Baraka, Main)
II	Housing Territory	Faculty housing
III	Shopping Area	METU shopping center
IV	Social and Cultural Activity Center	KKM and Social building, Open and closed tennis courts
V	Core Campus North	Human Science, Mathematics, Biology , Faculty of Architecture, Faculty of Economic Administrative Sciences-I, Kinder garden
VI	Core Campus Center	Library, Engineering Science, Cafeteria, Presidency, Çatı, Chemistry, Industrial Eng., Statistics, Physics, Plant Biotechnology Research Lab.
VII	Core Campus South	Electric and Electronic Engineering, Computer Center, Computer Eng., Civil Eng., Hydromechanics Lab, Chemical Eng., Mechanical Eng.
VIII	Extended Campus Areas 1	Coastal and Harbor Engineering, Environmental Eng., Metallurgical and Mat. Eng.,
IX	Extended Campus Areas 2	Geological Eng., Mining Eng., Petroleum And Natural Gas Eng., Food Eng.,
X	Extended Campus Areas 3	Aerospace Eng.
XI	ODTUKENT	ODTUKENT Guest House 1&2
XII	New Campus South	Informatics Institute, TUBITAK, Biltir, ODTUKENT sport center, Cryptography, Crash test lab.
XIII	New Campus North	Faculty of Economic Administrative Sciences-II, Research and Implementation Center for Build Environment, Foreign Languages, Faculty of Education
XIV	Technopolis	Technopolis

4.2 Campus Network Attributes

Current METU campus road network is illustrated in Figure 4.2. The road segments were drawn with different thickness to show the different number of the lanes. The thick black lines indicate two lane divided urban road which have a length of 2.58 km with a speed limit 50 km/h. However, the road segment with an arrow represents one direction urban road (2.0 km length) with a two lane and a speed limit of 30 km/h. The thin black colors indicate the undivided two lane urban road with a speed limit of 30 km/h. Its length is approximately 8.85 km. Finally, the gray colors represent parking lot connectors with a speed limit of 5 km/h. Totally, campus road length was calculated as 20.92 km (including the length of parking lot connectors).

METU has 79 different parking lots with various capacities. Each department has more than one parking lots which are dedicated to academic personnel and students, separately, and parking lots capacities are generally ranges from 0 to 25, 25 to50, 50 to 75. The layout and capacities of parking lots in CTAZs is shown in Figure 4.3, and its capacities are given in Table B.1. The total parking capacity of METU campus was determined as 3614 vehicles.

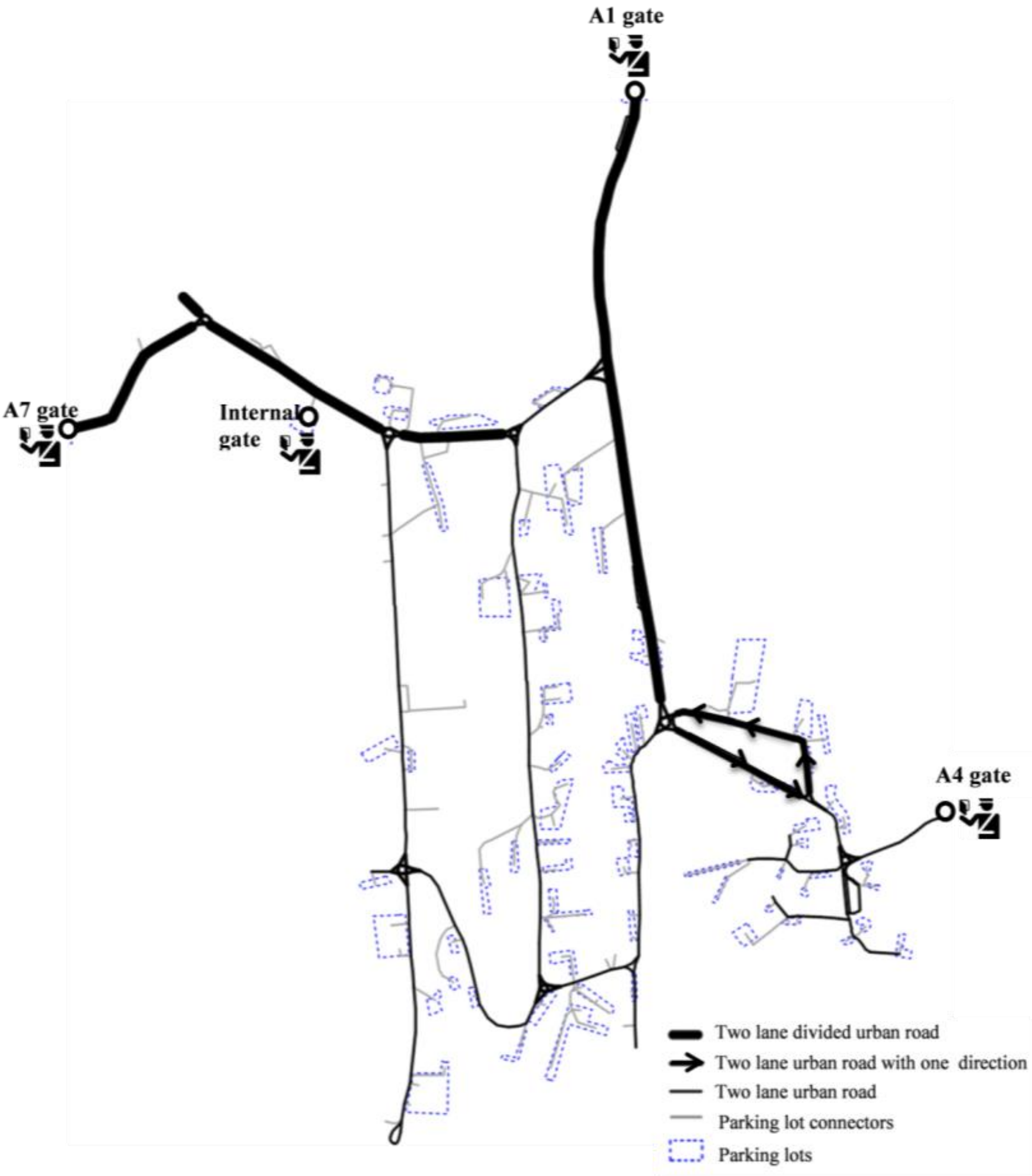


Figure 4.2 METU campus study road network structure

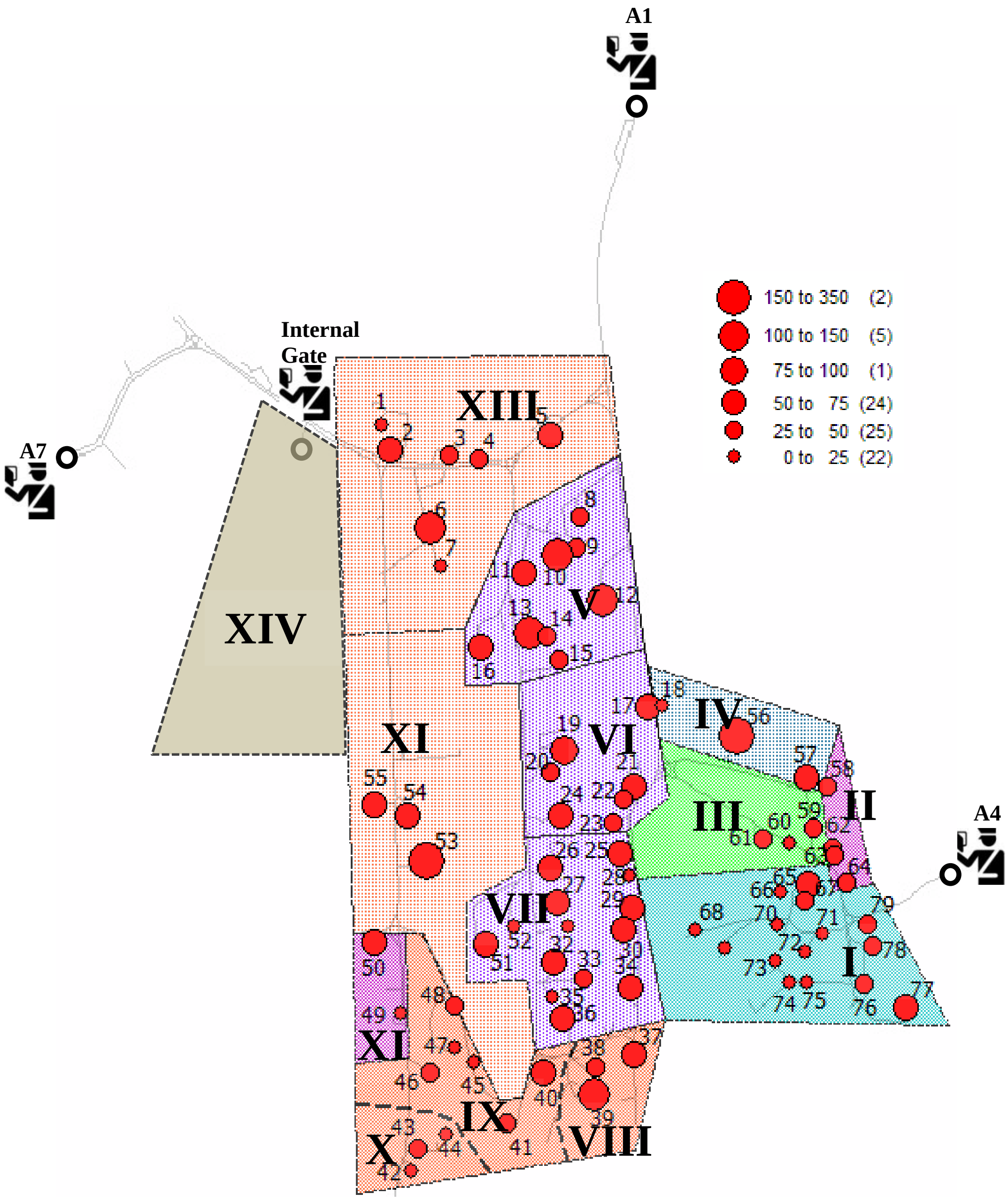


Figure 4.3 Location and capacities of parking lots in METU campus

4.3 METU Campus Travel Data Summary

Travel data was mainly obtained by utilization of data from existing gate control systems, such as the radio frequency identification system (RFID) and video recordings, with supplemental data collections via parking lot surveys.

The RFID system data were taken on two Wednesdays (Nov 10, 2010 and May 4, 2011), during which parking lot surveys were also performed. In addition, RFID system data for a full week of 21-27 November 2011 were studied for control purposes. To evaluate the accuracy of gate RFID system, gate video records were taken on another Wednesday (October 19, 2011). The data collection dates and data collection types are summarized in Table 4.2.

Table 4.2 Data collection dates and types

Date	Gate Activity Data		Parking Survey
	(RFID)	Video	
4 May 2011	YES	---	08.30-09.30 10.30-11.30 12.30-13.30 16.30-17.30
10 Nov 2010	YES	---	10.30-11.30 13.30-14.30 15.30-16.30
19 Oct 2011	NO	YES	---
21-27 Nov 2011 (Control data)	YES	---	---

4.3.1 Gate Activity Data

The gate activity profile of a campus in a day is obtained by taking the 24hr gate RFID data from all four gates, and video records from main gates. These data sources and their characteristics are summarized in the following subsections.

<u>RFID Based Gate Data</u>

Although it is an easy way to collect data, RFID system has some drawbacks. The system malfunctions may miss an entry or an exit, or record multiple entries for the same vehicle movement. Additionally, a visiting vehicle or a non-campus taxi without an RFID card sticker is not recorded in the database. Therefore, such problems cause unmatched movements among gate data, and underestimation of campus mobility. In addition, the analysis of the data showed that there had been a reading problem at the exit lanes of A1 gate, causing a biased in the gate activity calculations by RFID data. For this reason, gate video camera data was used to verify the RFID system data and to determine the exact number of entries and exits to the campus.

In the RFID system, eight major sticker types are used on METU campus. These are academic, administrative and student stickers, stickers for graduate students, guesthouse (provided for academic personnel’s family who live on campus), METU foundation school sticker, Technopolis, and guest stickers. Furthermore, these sticker types are divided into sub-groups that are summarized as follows:

- **Academic Stickers:** It is divided into two groups, permanent academic, and temporary academic. Permanent academic are provided for university instructors, professors and emeritus instructors whereas, temporary academic sticker is provided for part-time instructors and research assistants. They are allowed to use all three main gates.

- **Administrative Stickers:** Again it is divided into two groups; permanent administrative and temporary administrative. Similarly, permanent administrative stickers are dedicated for full time admins whereas the other one is only for temporarily administratives.

- **Student Stickers:** There are two types; Yellow sticker and brown sticker. The difference between these sticker types is; a vehicle with a yellow sticker type may park the department parking lots whereas, a vehicle with a brown sticker may only park in certain parking lots.

- **Graduate Student Stickers:** This sticker is given to METU alumni.

- **Guest Sticker:** This type of sticker is given for taxies and *dolmus*, and sport club, swimming pool members coming from other locations and people who work in campus such as bank personnel, Moreover, it is given to the families of student who bring his/her children to the campus but not parked anywhere. This type of stickers can only use A1 and A4 gates.

- **Technopolis Stickers:** These stickers are given to the Technopolis workers who are just allowed to use A4 and A7 gates.

- **Mustafa Parlar Foundation Stickers:** These stickers are dedicated on Mustafa Parlar Foundation, KOSGEB and ODTU-UZAY workers.

  METU Foundation Sticker: These stickers are given the guardians of METU college students. They can only use A4 and A7 gates.

Gate Video Camera Data

Gate video camera recordings from the main 3 gates for a 24-hr period were taken on another Wednesday (19 October 2011). It was deciphered manually providing vehicle type based statistics (private car, taxis, minibuses, buses and others) without the license plate numbers for every 15-minute counts (see Figure 4.4). This way, it was possible to verify independently;

- daily number of vehicles entering or exiting by type
- exit/entry profiles of each gate
- peak hours

When compared with RFID based data, video recording captured a higher entry-exit activity level, with or without sticker, read or unread activities. Furthermore, the analysis of the data showed that there had been a reading problem at the exit lanes of A1 gate, causing a biased in the gate activity calculations by RFID data, which was corrected based on video data recordings.

Figure 4.4 Screenshot of gate video camera from main gate

4.3.2 Comparison of Gate Data

Table 4.3 shows that video records revealed an almost equal numbers of entering and exiting movements at the campus gates, while RFID traffic counts presented seriously fewer numbers of exits on both survey days and the control week. A gate-based analysis revealed that the problem mostly occurred at gate A1, which had significant fewer number of exits recorded (this has to be corrected in the O-D estimation step.) Furthermore, comparing the total number of entries (which are more reliable for the RFID counts) showed that, there were around 10000 per day recorded in the RFID system, while in video records this number was around 15000 per day. The difference was probably the entries by non-sticker holders. Thus, the travel demand forecasted using the RFID data must be scaled up to a more realistic level.

Table 4.3 Comparisons of gate movements from RFID and video recordings

		Gate RFID data						**Gate video data**	
		Nov 10, 2010 (Wed)		**May 4, 2011 (Wed)**		**23 Nov, 2011 (Wed)**		**19 Oct, 2011 (Wed)**	
Total	Entry	9522		10065		12191		15280	
	Exit	6034		6422		7117		14828	
Δ= Entry-Exit		3488		3643		5074		452	
	Gate-based								
Gate		#	ratio	#	ratio	#	ratio	#	ratio
A1	Entry	3672	**3.55**	3317	**4.2**	5354	**3.6**	5746	**0.94**
	Exit	1032		784		1482		6066	
A4	Entry	3720	1.2	4375	1.2	4116	1.2	5839	1.01
	Exit	3071		3675		3562		5777	
A7	Entry	2130	1.1	2373	1.2	2724	1.3	3695	1.24
	Exit	1932		1963		2076		2985	

4.3.3 Parking Lot Surveys

While RFID data provides gate-to-gate mobility information, most of the trips end somewhere in the campus before they are destined to another gate. To find in-campus travel demand, it is required to determine both origin and destination information for every trip, which was supported by parking lot counts. For this purpose, on the days of RFID data collection of 10 Nov 2010 (in 3 periods at 09:30-10:30, 12:30-13:30, 15:30-16:30) and 4 May 2011 (in 4 periods at 08:30-09:30, 10:30-11:30, 12:30-13:30, 16:30-17:30) vehicles parked in 79 campus parking lots were counted to get their license plates and locations.

The occupancies of parking lots for different periods are illustrated in Table B.2 for Nov 10,2010 and Table B.3 for May 4, 2011 parking surveys. The results are as follows:

- For the morning time;
    - at 08:30-09:30, parking lot occupancy rate was found as 38.1%
    - at 10:30-11:30, parking lot occupancy rate was 70.4% for the spring survey, 73.2% for the winter survey
- For the noon time;
    - at 12:30-13:30, parking lot occupancy rate was 74.6 % for spring survey,
    - at 13:30-14:30, parking lot occupancy rate was 78.5 % for winter survey
- For the afternoon time;
    - at 15:30-16:30, parking lot occupancy rate was 75.2 % for winter survey
    - at 16:30-17:30, parking lot occupancy rate was 61 % for spring survey

Additionally, 85+% occupancy rates of each parking lot were also calculated for each parking survey periods separately and illustrated in Figure 4.5 for Nov 10, 2010 survey day, and Figure B.1 for May 4, 2011 survey days.

It was found that campus parking lots reach maximum occupancy rate at noon times with an approximately 76% vehicle occupancy. This percentage is not much more for the whole campus but there has been serious parking problem in METU campus because the distribution of vehicles into parking lots showed great differences. For example, parking lots in the core campus (especially Regions VI and VII) are heavily congested with illegal parking along the parking lot roads, and the large parking lot of the Cultural and Convention Center (CCC) in Region IV was full during lunch hours due to food courts in the CCC and Regions II and III. It was difficult to find any empty space for parking. However, for the new campus region, (Regions XII and XIII) it was not as crowded as Core Campus Region; only education faculty and foreign languages parking lots were full capacity during the day and TUBITAK parking lots showed more than 85% occupancy rate for the first two counting hours on May 4, 2011 (see Appendix B) . Furthermore, parking lots in Region VIII, IX and X, just Geological Engineering and Metallurgy and Materials Engineering parking lots exceed 85% capacity during the day for the first survey day (Nov 10, 2010). However for the second survey day (May 4, 2011), it was not exceeding the limits. Parking lots in Region XI did not reach more than 85% occupancy for both survey days.

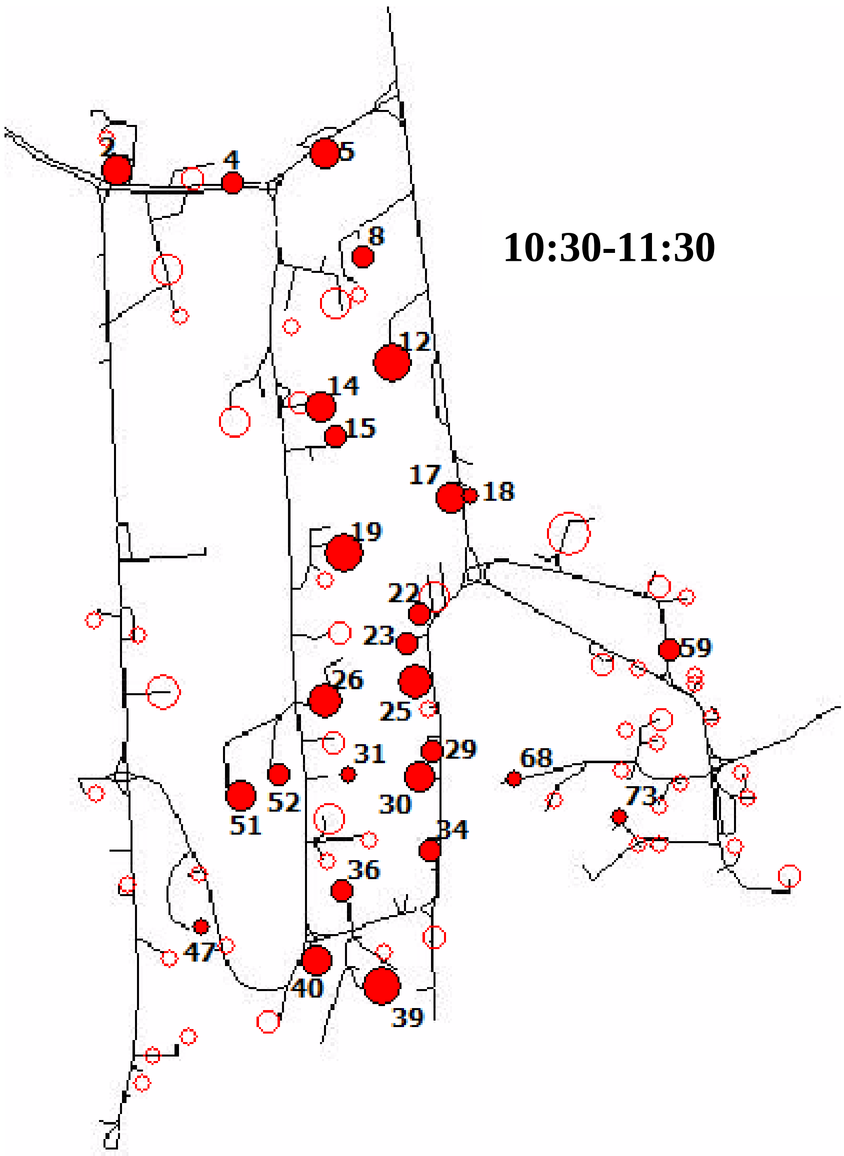


Figure 4.5 85+% Parking lot occupancy rate of METU campus at 10:30-11:30 parking survey on Nov 10, 2010

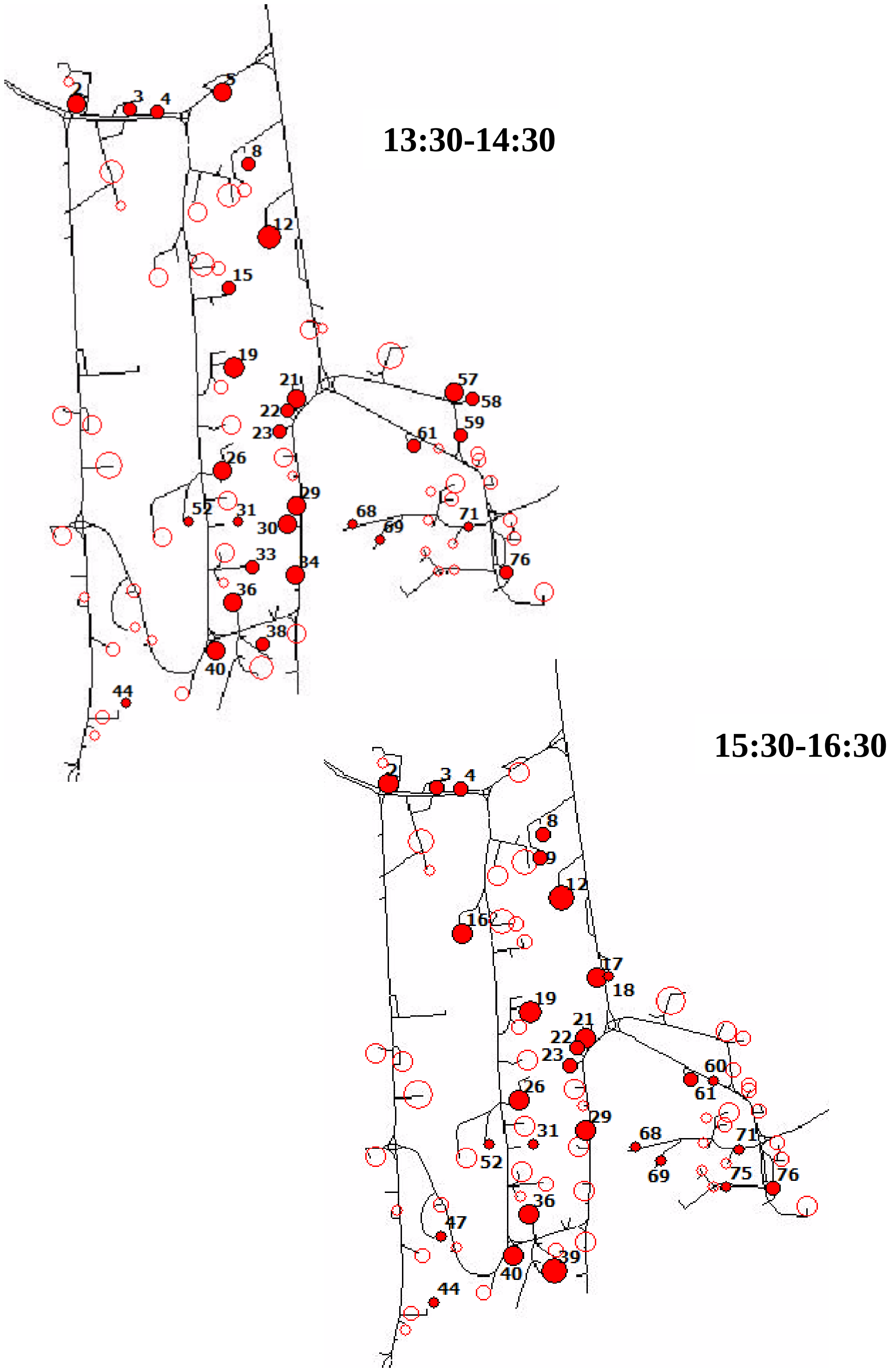


Figure 4.5 85+% Parking lot occupancy rate of METU campus at 13:30-14:30 and 15:30-16:30 parking surveys on Nov 10, 2010 (cont'd)

CHAPTER 5

CAMPUS TRAVEL DEMAND ANALYSIS

5.1 Gate Activity Analysis

Using a 24-hr RFID data of the three main campus gates, entry and exit (and daily, which is the sum of the two) profiles at the gates are created. 15-min analysis of these movements enabled the detection of the peak hours at the gates. Furthermore, distribution of the entries and exits by sticker holder type revealed insights on the commute behavior of these groups.

5.1.1 Gate Activity Profiles

The gate activity on campus can be analyzed by using different measures. First, using a weeklong RFID data, campus entry&exit profiles of METU campus, which are the summation of entries, and exits, respectively from all 3 gates are examined. Figure 5.1 represents the entry profile of METU campus; while there is a limited entry demand from midnight to 06:00, a major entry demand is observed between 07:00-09:00; around 3000 entries are recorded in this time interval. After this time, it gradually decreases until 12:00 and entry to campus continues almost at a constant level and, after 18:00, it starts to decrease significantly. Figure 5.2 shows the exit profile of METU campus. Again, there are very few exits until 07:00, after which, the number of exiting vehicles increases and first peak is seen around 08:00-09:00 with 1500 exits. The second peak is seen at noon times (12:00-13:00) with 1200 exits. The highest exit demand is in a scattered nature, starting from 15:00 to 19:00. The highest volume is observed between 17:00-18:00. Over 2300 exits are recorded in this time interval. After 19.00, the number of exiting vehicles gradually decreases. Both profiles show a strong commute nature for a workplace with some additional trips of “home,” which are performed most likely by the family member of staff on campus.

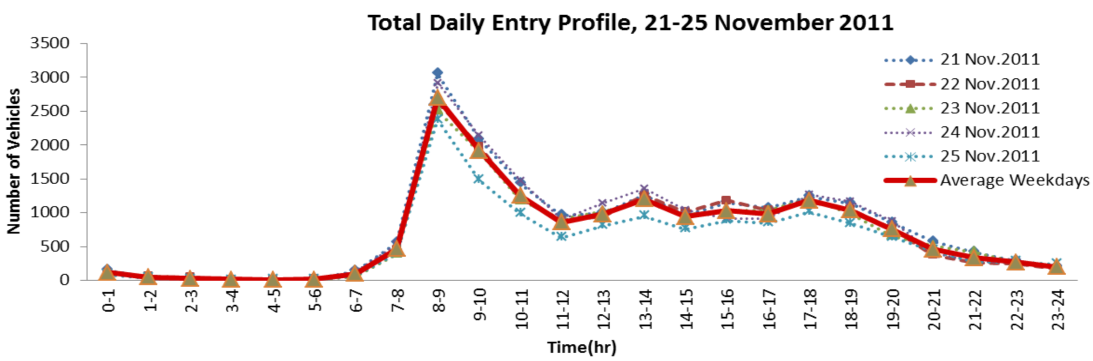


Figure 5.1 Total daily entry profile of METU campus including all entries from three main gates

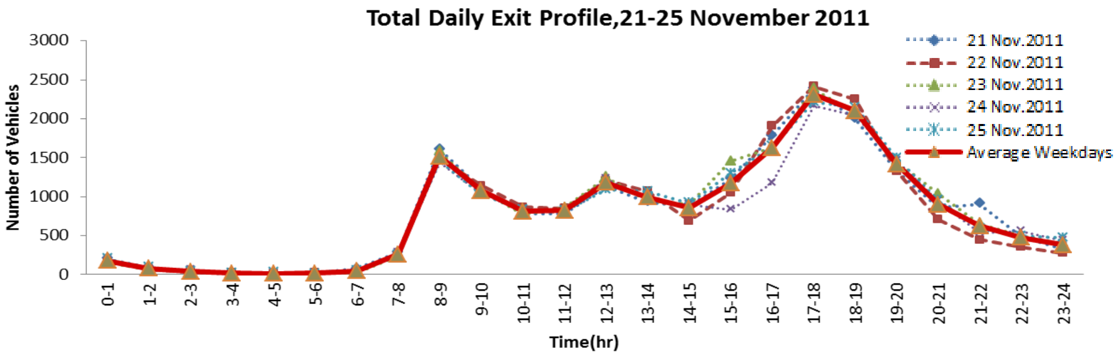


Figure 5.2 Total daily exit profile of METU campus including all exits from three main gates

Finally, the total daily profile of the campus (sum of all entries and exits from the three main gates) is shown with an average weekday profile in Figure 5.3. In this profile, significant travel is observed between 07:00 to 22:00. It sharply increases and reaches the peak value at 08:00-09:00 in the morning. Later, travel activity decreases and shows a relatively small peak between 11:00-14:00. After 15:00 pm traffic activity increases because of the increase of the exiting vehicles. Evening peak hour is observed at 17:00-18:00.

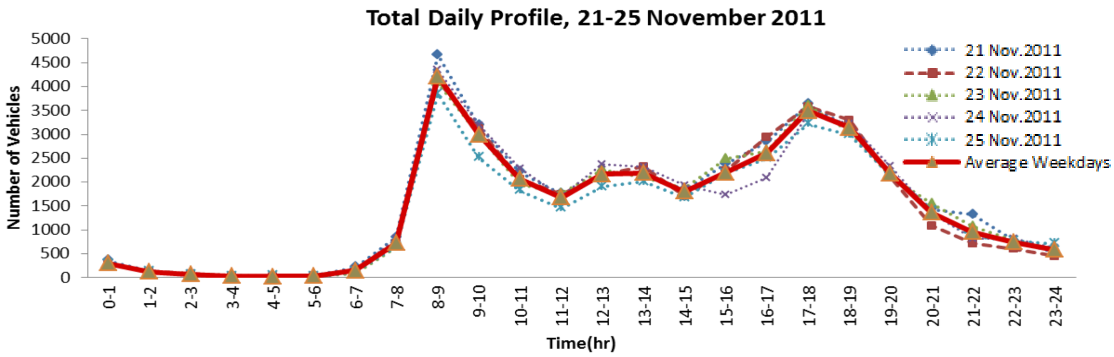


Figure 5.3 Total daily profile of METU campus including all entry-exit from three main gates

Furthermore, it is important to analyze entry and exit profiles of main gates to capture their usage in access to campus. For this reason, entry and exit profiles on both survey days and control weeks (see Appendix C) were drawn by gate. The results showed that A1and A4 gates are used more actively than A7 gate. For entry, A1and A4 gate are used more between 07:00-22:00, whereas A7 gate is used only in morning hours. For exit, A1 and A4 gates are mostly preferred by vehicles as an exit during the day. However, A7 gate is active only morning and evening peak hours.

A weekly gate activity profile of METU campus is illustrated in Appendix C, showing variations among different days of the week. Figure C.15 indicates the average weekdays and weekend entry profile that there are fewer number of vehicles entering to campus as expected at the weekend. Morning peak hour shifts to 09:00-10:00, and entering to campus continues with an almost constant level until 17:00-18:00 and then it decreases. On the other hand, weekend exit profile shows that again, morning peak hour shifts to 09:00-10:00 and exiting to campus is continuously increase until 17:00-18.00. As weekend traffic is much smaller and does not include much commute travel, it will not be included in the analysis of this study.

5.1.2 Determination of Peak-Hour

To determine peak hour more precisely, it is required to study variations on shorter periods. A 30-minute total daily traffic volume graph was drawn starting from 06:00 to 22:00 for survey, control and video recording data (see Figure 5.4). This revealed the potential location of morning and evening peaks between 07:30-09:30 and 17:00-18:30. A further analysis of traffic counts in 15-minute time intervals are shown in Table 5.1. For Nov 10, 2010 RFID data, peak-hour volume (PHV) was reached at 08:00-09:00 time interval with a total of 2078 vehicles (1582 entering and 496 exiting); and, evening peak volume was reached at 17:15-18:15 time interval with 1368 vehicles (603 entering and 765 exiting). For the May 4, 2011, PHV was reached at 08:15-09:15 time interval with 2476 vehicles (1946 entering and 530 exiting). Evening peak volume was reached at 17:15-18:15 with 1472 vehicles (630 entering and 832 exiting). Furthermore, the control week of the Wednesday of RIFD data showed similar results that peak hours was found as 08:15-09:15 and 17:15-18:15 for morning and evening times. On the other hand, video recording data showed morning peak at 08:15-09:15 with 4307 vehicles and evening peak at 17:30-18:30 with 2977 vehicles. While the peak times are similar, PHV from video records reflect also non-sticker entries that they should be considered to reflect real values more. As a conclusion, in-campus morning peak hour was selected as 08:15-09:15 and evening peak hour was selected as 17:15-18:15.

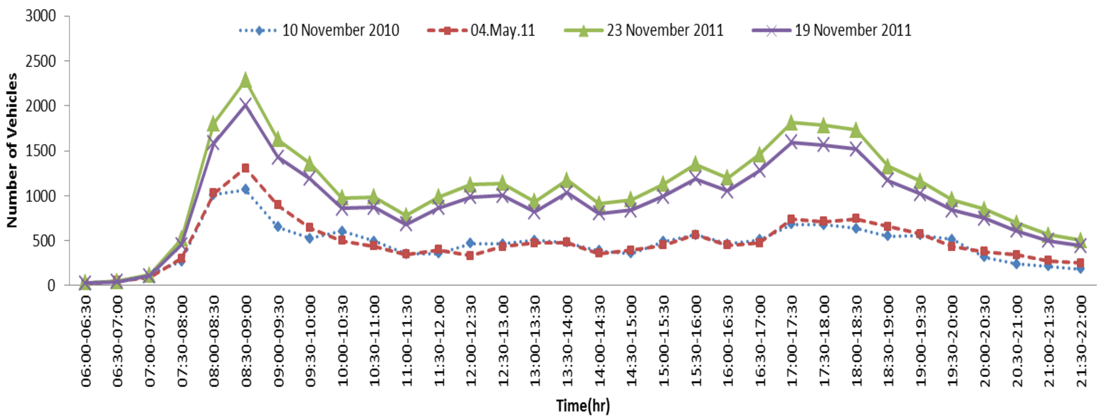


Figure 5.4 Total daily profiles for 30-minute time interval in a day

Table 5.1 Morning and evening period peak hour analysis (15-minute time intervals) from survey, control and video recording days

Time period	**Nov 10, 2010**			**May 4, 2011**			**Nov 23, 2011**			**Video Recording**		
	Entry	**Exit**	**Total**	**Entry**	**Exit**	**Total**	**Entry**	**Exit**	**Total**	**Entry**	**Exit**	**Total**
07:45-08:00	137	43	180	154	32	186	215	129	344	269	68	337
08:00-08:15	**292**	**82**	**374**	281	71	352	466	232	698	510	170	673
08:15-08:30	**503**	**135**	**638**	**537**	**137**	**674**	**730**	**376**	**1106**	**857**	**307**	**1155**
08:30-08:45	**436**	**165**	**601**	**544**	**183**	**727**	**688**	**489**	**1177**	**833**	**398**	**1236**
08:45-09:00	**351**	**114**	**465**	**462**	**117**	**579**	**624**	**483**	**1107**	**646**	**367**	**1024**
09:00-09:15	269	58	327	**403**	**93**	**496**	**530**	**313**	**843**	**665**	**235**	**892**
09:15-09:30	259	63	322	329	72	401	520	260	780	545	257	803
. . .												
17:00-17:15	**160**	159	319	150	171	321	**304**	584	888	233	447	680
17:15-17:30	**171**	**191**	**362**	174	**243**	**417**	**305**	**620**	**925**	257	501	758
17:30-17:45	**143**	**208**	**351**	137	**213**	**350**	**307**	**623**	**930**	**243**	**519**	**762**
17:45-18:00	**145**	**183**	**328**	**164**	**197**	**361**	**299**	**553**	**852**	**232**	**473**	**705**
18:00-18:15	144	**183**	**327**	**155**	**189**	**344**	265	**593**	**858**	**239**	**492**	**731**
18:15-18:30	148	162	310	**175**	221	396	267	605	872	**264**	**515**	**779**
18:30-18.45	122	143	265	**139**	198	337	217	479	696	198	390	588
18.45-19.00	147	136	283	161	158	319	237	393	630	214	334	548
. . .												
Peak Hours a.m. p.m	**08:00-09:00 17:15-18:15**			**08:15-09:15 17:15-18.15**			**08:15-09:15 17:15-18:15**			**08:15-09:15 17:30-18:30**		
	a.m.	p.m.		a.m.	p.m.		a.m.	p.m.		a.m.	p.m.	
Hourly Volume	**2078**	**1368**		**2476**	**1472**		**4233**	**3565**		**4307**	**2977**	

5.1.3 Gate Activity by Sticker-Holder Type

Among the sticker holder groups summarized in Section 4.3.1, the number of graduate student stickers and Mustafa Parlar foundation stickers were not significant enough and the travel behavior of Technopolis workers is not within the scope of this study; thus, they were not examined separately. Moreover, vehicles with a METU foundation sticker were generally active only morning and afternoon hours to drop off/pick up the children to/from the college. This study focused on travel behavior analysis of main traveler groups as academic staff, administrative personnel and students.

Furthermore, guest stickers (especially taxies and *dolmus*) also played an important role so it was also studied. For this reason, gate RFID data and video recording data were used to analyze the travel behavior of university community, and results are shown in Table 5.2.

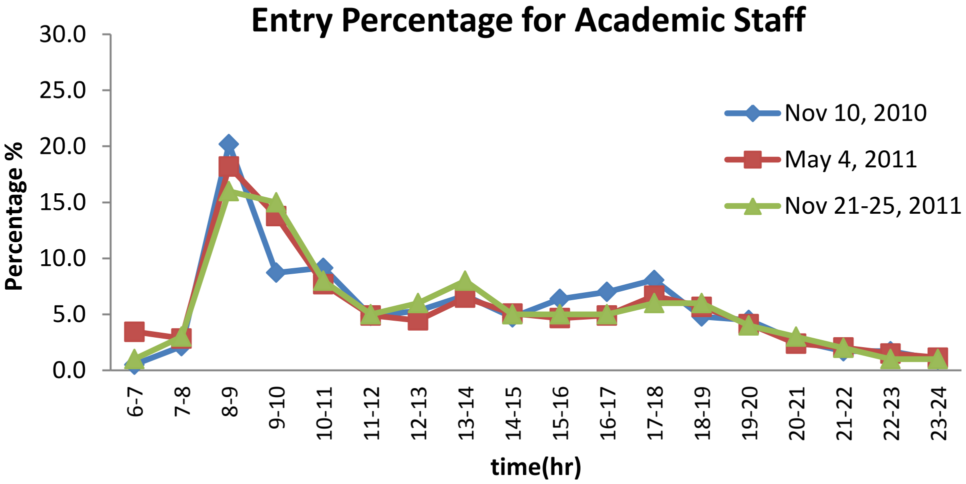
Table 5.2 Sticker types and distributions in survey, control, and video recording data

	Nov 10, 2010	**May 4, 2011**	**Nov 23, 2011**	**Oct 19, 2011**
Daily Total Activities (gate RFID data)				**(Gate video recordings)**
Entry	9522	10065	12191	15280
Exit	6034	6588	7117	14828
Entry Activity by Sticker Type				
Academic Personnel	1585	2466	2845	
Administrative Personnel	954	992	998	---
Students	2087	2661	3041	
Taxi	624	638	783	1147
Dolmuş	---	202	327	357
Bus	---	---	---	211
Exit Activity by Sticker Type				
Academic Personnel	1514	1594	1803	
Administrative Personnel	549	563	600	---
Students	1161	1474	1587	
Taxi	343	371	440	1000
Dolmus	---	68	112	330
Bus	---	---	---	200

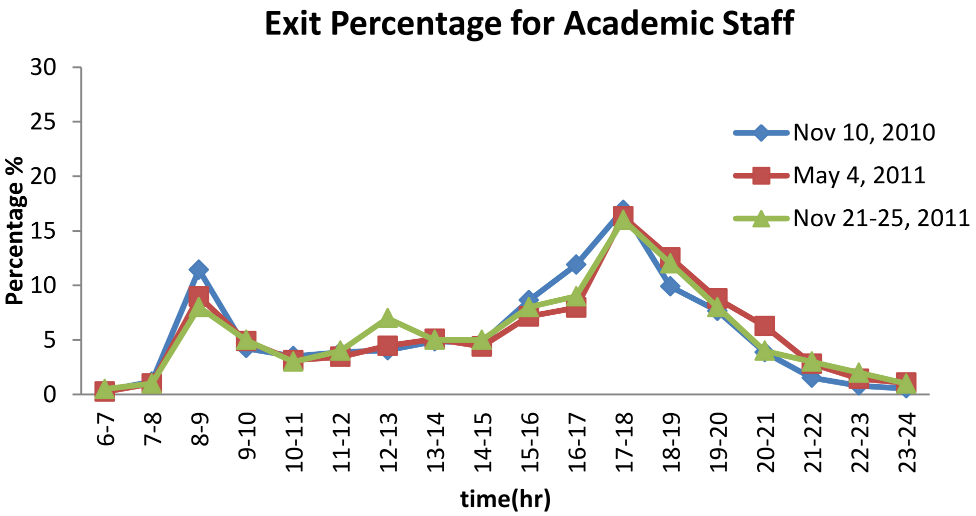
*Total, entry and exit values belong to 3 main campus gates information.

The number of entry and exit movements of different travelers was identified from RFID data, but it was not possible to determine them with video recording, separately. Also, the number of taxies obtained from video recording data was greater than the number of taxies in RFID data. This is expectable, because taxi sticker is given just for METU campus taxies, but many taxies are coming to the campus from other locations in a day. Although there was a defined sticker type for *dolmus*, the numbers of *dolmus* in video recordings are also greater than the RFID data values. This may result from reading problems at the gates. Furthermore, the number of entries and exits showed differences for *taxies* and *dolmus* for RFID data, this might be again the reading problem of the exit lane of A1 gate. Finally, the number of buses coming to the campus was not determined from RFID data because of no defined sticker type for EGO buses, so it was determined from video recording data.

Using the RFID data, characteristics of different traveler groups were examined from two Wednesdays and full week control data. Entry&exit profiles of academic sticker-holders in a day are shown in Figure 5.5. Among the 1585 entry records, approximately 20% of academic travelers arrive at the campus at between 08:00-09:00, and entry to campus continues during the day and small peak is seen at noon and evening time. Exit profile of academic sticker-holders show a small peak at 08:00-09:00, followed by even smaller peak at noontime. A major exit demand is observed during the evening hours, which starts from 15:00 and continues until 21:00. Among the 1514 exit records, 16% of academic traveler leaves the campus between 17:00-18:00 with 242 vehicles.



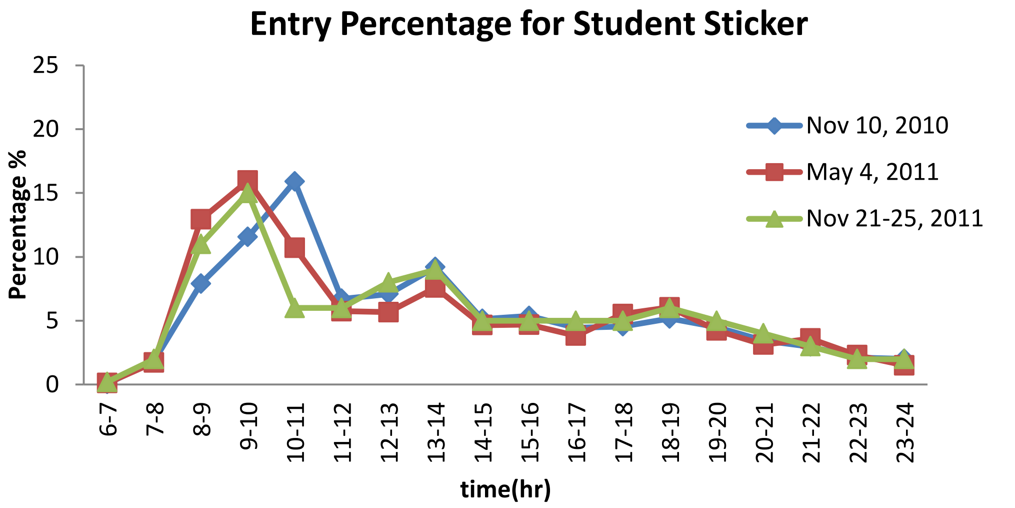
(a)



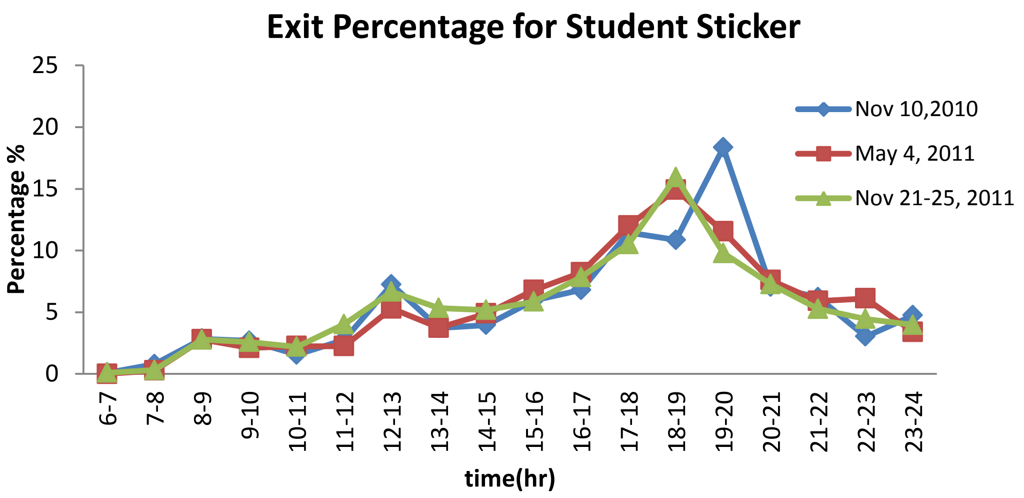
(b)

Figure 5.5 Hourly percent distribution of a) entry and b) exit movements in a day by academic sticker-holders

Exit and entry profiles of student travelers are shown in Figure 5.6. Entry to the campus starts to increase after 08:00 (except for November 10 results), morning peak is seen around 09:00-10:00. On November 10 results, it shifts to 10:00-11:00 because of the cancellation of the lessons for the first two hours due to the anniversary of Ataturk's death. On the analysis day of May 4, 2011, approximately 15% entries are performed at morning peak, after which, entries gradually decreases during the day. The exits of students start from 08:00 and gradually increase throughout the day. After that, they have again scattered evening peak that start from 15:00 to 20:00. Evening exit peak hour is seen at 18:00-19:00 on May 4, 2011 with approximately 16% of them exits, and 19:00-20:00 on Nov 10, 2010 data with approximately 19%.



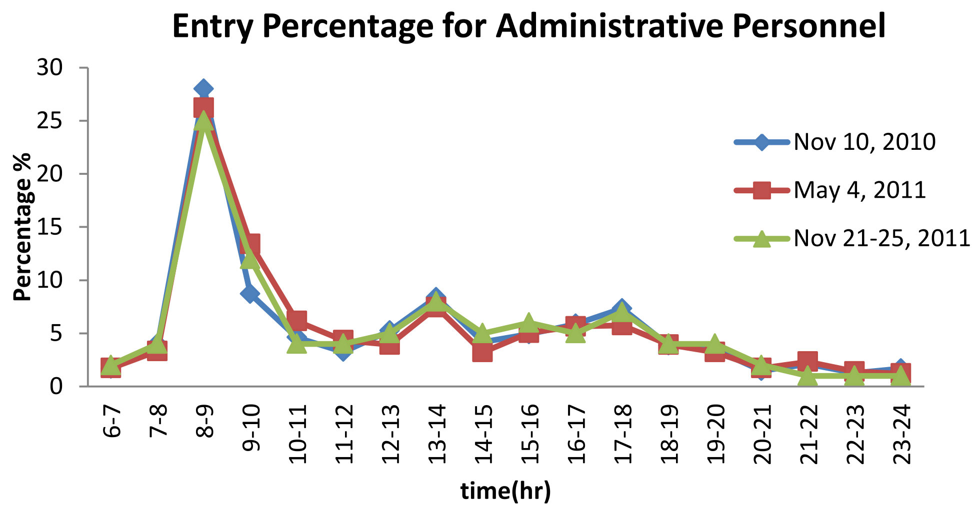
(a)



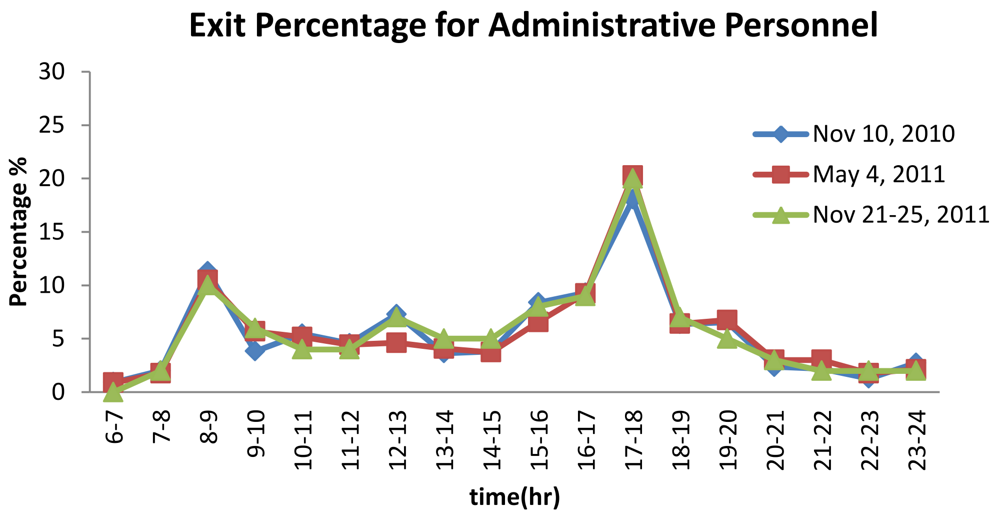
(b)

Figure 5.6 Hourly percent distribution of a) entry and b) exit movements in a day by student sticker-holders

The majority of administrative personnel (27%) arrive at the campus for the morning time at 08:00-09:00 (see Figure 5.7). While there is always a small entry demand at noon times, this is may be due to travel during lunch break. A small but persistent entry demand is observed until 18:00. For the exiting of administrative staff, the first peak is seen in the morning at 08:00-09:00, and small peak is seen at noon. Leaving the campus increases after 15:00 and reaches peak value at 17:00-18:00. This pattern shows the impact of more clearly defined working hours for administrative personnel.



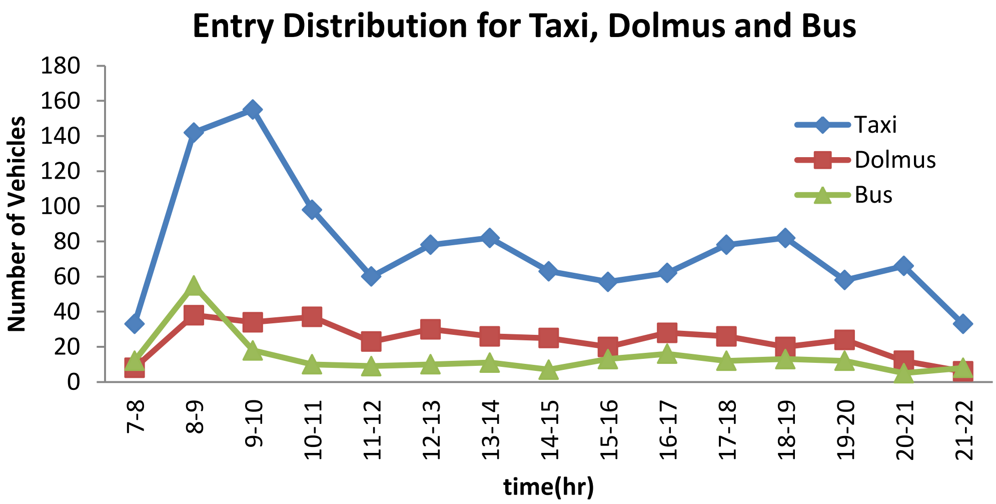
(a)



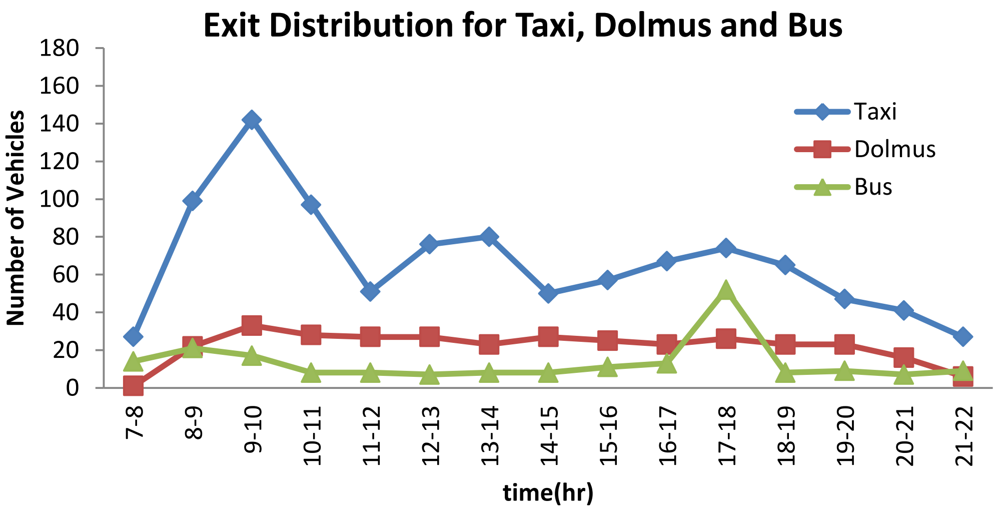
(b)

Figure 5.7 Hourly percent distribution of a) entry and b) exit movements in a day by administrative personnel sticker-holders

Furthermore, the other alternative transportation modes, such as taxi, bus and *dolmus* play an important role for the campus mobility. The gate profile of alternative transportation modes are seen in Figure 5.8. During the day, the taxi mobility has been considerably high, so it must be taken into consideration while creating campus transportation model. *Dolmus* is also important for METU campus; it shows uniform distribution during the day. Finally, buses are another important transportation mode and the number of buses entering the campus increases at morning peak hours. Similarly, the number of buses exiting the campus increases at evening peak hours.



(a)



(b)

Figure 5.8 Hourly distribution of a) entry and b) exit movements in a day for taxies, dolmus and bus (from video records)

5.2 Gate-to-Gate Mobility Analysis

To gain more insights about travel within METU campus, the gate activity data must be further studied. First step would be determination of the gate-to-gate trip information as mentioned in methodology section. For this purpose, gate RFID data were analyzed by using MATLAB program to identify matched trips (detected trips): A trip is matched if an entry and consecutive exit information for a vehicle are found. These trips are presented in the "detected" columns of Table 5.3. Unmatched movements were also seen during this process. In other words, a vehicle has a recorded entry but not recorded exit or vice versa. This situation may have several reasons: It may be due to the reading problem of RFID system or vehicle may stay overnight (a vehicle would have recorded exit, but not a recorded entry) or vehicle may enter to the campus, but not leave. Though the partial information reveals the trip, the missing information (exit or entry) must be guessed. Thus, these trips were defined as "guessed trips." Detailed gate-to-gate trip information for survey and control days is illustrated in Table 5.3. This process revealed a total number of 5500 to 6500 detected trips between gates for the selected count days. However, there are several missing entry or exit movements (almost half of the detected trips). This gate-to-gate analysis suggests a daily mobility of 8000-9000 trips in a day, based on the RFID data only.

Table 5.3 Gate-to-gate trip information for survey and control days

	10 Nov 2010		**4 May 2011**		**23 November 2011**	
	Detected	**Guessed**	**Observed**	**Guessed**	**Observed**	**Guessed**
Total	5680	3132	5997	3226	6505	3545
By Gate						
From A1						
To A1	512	---	339	---	589	---
To A4	**735**	---	**757**	---	**888**	---
To A7	334	---	265	---	318	---
To A8	149	---	143	---	134	---
To …	---	1176	---	1186	---	1564
From A4						
To A1	151		144	---	332	---
To A4	**1162**		**1540**	---	**1264**	---
To A7	420		458	---	481	---
To A8	429		495	---	487	---
To …		824		950		701
From A7						
To A1	68		54		158	
To A4	371		440		516	
To A7	**615**		**650**		**721**	
To A8	332		462		428	
To …		463		448		508
From A8						
To A1	50		16		39	
To A4	**314**		**197**		**116**	
To A7	38		37		34	
From …						
To A1		116		78		142
To A4		276		299		**351**
To A7		277		269		279

According to the Table 5.3, 2906 vehicles entered from A1 gate on Nov 10, 2010 and 735 of them exited from A4, 512 of them exited from A1 gate. Furthermore, 1176 vehicles had no exit records. For the same day, 2986 vehicles entered to campus from A4 gate, and 1162 of them exited from the same gate. However, only 151 vehicles were recorded at the A1 exit. Similarly, 1849 vehicles entered from A7 gate but only 68 of them were recorded at the A1 exit. Since A1 gate is the most active gate of METU, this number shows that there is a reading problem at the exit part of the A1 gate.

5.2.1 Gate-to-gate Mobility by Stay Time

Though it is important to understand the gate-to-gate mobility, it is also crucially important to understand how long the vehicles stay on campus. The stay time of a vehicle based on gate RFID data was calculated by matching an entry and an exit movement for a license plate, and then, simply taking the difference between the matched exit and the entry times. Further decomposition of these trips by stay time showed that majority of vehicles (almost 45%) stay in campus for less than 15 minutes (see Table 5.4). A second major group of travelers stay between 1-5 hours (almost 22%), which is more like a half workday time; checking the entry time of these stays did not reveal any specific entry time, which means vehicles staying up to 5 hours can enter at any time in a day. Finally, the third group of travelers staying 5-10 hours mostly start at 08:00-09:00 in the morning, suggesting that they may be academic or administrative staffs.

Table 5.4 Campus stay time distribution (gate data only)

	Number of Trips					
Campus Stay Time	**Nov 10, 2010**		**May 4, 2011**		**Nov 23, 2011***	
Total estimated trips	**8814**		**9223**		**10050**	
Total detected trips	**5680**		**5997**		**6505**	
Stay Time						
<15min	***2599***		***2635***		***2804***	
15-30min	*445*		*497*		*545*	
30min-1h	*420*		*452*		*489*	
1h-5h	***1301***		***1346***		***1465***	
5h-10h	***754***		***867***		***1029***	
10h +	*161*		*200*		*173*	
Trips with missing movements	**Entry**	**Exit**	**Entry**	**Exit**	**Entry**	**Exit**
	669	2465	643	2583	772	2773
	3134		**3226**		**3545**	

Campus stay time of vehicles by entry time was also analyzed and showed similar results for all Wednesday days (see Table 5.5 and 5.6 for short and long stay trips). Among short stay trips, approximately 30% of vehicles entered to campus between 08:00-10:00 and 46% these vehicles were staying less than 15 minutes. The short stay ratios were even higher for the other time intervals. For example, this ratio was 27% for 11:00-12:00 and 30% for 14:00-15:00 time interval. For the evening peak, again this ratio raised to 56%. Short stays, which were 15-30 minutes and 30 minutes-1 hour, did not show any dominant entry time interval.

Table 5.5 Campus stay time of vehicles by entry time for short stays (up to 1 h)

	Number of Vehicle (Entry)			Stay Time								
				0-15min			15-30min			30min-1h		
Entry time	**Nov 10, 2010**	**May 4, 2011**	**Nov 23, 2011**	**Nov 10, 2010**	**May 4, 2011**	**Nov 23, 2011**	**Nov 10, 2010**	**May 4, 2011**	**Nov 23, 2011**	**Nov 10, 2010**	**May 4, 2011**	**Nov 23, 2011**
7-8	175	180	177	96	103	78	9	10	1	5	8	10
8-9	**971**	**1147**	**1210**	491	568	573	45	47	75	24	31	30
9-10	**596**	**753**	**821**	239	307	320	28	29	27	25	24	30
10-11	**463**	388	**414**	122	98	90	26	22	23	33	19	27
11-12	290	289	319	77	73	85	24	24	26	26	29	30
12-13	346	261	394	134	78	107	25	19	21	26	18	30
13-14	**433**	**431**	**465**	176	181	174	24	24	26	31	20	30
14-15	291	287	378	88	91	109	31	28	38	38	49	64
15-16	337	312	**415**	129	109	159	47	60	77	47	40	54
16-17	312	309	393	149	123	181	35	38	65	29	49	49
17-18	375	**415**	**494**	225	227	308	41	43	63	21	38	26
18-19	**421**	**429**	393	265	242	251	46	44	36	24	42	23
19-20	265	248	212	158	124	116	31	39	25	28	28	27
20-21	152	181	167	78	108	109	15	35	18	26	10	14
21-22	88	121	92	54	63	56	4	11	11	21	27	18
Total (15 hrs)	**5515**	**5751**	**6344**	**2481**	**2495**	**2716**	431	473	532	404	432	462

For the long stay trips, which were defined as more than 1hour is illustrated in Table 5.6. The stays up to 5 hours did not show dominant entry time interval. For the entries between 08:00-10:00, 14% of total travelers stayed in campus up to 5 hours. The other long stays that are 5 hours to 10 hours, or more than 10 hours were majorly observed at morning entries, as expected. Approximately, 25% of the vehicles entering to campus between 08:00-10:00 stayed 5-10 hours, while only 5-7% of vehicles stayed more than 10 hours.

Table 5.6 Campus stay time of vehicles by entry time for long stays (more than 1 h)

	Number of Vehicle (Entry)			Stay Time								
				1h-5h			5h-10h			10+h		
Entry time	**Nov 10, 2010**	**May 4, 2011**	**Nov 23, 2011**	**Nov 10, 2010**	**May 4, 2011**	**Nov 23, 2011**	**Nov 10, 2010**	**May 4, 2011**	**Nov 23, 2011**	**Nov 10, 2010**	**May 4, 2011**	**Nov 23, 2011**
7-8	175	180	177	24	17	26	23	24	38	18	18	24
8-9	**971**	**1147**	**1210**	110	139	141	240	285	322	61	77	69
9-10	**596**	**753**	**821**	104	141	134	150	204	261	50	48	49
10-11	**463**	388	**414**	131	100	125	138	120	133	13	29	16
11-12	290	289	319	84	79	87	72	74	88	7	10	3
12-13	346	261	394	105	104	163	54	42	71	2	---	2
13-14	**433**	**431**	**465**	154	152	185	48	54	50	---	---	---
14-15	291	287	378	116	95	142	18	24	25	---	---	---
15-16	337	312	**415**	107	94	111	7	9	14	---	---	---
16-17	312	309	393	93	93	91	6	6	7	---	---	---
17-18	375	**415**	**494**	85	99	92	3	8	5	---	---	---
18-19	**421**	**429**	393	86	99	78	---	2	5	---	---	---
19-20	265	248	212	48	57	44	---	---	---	---	---	---
20-21	152	181	167	33	28	26	---	---	---	---	---	---
21-22	88	121	92	9	20	7	---	---	---	---	---	---
Total (15 hrs)	**5515**	**5751**	**6344**	**1289**	**1317**	**1452**	**749**	**852**	**1019**	151	182	163

5.2.2 Inter Gate Analysis with Stay Time

To detect any possible "transit" trips (trips entering from one gate and exiting from another in a short period) or gate usage of daylong commute, gate information was crossed with stay time. A separate MATLAB code was written to perform this analysis. Results are presented in Table 5.7. It shows almost similar results for three Wednesdays, so the key findings are explained only for Nov 10 ,2010 data. The key findings are as follows:

- Among 1730 vehicles entering from A1 gate,
    - 735 of them (approximately 42%) were exiting from A4 gate, 512 of them (30%) from A1, and 334 of them (19.3%) of them from A7 gate.
    - Among 512 vehicles exiting at A1, 84 of them (16.4%) stayed in campus less than 15 minutes, 183 of them (35.7%) stayed up to 5 hours, and 106 of them (20.7%) stayed more than 10 hours.
    - Among 735 vehicles, 360 of them (49.2%) were staying less than 15 minutes, 172 of them (23.4%) stayed up to 5 hours.
    - Among 334 vehicles, 107 of them (32.0%) stayed less than 15 minutes and 124 of them (37.1%) stayed up to 5 hours.

Table 5.7 The distribution of number of vehicles by gate-to-gate and stay time

Nov 10, 2010															
	From A1 to				From A4 to				From A7 to				From A8 to		
Stay-time	**A1**	**A4**	**A7**	**A8**	**A1**	**A4**	**A7**	**A8**	**A1**	**A4**	**A7**	**A8**	**A1**	**A4**	**A7**
0-15min	84	**360**	**107**	**112**	58	**192**	**273**	**372**	26	**225**	**171**	**300**	39	**272**	8
15-30min	64	54	19	7	12	119	24	16	9	34	68	12	1	5	1
30min-1h	50	41	23	14	10	**135**	21	24	7	24	49	6	4	6	6
1h-5h	**183**	**172**	**124**	13	42	**420**	72	13	15	55	**142**	9	5	23	13
5h-10h	**106**	94	50	3	24	**233**	26	3	9	26	**158**	5	1	6	10
10+hr	25	14	11	---	5	63	4	1	2	7	27	---	---	2	---
Total	**512**	**735**	334	149	151	**1162**	**420**	**429**	68	371	**615**	**332**	50	**314**	38
	1730				**2162**				**1386**				**402**		
May 4, 2011															
	From A1 to				From A4 to				From A7 to				From A8 to		
Stay-time	**A1**	**A4**	**A7**	**A8**	**A1**	**A4**	**A7**	**A8**	**A1**	**A4**	**A7**	**A8**	**A1**	**A4**	**A7**
0-15min	53	**338**	56	98	66	**237**	**306**	**429**	17	**272**	**194**	**403**	3	154	9
15-30min	40	54	20	7	9	**178**	23	21	6	40	67	18	4	6	4
30min-1h	41	61	17	6	14	**169**	29	18	4	18	54	8	1	9	3
1h-5h	**121**	**170**	87	27	37	**521**	68	20	16	67	149	22	6	21	14
5h-10h	72	**108**	72	4	13	**333**	32	7	9	33	159	11	2	7	5
10+hr	12	26	13	1	5	**102**	0	0	2	10	27	0	0	0	2
Total	339	**757**	265	143	144	**1540**	**458**	**495**	54	**440**	**650**	**462**	16	**197**	37
	1504				**2637**				**1606**				**250**		
Nov 23, 2011															
	From A1 to				From A4 to				From A7 to				From A8 to		
Stay-time	**A1**	**A4**	**A7**	**A8**	**A1**	**A4**	**A7**	**A8**	**A1**	**A4**	**A7**	**A8**	**A1**	**A4**	**A7**
0-15min	83	**398**	83	89	131	192	310	385	62	361	233	399	13	61	4
15-30min	54	63	27	10	26	141	29	58	15	27	74	7	4	6	4
30min-1h	52	80	27	10	26	110	41	23	9	30	60	9	3	4	5
1h-5h	209	221	117	20	94	396	63	18	36	65	159	12	12	27	16
5h-10h	171	107	55	4	51	343	34	3	31	32	167	1	7	18	5
10+hr	20	19	9	1	4	82	4	---	5	1	28	0	0	0	0
Total	**589**	**888**	318	134	332	**1264**	481	487	158	**516**	**721**	**428**	39	**116**	34
	1929				**2264**				**1823**				**189**		

  - For the 0-15minutes time interval, among 663 vehicles, the majority of them (360 vehicles) were exiting from A4 gate with an approximately 54.3% and 107 of them (16.1%) were exiting from A7 gate.
  - For the 1h-5h time interval, among 492 vehicles, 183 of the vehicles (37.2%) were exiting from A1, 172 of them (35.0%) from A4 and 124 of them (25.2%) from A7 gate.
  - For the 5h-10h time interval, among 253 vehicles, 106 of them (41.9%) were exiting from A1, 94 of them (37.2%) from A4 and 50 of them (19.8%) from A7 gate.

- Among 2162 vehicles entering from A4 gate;
  - 162 of them (approximately 53.7%) were exiting from A4 gate, 151 of them (6.9%) from A1, and 420 of them (19.3%) of them from A7 gate.
  - Among 1162 vehicles, 192 of them (16.5%) stayed in campus less than 15 minutes, 420 of them (36.1%) stayed up to 5 hours, and 233 of them (20.1%) stayed more than 10 hours.
  - Among 151 vehicles, 58 of them (38.4%) were staying less than 15 minutes, 42 of them (27.8%) stayed up to 5 hours.

- Among 420 vehicles, 273 of them (65.0%) stayed less than 15 minutes and 72 of them (17.1%) stayed up to 5 hours.
- For the 0-15minutes time interval, among 895 vehicles, the majority of them (372 vehicles) were exiting from A8 gate with an approximately 41.6% and 273 of them (30.5%) were exiting from A7 gate and 192 of them (21.4%) were exiting from A4 gate.
- For the 1h-5h time interval, among 547 vehicles, 420 of the vehicles (76.7%) were exiting from A4, 72 of them (13.2%) from A4 gate.
- For the 5h-10h time interval, among 283 vehicles, 233 of them (82.3%) were exiting from A4 gate.

- Among 1386 vehicles entering from A7 gate;
    - 371 of them (26.7%) were exiting from A4 gate, 68 of them (4.9%) from A1, and 615 of them (44.4%) of them from A7 gate.
    - Among 371 vehicles, 225 of them (60.6%) stayed in campus less than 15 minutes, 55 of them (14.8%) stayed up to 5 hours.
    - Among 68 vehicles, 26 of them (38.2%) were staying less than 15 minutes.
    - Among 615 vehicles, 171 of them (27.8%) stayed less than 15 minutes and 142 of them (23.1%) stayed up to 5 hours, and 158 of them (25.7%) stayed more than 10 hours.
    - For the 0-15minutes time interval, among 722 vehicles, the majority of them (300 vehicles) were exiting from A8 gate with an approximately 41.6% and 225 of them (31.2%) were exiting from A4 gate and 171 of them (23.7) from A7 gate.
    - For the 1h-5h time interval, among 221 vehicles, 142 of the vehicles (64.3%) were exiting from A7 gate.
    - For the 5h-10h time interval, among 198 vehicles, 158 of them (79.8%) were exiting from A7 gate.

As a result, it was found that entry gate of a vehicle is the same as the exiting gate in general, except for a vehicle has a stay time less than 15 minutes. Moreover, A4 gate is more used gate for exiting the campus. For the minor gate A8, vehicles prefer to use A4 and A7 as a major entry gates. It can be concluded that A1 and A4 gate is the most active gates when comparing the A7 gate.

5.3 In-Campus Origin-Destination Estimation

Similar to gate-to-gate mobility, matched trips (detected trips) were searched to create origin-destination (O-D) matrix. Trips that can be matched will be; parking lot-to-parking lot, parking lot-to-gate, parking lot-to-Technopolis, gate-to-parking-lot, or gate-to-Technopolis. Unmatched trips were processed as guessed trips, which were defined by adding an artificial entry or an exit; this is a case when a vehicle is observed entering a gate/in a parking lot with no matching exit, or observed exiting a gate/in a parking lot with no matching entry. In creating O-D estimation step, trips with guessed origins or destinations were assigned to parking lots randomly (see Appendix D for the O-D estimation assumptions).

The steps of the creating in-campus private car demand are summarized for both count days in Table 5.8. The gate RFID data process in Step I revealed approximately 8000 trips in or out of the campus. In Step II, using the parking lot surveys, the gate movements were matched with their origins/destinations in the campus or in the Regions I –XIII. This suggested a total in-campus demand closed to 14000 trips/day. This showed that the majority of the private car demand was from gates towards the parking lots and Technopolis.

Table 5.8 Daily in-campus private car demand estimation

O-D Estimation steps	Trips Information	Nov 10, 2010	May 4, 2011
I) From gate data	Detected trips	5112	5483
	Missing Trips	3007	3099
	Total	**8119**	**8582**
II) From gate and parking survey data	Gate-to-gate	2741	3094
	Parking lot-to-parking lot	998	1132
	Between gates& parking lots	8403	9258
	Between gates & Technopolis	1034	1147
	Between parking lots & Technopolis	210	273
	Total	**13386**	**14904**
III) With trip chaining correction for gate-to-gate trips	Gate-to-gate	---	---
	Parking lot-to-parking lot	998	1132
	Between gates& parking lots	13885	15564
	Between gates & Technopolis	1034	1147
	Between parking lots & Technopolis	210	273
	Total	**16127**	**18116**
IV) With gate malfunction correction	Gate-to-gate	---	---
	Parking lot-to-parking lot	998	1132
	Between gates& parking lots	15835	18495
	Between gates & Technopolis	1034	1147
	Between parking lots & Technopolis	210	273
	Total	**18077**	**21047**

The traffic between the campus destinations was only close to 1000 trips per day. However, still a significant number of gate-to-gate (around 3000) were left without a campus location destination. This was expected, considering the facts that i) majority of the campus stay times was less than 15 minutes, and ii) parking lot surveys were conducted on certain time intervals during the day. As the campus roads are not accessible to non-campus users officially, these trips were divided into two chained trips as, gate-to-parking lot and parking lot-to-gate in Step III. This pushed the number of daily trips over 16000 per day. Finally, the missing exits at A1 were corrected to match expected ratio, resulting in a daily private car demand over 18000 for METU Campus. Finally, the private car O-D matrix of METU campus for both study days is shown in Table 5.9.

Table 5.9 Daily in-campus private car O-D matrix of METU campus

10 November 2010		**Regions** I –XIII	**XIV**	**Gates**		
				A1	**A4**	**A7**
Parking Lots in **Regions I –XIII**		998	116	3454	3126	1539
Region XIV (Technopolis)		94	0	1	149	28
Gates	**A1**	3148	29	0		
	A4	3102	466			
	A7	1466	361			
Total=18077 private car trips						

4 May 2011		**Regions I –XIII**	**XIV**	**Gates**		
				A1	**A4**	**A7**
Parking Lots in **Regions I –XIII**		1132	165	4107	3650	1808
Region XIV (Technopolis)		108	0	7	165	19
Gates	**A1**	3654	93	0		
	A4	3457	450			
	A7	1819	413			
Total=21047 private car trips						

CHAPTER 6

CAMPUS TRAFFIC ASSIGNMENT AND CARBON EMISSIONS

6.1 Campus Network in PTV VISUM

The O-D matrix developed and calibrated as discussed above must be assigned to the campus network to get the flows on campus roads, and ultimately the total vehicle-km, which is the main input for the emissions calculations. The assignment part of this study was performed using the PTV VISUM software, which requires the graphical representation of campus road network in terms of nodes and links, and CTAZs in terms of zones. In VISUM, zones are the regions where the trips are generated or terminated, such as parking lots and main gates; the generated traffic is connected to the real road segments/parking lots via zone connectors. Beyond the 13-region CTAZs, the parking lots on campus were grouped in smaller numbers to create 40 zones in VISUM to get a more precise depiction of the road network usage. The VISUM zones are illustrated in Figure 6.1 with polygons and distribution of parking lots into the CTAZs is shown in Table D.1.

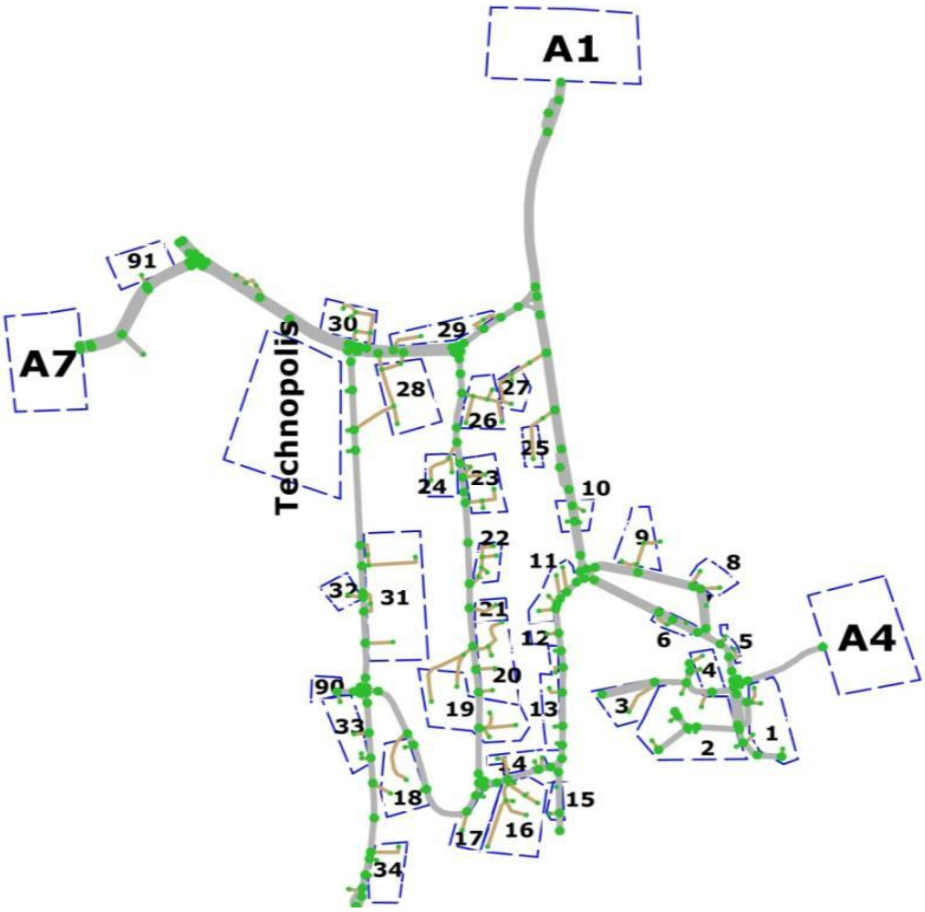


Figure 6.1 METU campus traffic network and zones in PTV VISUM

Campus transportation network in VISUM included 698 links and 302 nodes. The links in gray represent road segment and were drawn with different thicknesses showing different number of lanes. The capacities of the lanes were taken as 600 cars/h/lane. Finally, links in brown show roads in parking lots (have a speed limit of 5 km/h).

6.2 Daily Campus Traffic Assignment and Emissions

Normally, there is no congestion in METU campus network except morning and evening peak hours. So, the daily assignment will be performed in 3 steps; morning peak assignment, evening peak assignment, and off-peak assignment. While the peak hours will be only one-hour assignments, off-peak assignment will cover 13 hours. To display the methodology over a simple case, first the peak hour congestions will be ignored and daily traffic will be assigned to the network producing daily vehicle-km and speed profiles for different segments of the METU campus road network. The results will be used to get the daily emission for private car trips on campus as described in 6.2.2.

6.2.1 Average Daily Traffic Assignment Using PTV VISUM

During the PTV VISUM analysis, selection of the assignment principle is not very crucial in case of METU campus, as there are not many route options for most of the O-D pairs. To represent the commute behavior, a user equilibrium assignment was chosen for this study. When observing the O-D matrix of two counting days (see Table 5.9), they have almost similar characteristics so, only May 4, 2011 day of the O-D was used in traffic assignment part. Total daily O-D matrix of May 4, 2011 is shown in Table 6.1. To display the impact of congestion on the emissions, first the daily demand was assigned totally to the network for which the assignment results are presented in Figure 6.2. As a result of the assignment, information on travel time of a link, number of vehicles, and average speed of vehicles that use this link was obtained. The volumes on the most commonly used links (volumes over 1500 cars/day) are displayed numerically.

To show the speed estimation on the links, PTV VISUM screenshot was provided for a link (Link 2572) with a length of 0.192 km on the d-j corridor segment (see Figure 6.2). The assigned showed 5068 private cars daily on the link. While the link speed had a 50 km/h limit, due to the heavy traffic, the expected average daily speed is estimated as 46 km/h. The speed profile of campus in a day is shown in Figure 6.3.

The total vehicle-km can be simply calculated by multiplying length of a link with number of vehicles that use this link, which was calculated by VISUM directly under the attribute name "VehKmTravPrT(AP)" (see Figure 6.4). For May 4, 2011, addition of the entire link vehicle-km in the campus network resulted in a campus-wide daily 42028.6 vehicle-km.

It should be noted that majority of the in-campus demand and the vehicle-km is due to the access of campus from main gates. Thus, the majority of the traffic was observed on the corridors between A1-A4 gates (circling one-way around the shopping area) and A1-Technopolis. Secondly, larger flows were observed in the northern parts of the campus while the southern parts had relatively calmer traffic conditions.

Table 6.1 Daily O-D matrix of METU campus between 07:00-22:00, on May 4, 2011

40x40		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	90	91	A1	A4	A7	A8
	Sum	339	200	234	186	199	289	145	189	797	229	420	205	361	153	69	318	223	166	399	345	163	228	356	166	320	316	110	295	315	643	513	133	236	113	473	324	4114	3815	1827	1121
1	342		1	1				1	4	3	1	4		1					1	3		1	1	2	2	6	7		6	1	2	1	1	3		2		99	134	50	4
2	243					1		1		1							1	1						1		2					1							103	94	34	3
3	270	2				1		1		2	2							1		1						4	1			1	3			1	1	1		156	74	17	1
4	229	1		1			1				1	2																	2				1	2		1		88	89	36	4
5	231	1	1	1			1					1		2			2	2	1	1					1				1					1				92	84	35	4
6	328	2		1		1	2					1	1	2				3	1	1	1	1	1	1		2	2				2	1		1				183	84	28	6
7	200	1	1	2	1					1	1	1	1		1					2	1			2					2	1	2	4				1		108	46	17	4
8	241	12					1	1		1		1	1			1			1	1	1					2				3	1		1	2	1			110	66	28	6
9	764	5	4	3	1		2	1				1	1	6	1	1	6	2		2	1	1	4	2		2	1	1	1	3	3	2	3		3	1		370	234	80	16
10	262	3	1	2		2		1	1	1		3	1										1						2		1		1	2		4		108	83	40	5
11	434	3	2	2		7	3	1	2	5	1	1		2	5		1	4		1	2	1			1	1	1				2		2	5	3	7		177	136	50	6
12	245	3	4	1				2		1	1			1	1				1		1					1				1		3				6		91	92	32	3
13	380	2	1	2		1	3		1	5				1		2		2				1				4							3	2		11		137	142	56	4
14	203		1						1	1		2	1				2	1	1																	6		81	73	30	3
15	126									2		1								1				1								3				3		57	42	15	1
16	337					4			1	8		1							1	1			1			2										4		125	124	59	6
17	264	2		2		4	3	1		3		5		2	1			1	1		1			4					1	1			1	1		6		91	90	38	5
18	215	2	1	2		1	1			3		4	1		1		2			2						2	1						1			3		73	79	33	3
19	413	12	2	4		1	2	3		6	1	4			1		2	1				3	2	3		3			1					3	3	7		138	148	56	7
20	376		1				1			3			1	1						1						2					1		1	3		9		168	112	67	5
21	214	1	1			1		3		1				2	1				1	1	2											2				8		99	59	29	3
22	264			1	1	1	2	1	1		1	1	1				4		1		1			1										1	1	9		92	91	50	3
23	388		1	1	1	1	1			2	2		1							3		2	1	1		1	1			1		1	1	2		5		147	133	72	7
24	212	2		3						2										1													1	4		1		90	71	33	4
25	345	5	2	6		2	1			5	1	3		3			2	1	1	5							1			1				1		2		144	114	42	3
26	338	8		1			2	1		4		1							1							2			1						1	3		130	122	55	6
27	166			1	1																			1			2						1			4		68	62	24	2
28	316	5				2	1	3	1	3	1													1		3	1	1						1		2		118	107	58	8
29	346	3	1			2	2		2	6	1	2						1		1		2		4						4			3			23		110	107	66	6
30	649	1		2		2	1	2	1	3	1	2		1					1	2	1	1		1		2								3		5		135	391	81	10
31	463	1				2	1	1		1			2			2					1	2					1						2	1		4		180	154	96	12
32	180		2	1			2			2							1				1			1								2		1		1		84	56	23	3
33	173	1		1	2	1			1	3	1	2	1	1						4		2	1	1	4		2	1			4	1	1		1			59	58	19	1
34	170						2	1	1	3		5		1	1				1	1						1	1								3	3		67	55	23	1
90	281	1					1	2	2	2	5	3	6	6			4	4	2	5	12	5	17	9	2	2	1	3	7	10	10	3			2			28	43	84	
91	254																																					1	1	252	
A1	3747	92	68	90	75	69	118	52	81	319	95	147	76	140	65	31	127	84	66	150	164	76	89	147	68	114	129	48	109	125	136	209	52	85	45	112	1				93
A4	3907	119	79	81	65	64	92	40	61	294	74	164	82	131	51	22	113	77	55	140	90	35	71	104	57	120	112	37	100	100	400	159	32	76	29	116	15				450
A7	2232	45	26	20	37	27	40	22	26	90	34	54	26	55	24	9	46	36	29	64	61	24	38	64	31	40	49	18	57	59	71	111	21	34	20	103	308				413
A8	299	4		2	2	2	3	4	2	11	5	4	2	3		1	5	2		5	4	6	1	5		2	3	1	5	4	4	11	4	1				7	165	19	

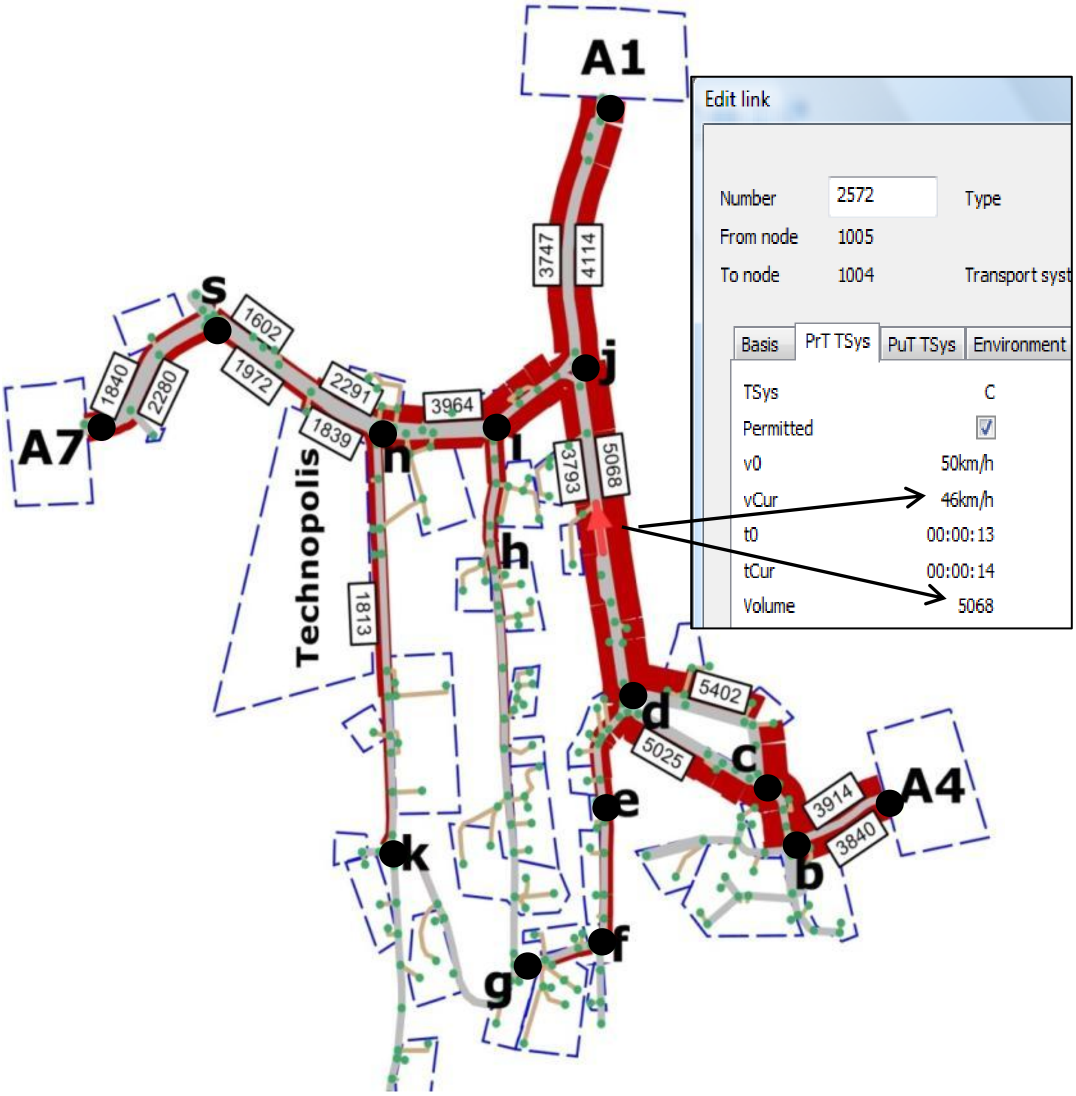


Figure 6.2 Daily campus traffic assignment result between 07:00-22:00

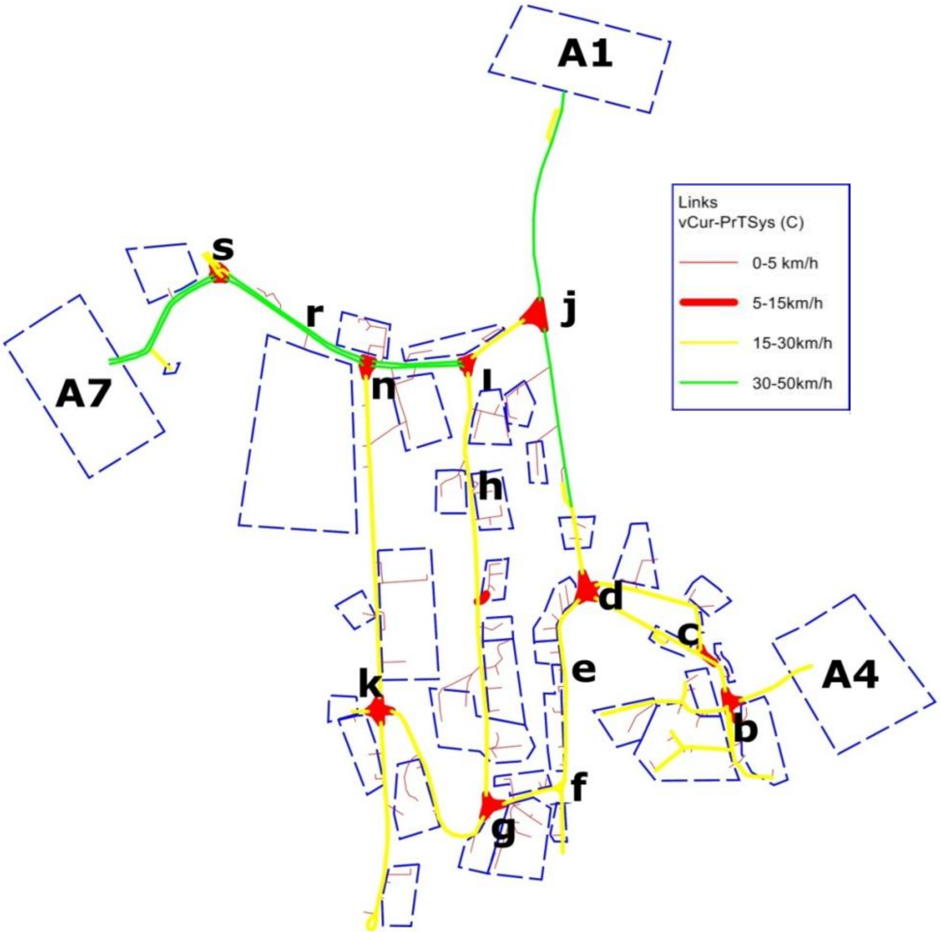
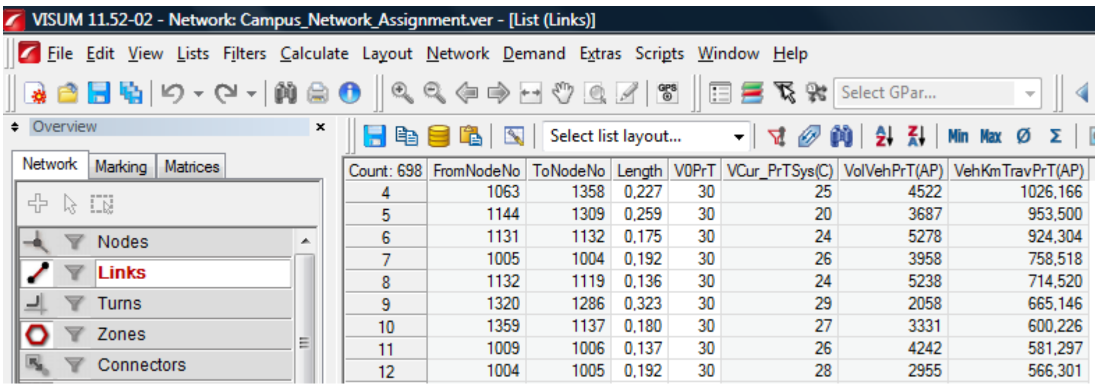


Figure 6.3 Speed profile of a campus in a day



Count: 698	FromNodeNo	ToNodeNo	Length	V0PrT	VCur_PrTSys(C)	VolVehPrT(AP)	VehKmTravPrT(AP)
4	1063	1358	0,227	30	25	4522	1026,166
5	1144	1309	0,259	30	20	3687	953,500
6	1131	1132	0,175	30	24	5278	924,304
7	1005	1004	0,192	30	26	3958	758,518
8	1132	1119	0,136	30	24	5238	714,520
9	1320	1286	0,323	30	29	2058	665,146
10	1359	1137	0,180	30	27	3331	600,226
11	1009	1006	0,137	30	26	4242	581,297
12	1004	1005	0,192	30	28	2955	566,301

Figure 6.4 Link attribute file showing the vehicle-km values in VISUM.

6.2.2 Campus Private Car Daily Emissions

VISUM software provided vehicle emissions directly based on a procedure described in Handbook Emission Factors for Road Transport (HBEFA, 2012). This method required the definition of fleet composition in terms of fuel type in advance. Since we have no exact information about fleet composition of campus vehicles, Turkish Statistics Institute (2012) data was taken to consideration while creating fleet composition. That is; 40.6% of automobiles are LPG, 35.9% of automobiles are gasoline, and 22.9% of them are diesel. Furthermore, cold start emission points should define to get reliable results, because vehicle with cold start emissions produces more carbon emission. Therefore, campus-parking zones were defined as cold start emission points. As a result, PTV VISUM estimated carbon emissions for METU campus as 9846 kg/day CO_2 and 97.6 kg/day CO for the May 4, 2011 survey day.

To compare with the VISUM carbon emission results, a second estimation was obtained by using the speed-CO_2, and speed-CO relations provided by Barth and Boriboonsomsin (2009) and *VISUM Basics* (2009), respectively. This way, total vehicle-km of 42028.6 caused carbon emissions of 10025.7 kg/day CO_2 and 85.1 kg/day of CO, which are very close to those provided by the PTV VISUM.

Table 6.2 Daily carbon emissions based on speed levels found by VISUM simulation (May 4, 2011)

Speed km/h	Unit CO_2 (g/km)	Unit CO (g/km)	Daily assignment and emissions			
			Vehicle-km	(%)	CO_2 (kg)	CO (kg)
0-5	683	2.4	1135.4	(2.7)	775.5	2.7
5-15	323	2.2	4528.3	(10.8)	1459.4	9.9
15-30	218	2.1	20770.3	(49.4)	4527.9	43.6
30-50	204	1.8	15994.6	(37.1)	3262.9	28.8
		Total	**42028.6**	**(100.0)**	**10025.7**	**85.1**

6.3 Daily Emissions Considering Peak Hour Congestions

As congestion can change the travel speed, thus the emission during congested hours, it is important to assign the congested hours and uncongested periods separately. To obtain the daily emissions, it is necessary to simply assign i) morning peak hour demand (1 hour), ii) evening peak hour demand (1 hour), and iii) the remaining off-peak (13 hours) demand separately, and get the link volumes and average travel speeds in these periods, to calculate the emissions during these three analysis periods.

To show the impact of the peak hour congestions, the daily demand matrix was divided into three submatrices for the morning peak, evening peak and off-peak hours are presented in Appendix E.
The traffic assignments for these three periods are performed as presented below, and the estimated emissions during the vehicular mobility in these periods are calculated consequently, and added to get the daily emission with consideration of the congestion during peak hours as explained below.

6.3.1 Morning Peak Emissions

Morning peak hour was found at 08:15-09:15 with around 2000 vehicles entering to campus (accounted for 20% of daily entry). The distributions of travelers in this time limit are as follows: 19% academics, 11% administrative personnel, 15% students and 53% others. The O-D matrix of the morning peak (see Table E.1) was assigned to the network, assignment results are shown in Figure 6.5, and corridor volumes are presented in Table 6.3. The directionality of the traffic towards the core campus can be seen by the volume difference of two sides of the corridor segments (such as A1-j and j-A1). For the Link 2572, the peak hour assignment showed an hourly volume of 663 cars with an average speed of 38 km/h, which was 46 km/h during the average daily assignment. Finally, speed profile of morning peak is presented in Figure 6.6. The critical road segments were found as j-i and A4-c.

Morning peak vehicle-km was found as 5863.1, which accounts for 14.0% of total trips. Finally, Table 6.4 shows the operating speeds and corresponding vehicle-km and carbon emissions. 5863.1 vehicle-km produced 1483.9 kg CO_2 and 12.1 kg CO. The majority of vehicles (40.7%) were traveling with an average speed of 15-30 km/h, 37.2% of them were traveling with an average speed of 30-50 km/h, and 17.2% of them were traveling with an average speed of 5-15 km/h.

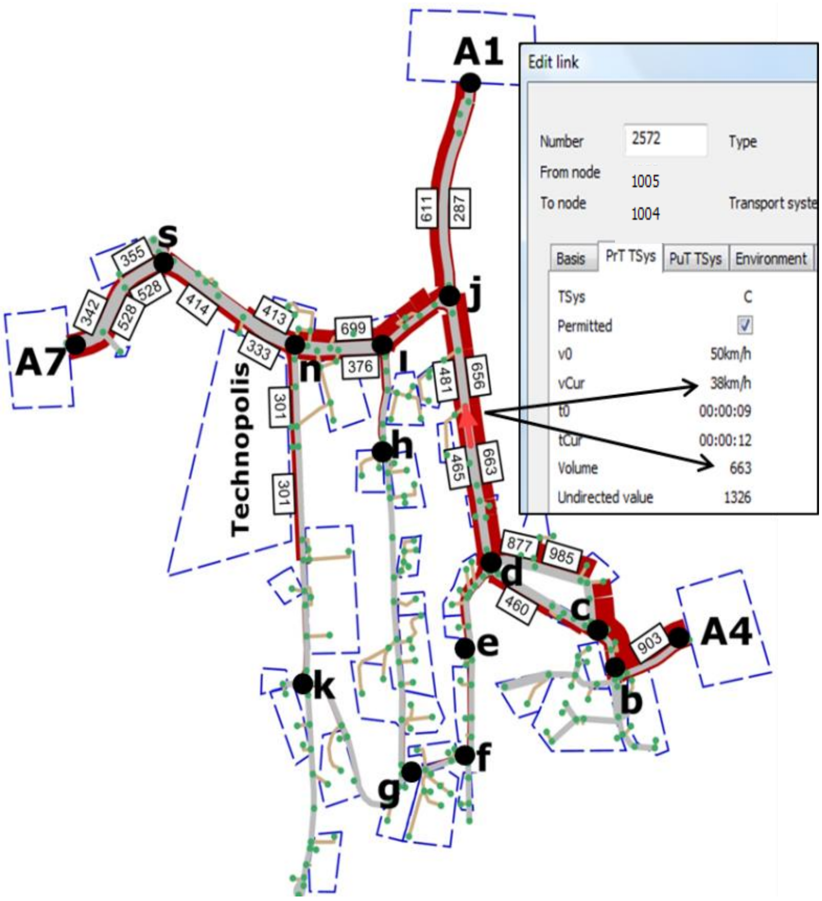


Figure 6.5 Campus traffic assignment result for morning peak (between 08:15-09:15)

Table 6.3 Morning and evening peak hour corridor volumes on selected road segments

Segment	Morning Peak	Evening Peak	Segment	Morning Peak	Evening Peak
A4-b	903	235	**j-d**	460	372
b-A4	238	652	**d-j**	608	570
b-c	883	262	**j-A1**	287	633
c-b	277	655	**A1-j**	611	266
c-d	877	366	**i-n**	699	395
d-c	417	709	**n-i**	371	328
d-e	359	112	**n-k**	301	185
e-d	139	426	**k-n**	127	72
e-f	219	50	**k-g**	147	82
f-e	131	261	**g-k**	20	11
f-g	206	73	**n-r**	413	266
g-f	117	240	**r-n**	333	253
g-h	192	118	**r-s**	241	227
h-g	92	112	**s-r**	414	205
h-i	166	327	**s-A7**	342	248
i-h	203	119	**A7-s**	527	234
i-j	329	459			
j-i	801	318			

Table 6.4 Morning peak emission results

Speed km/h	**Vehicle-km**	**(%)**	**CO_2 (kg)**	**CO (kg)**
	Morning Peak Emissions			
0-5	**286.4**	**(4.9)**	195.6	0.7
5-15	**1009.1**	**(17.2)**	325.9	2.3
15-30	**2387.5**	**(40.7)**	476.1	5.2
30-50	2180.1	(37.2)	486.3	3.9
Total	**5863.1**	**(100.0)**	**1483.9**	**12.1**

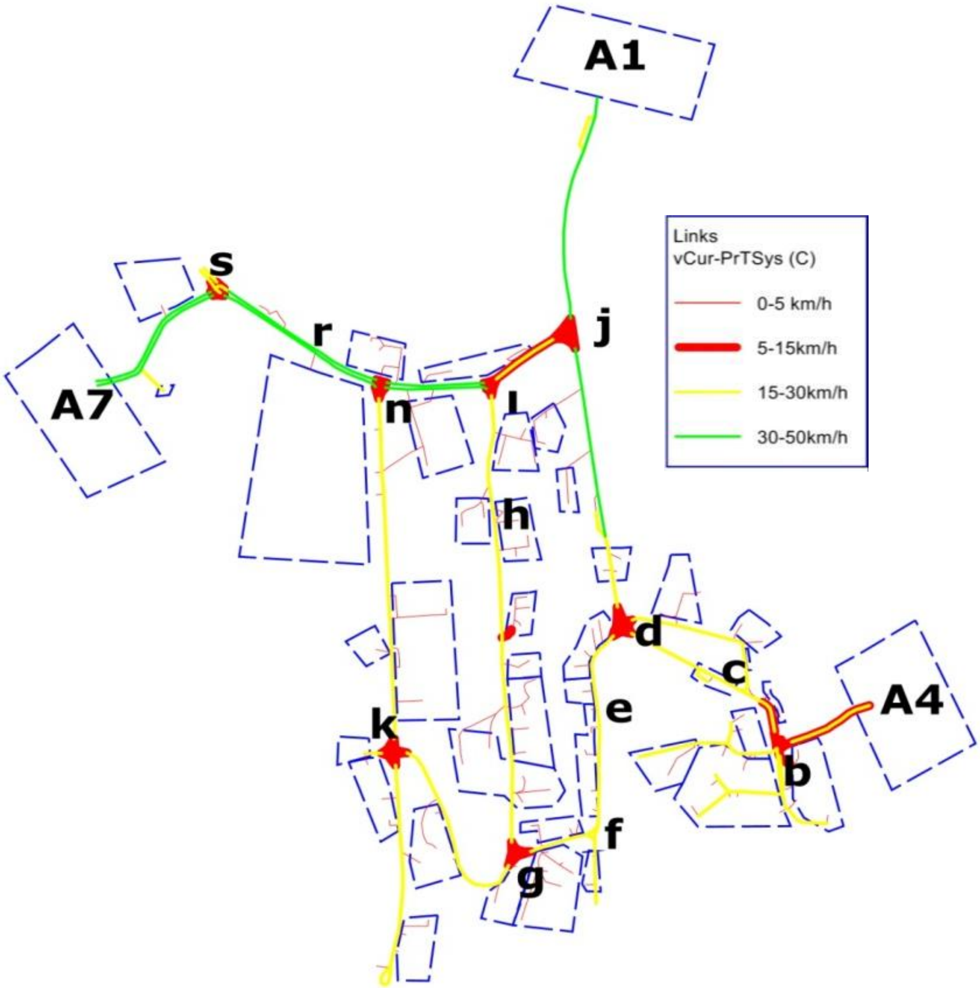


Figure 6.6 Speed profile of METU campus at the morning peak

6.3.2 Evening Peak Emissions

Evening peak hour was found as 17:15-18:15; around 1500 vehicles exiting the campus, which account for 15% of daily exit. The distributions of travelers in this time limit are; 20.2% academic, 8.1% administrative personnel, 23.5% student and 48.2% others. The O-D of evening peak (see Table E.2) was assigned to the network, and assignment result is shown in Figure 6.7 and corridor volumes are seen in Table 6.3. The directionality of the traffic towards the gates can be seen by the volume difference of two sides of the corridor segments (such as b-A4 and A4-b) and, approximately 12% of total trips on road segments were traveled in these time intervals. For the same link (2572) the average speed was found as 41 km/h at the evening peak hour. Speed profile of the evening peak is seen in Figure 6.8. The critical road segment was determined as c-A4. Finally, evening peak vehicle-km was found as 4766.2 and this vehicle-km produced 1154.3 kg CO_2 and 9.5 kg CO. The operating speeds and the corresponding vehicle-km and carbon emissions are illustrated in Table 6.5. 43.2% of the vehicles were traveling with 15-30 km/h, 37.7% of them were 30-50 km/h, and 16.5% of them were traveling with an average speed of 5-15 km/h.

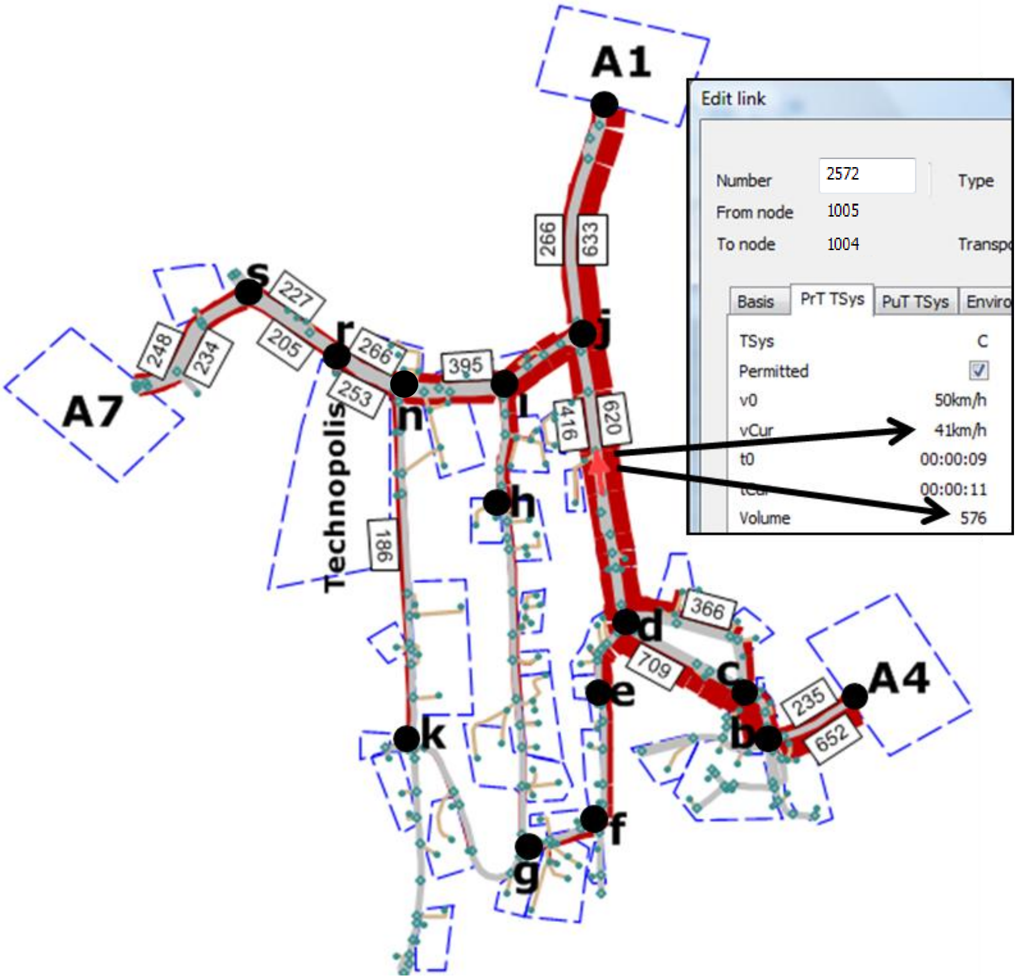


Figure 6.7 Campus traffic assignment result for evening peak (17:15-18:15)

Table 6.5 Evening peak emission results

Speed km/h	Vehicle-km	(%)	CO_2 (kg)	CO (kg)
	Evening Peak Emissions			
0-5	124.4	(2.6)	85.0	0.3
5-15	**787.1**	**(16.5)**	254.2	1.7
15-30	**2058.8**	**(43.2)**	448.7	4.3
30-50	1795.9	(37.7)	366.4	3.2
Total	**4766.2**	**(100.0)**	**1154.3**	**9.5**

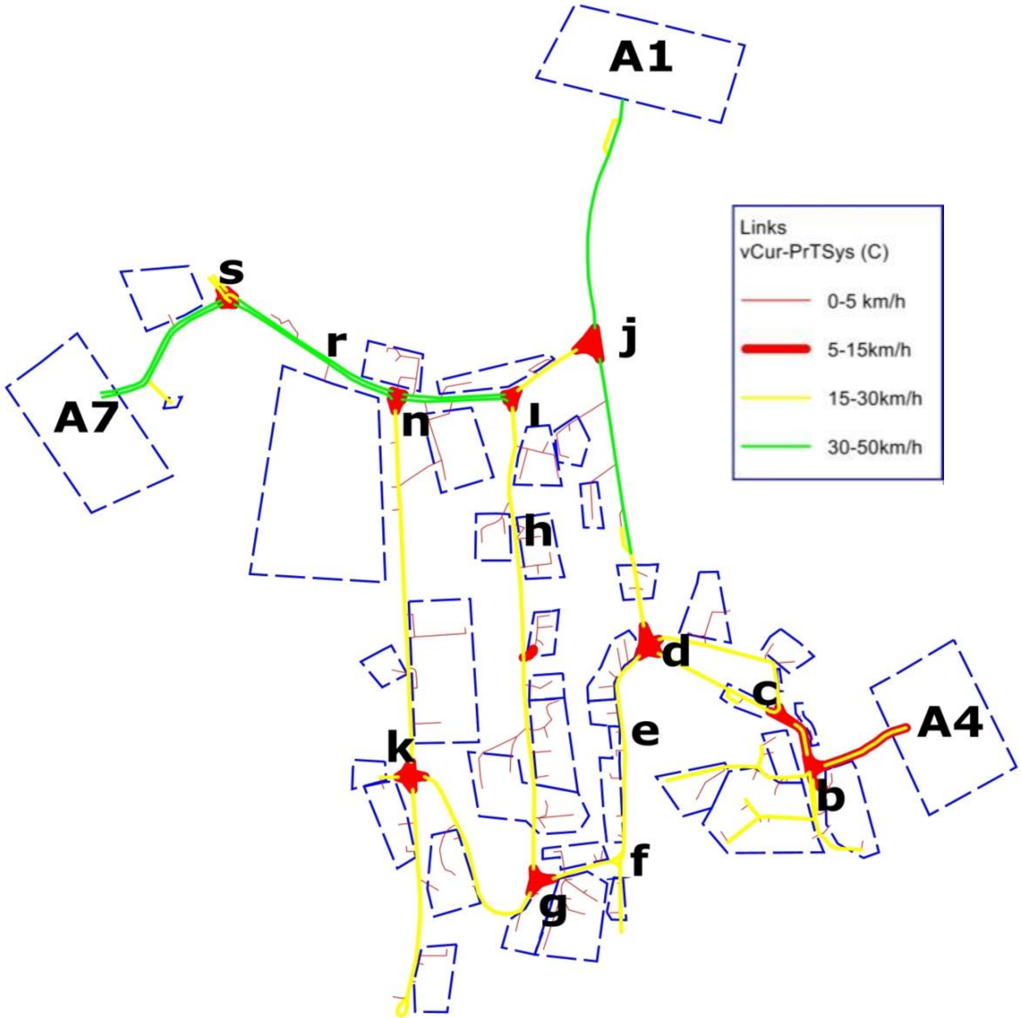


Figure 6.8 Speed profile of METU campus at the evening peak

6.3.3 Off-peak Traffic Emissions

The uncongested traffic conditions during the off-peak hours were observed after the assignment of the 15739 trips that took place during off peak periods (7:00-8:15; 9:15-17:15; 18:15-22:00). The result of this 13 hours demand according to a user-equilibrium principle by PTV VISUM is presented in Figure 6.9. Again, for the same link, link volume was 3752 with the average travel speed of 48 km/h, which is very close to the design speed of the road segment. Off-peak traffic assignment vehicle-km was found as 31406.0, this vehicle-km produced 7433.4 kg CO_2, and 62.8 kg CO (see Table 6.6). It is concluded that approximately 47.3% of vehicles were travelling with the average speed of 15-30 km/h on campus at off-peak hours, but this amount was 40.7% at morning and 43.2% at evening peak hour because of the congestion. In addition, a vehicle with a speed of 5-15 km/h range was 10.8% at off-peak, but for the peak hours, it was 17.2% and 16.5%. Vehicles with a speed of 0-5 km/h were assumed that they were travelling on parking lot routes that’s why vehicle-km proportions did not show considerable changes when comparing their off-peak and peak hour vehicle-km rates.

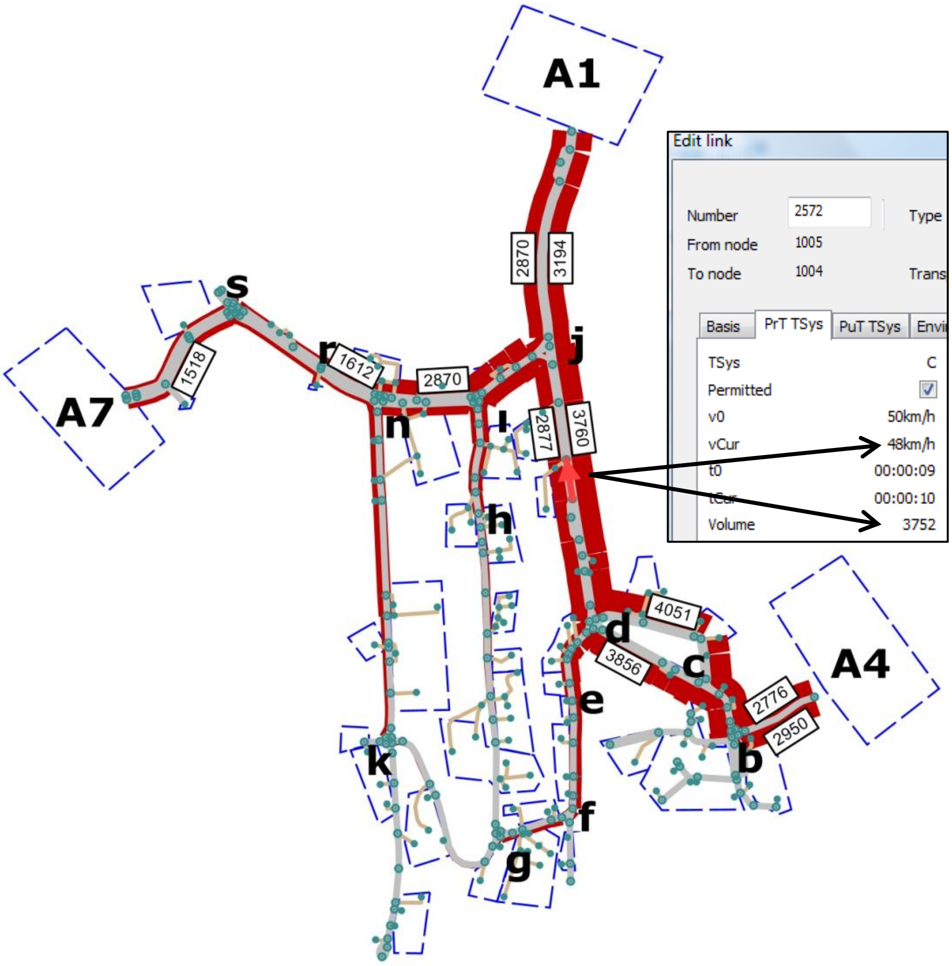


Figure 6.9 Off-peak traffic assignment result on May 4, 2011

Table 6.6 Off-peak emission results

Speed km/h	Vehicle-km	(%)	CO_2 (kg)	CO (kg)
	Off-peak emissions			
0-5	867.2	(2.8)	592.3	2.1
5-15	3386.2	(10.8)	1093.7	7.4
15-30	**14878.4**	**(47.3)**	3243.5	31.2
30-50	**12274.2**	**(39.1)**	2503.9	22.1
Total	**31406.0**	**(100.0)**	**7433.4**	**62.8**

6.3.4 Calculation of Daily Emissions Considering Peak Hour Congestions

Net daily emissions can be found by summing of peak hours emissions and off-peak emissions as mentioned. As a result, daily vehicle-km was found as 42035.3 and daily CO_2 emission was determined as 10071.6 kg/day (see Table 6.7) which is slightly higher than the CO_2 which was found after the daily assignment. This small difference is due to the congestion on the roads at peak hours.

On average, for METU campus CO_2/vehicle-km was found as 235 g/km, which suggests an overall campus average speed of 15-20 km/h; this is consistent with almost no congestion or delay on campus road. Furthermore, the peak-period analysis of emissions showed that there was more vehicle-km at lower speeds, as expected. Both vehicle-km and carbon emissions of morning peak and evening peak correspond to almost 14% and 12% of the daily values. The average CO_2/vehicle-km was found as 238 g/km and 252 g/km for morning and evening peaks, respectively, which was a little larger than the daily estimations, but not significantly different. This is mainly due to congestion on main corridors during the peak hours in the campus, not everywhere.

Table 6.7 Base case daily carbon emissions based on speed levels found by VISUM simulation

Speed km/h	Vehicle-km	(%)	CO_2 (kg)	CO (kg)
	Base Case Daily Emissions (sum of off-peak and peak hour emissions)			
0-5	1278.1	(3.1)	872.9	3.1
5-15	5182.4	(12.3)	1673.8	11.4
15-30	**19324.7**	**(45.9)**	4168.3	40.7
30-50	**16250.2**	**(39.5)**	3356.6	29.2
Total	**42035.3**	**(100.0)**	**10071.6**	**84.4**

6.4 Private Car Emissions by Traveler Groups

The O-D data was originally derived for the selected four groups, which were assigned together. PTV VISUM enables researchers to display traffic flows for each group as shown for student trips in Table 6.8 and in Figure 6.10. Though the assignment results were not different from the total daily assignment due to limited network connectivity and main O-D being at the gates, it enabled us to calculate the vehicle-km by different traveler groups. Total daily corridor volumes and corridor volumes by traveler types are shown in Table 6.9. See Appendix E for details of the group-based assignments.

The tabulation of vehicle-km values for different groups (see Table 6.10) showed that a major portion was traveled by Technopolis sticker holders and visitors in a day (41.9%). Secondly, students (excluding the research assistants with academic stickers) were responsible of the 29.4% of the daily vehicle-km. Among the personnel, academic group contributed more than twice the share of the administrative ones. Finally, for the base case, METU campus vehicle-km was determined as 42035.3.

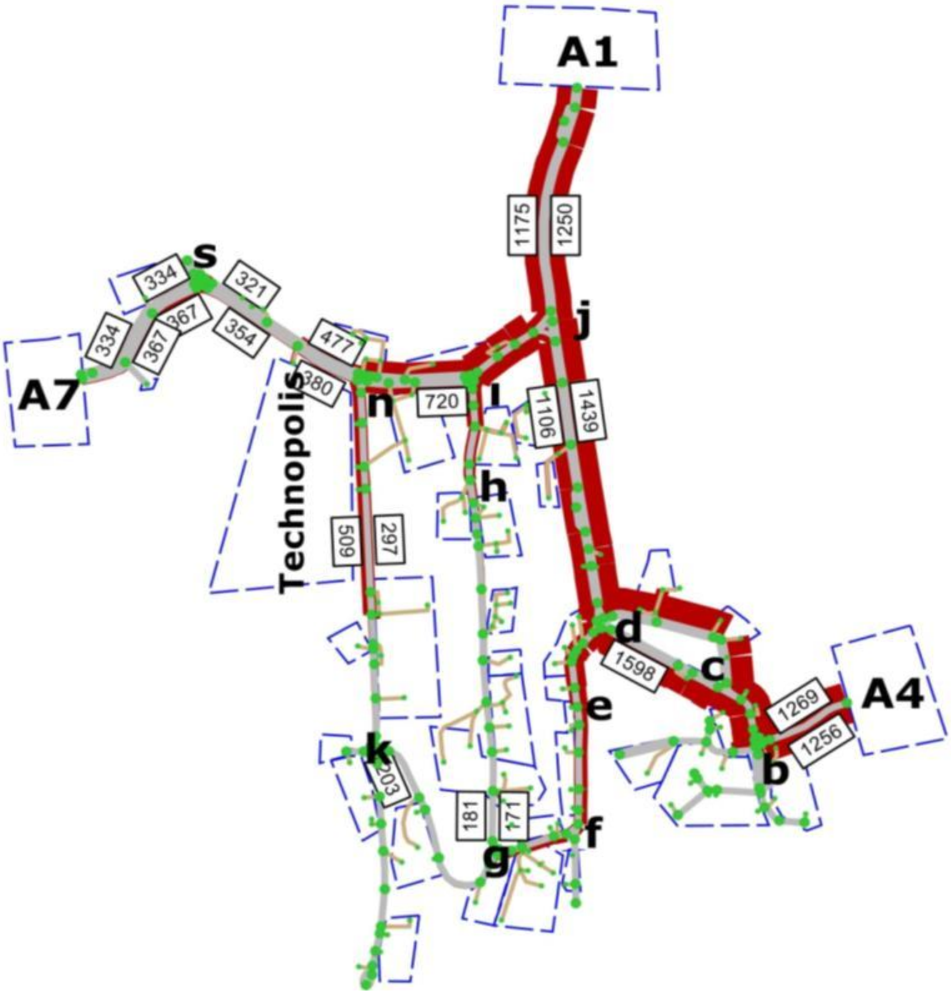


Figure 6.10 Campus traffic assignment results for Student Traveler

Table 6.8 O-D matrix of student travelers between 07:00-22:00

40x40		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	90	91	A1	A4	A7	A8
	Sum	126	60	80	42	37	77	28	32	399	38	112	60	133	42	19	101	72	59	174	93	37	33	84	52	142	148	18	102	56	170	270	44	31	44	0	13	1249	1254	334	188
1	125			1						3		2		1						1			1	1		5	2		3			1	1					38	53	11	1
2	77					1											1									1					1							30	34	7	2
3	81	1								1										1						2									1			39	33	3	
4	57																																					25	24	7	1
5	54													1																								24	23	5	1
6	89	1		1									1	2						1						1	1					1						41	28	7	4
7	47	1	1										1							1												1						24	17	1	
8	49											1	1																				1	1	1			19	17	5	3
9	350	2	3	2										4			3	2		2	1	1	1	2		2	1		1	1	1	1			2			157	129	26	6
10	53							1																														24	21	6	1
11	107	1	1	1			2	1	1	3				1	1			1			1					1	1				1			1				40	38	10	1
12	70		1					1																								1						29	31	5	2
13	132	2	1	2			3			3						1						1				2							1					43	58	14	1
14	57		1									1																										26	23	4	2
15	39											1																				2						23	12	1	
16	97									6									1	1																		35	41	10	3
17	83	1				1	1	1		2		1						1	1					3					1	1			1					34	26	7	1
18	76	1	1	2			1			1		3					2			1						2	1						1					29	24	6	1
19	179	8	1	4			2	1		5		2			1		2					1		3		2			1					3	3			59	62	15	4
20	89									2				1												2								2				35	33	13	1
21	52		1											1						1												2						29	16	2	
22	49						1																															21	21	5	1
23	88																			2						1	1											30	37	14	3
24	67	1								1										1																		32	23	7	2
25	140	2	2	3			1			4		3		2			2	1	1	3							1							1				50	50	13	1
26	144	2		1			2	1		2		1							1							2									1			59	50	18	4
27	38																																					19	16	3	
28	98	1						1	1	1																2												42	36	13	1
29	65	1								1		1						1						1														24	26	9	1
30	160						1							1					1	1						1												25	113	15	2
31	192	1					1			1			1			1					1	1					1						2					64	68	46	4
32	57		1				2																									2						29	17	4	2
33	53								1	2			1							4							1											22	19	3	
34	61						1		1	1		1		1					1	1						1	1								2			27	19	4	
90	0																																								
91	13																																							13	
A1	1175	37	17	22	14	14	26	5	12	170	16	42	21	49	17	7	43	27	26	66	46	14	11	30	21	47	62	7	39	23	40	113	18	8	13						52
A4	1269	55	25	39	19	15	22	13	12	157	16	43	30	56	19	9	38	32	20	64	30	12	14	30	24	53	60	8	42	22	113	89	11	13	14						50
A7	363	7	4	2	7	4	11	2	4	28	5	9	4	12	4	1	8	6	7	21	13	5	6	12	7	13	14	3	14	8	13	52	5	2	7		13				30
A8	58	1			2	2		1		5	1	1		1			2	1		2	1	2		2		2	1		1	1	1	5	3					2	16	2	

Table 6.9 Campus corridor daily volumes by traveler type

Seg.	Acad.	Admin. Pers.	Student	Others	Total
A4-b	796	367	1269	1482	3914
b-A4	788	329	1256	1467	3840
b-c	877	396	1325	1659	4257
c-b	810	359	1280	1609	4058
c-d	1034	459	1708	2199	5400
d-c	914	413	1598	2100	5025
d-e	338	207	462	559	1566
e-d	650	233	734	916	2533
e-f	175	86	274	268	803
f-e	406	119	536	571	1632
f-g	162	71	231	228	692
g-f	368	102	459	495	1424
g-h	277	77	244	209	807
h-g	191	62	181	193	627
h-i	465	162	580	623	1830
i-h	319	146	479	505	1449
i-j	696	294	984	1515	3489
j-i	1030	329	1287	1795	4441

Seg.	Acad.	Admin. Pers.	Student	Others	Total
j-d	568	357	1029	1667	3621
d-j	983	418	1390	2183	4974
j-A1	702	367	1250	1795	4114
A1-j	660	345	1175	1567	3747
i-n	1102	267	1033	1562	3964
n-i	608	216	648	1148	2620
n-k	784	100	509	418	1811
k-n	204	50	225	254	733
k-g	292	63	215	261	831
g-k	34	7	18	33	92
n-r	615	154	477	1045	2291
r-n	558	156	380	745	1839
r-s	536	145	321	600	1602
s-r	531	153	354	934	1972
s-A7	590	159	334	757	1840
A7-s	585	167	372	1152	2276

Table 6.10 Private car vehicle-km values (daily and peak hours) by sticker type from VISUM simulation

Time Period	Acad. Pers.	Admin. Pers.	Students	Others	Total
Daily vehicle-km (07:00-22:00)	9666.2 (23.0%)	3506.1 (8.4%)	12028.3 (28.6%)	16828.0 (40.0%)	**42028.6 (100.0%)**
Morning peak (08:15-09:15)	1172.6 (20.0%)	644.9 (11.0%)	937.2 (16.0%)	3108.4 (53.0%)	**5863.1 (100.0%)**
Evening peak (17:15-18:15)	963.2 (20.2%)	386.3 (8.1%)	1118.9 (23.5%)	2297.8 (48.2%)	**4766.2 (100.0%)**
Off-peak	6196.7 (19.7%)	2720.9 (8.6%)	10313.2 (32.8%)	12174.4 (38.9)	**31406.0 (100.0%)**
Daily total with congestion	8332.5 (19.8%)	3752.1 (8.9%)	12369.3 (29.4%)	17580.6 (41.9%)	**42035.3 (100.0%)**

6.5 Evaluation of METU In-Campus Private Car Emissions

In this section, yearly carbon emissions of METU campus will be calculated for the academic semester and summer holiday . Moreover, the net cost of emissions by students and short stay travelers during peak hours will be mentioned.

6.5.1 Annual In-Campus Private Car Emissions

Considering a 9 months academic year, and considered the working days, total CO_2 produced by all campus private car travelers was calculated as 2000.0 ton CO_2, and for the 3 month summer holiday, without students the total CO_2 was calculated as 495.3 ton. Totally, annual METU in-campus CO_2 emission by private car was found as 2495.3 ton. This in-campus CO_2 emission values is not meaningful to compare with the other university's carbon emissions, because they calculated their emissions starting from home to campus not only in-campus. On the other hand, we can check the change in the last 10-year period for METU campus. Gokbulut (2003) stated that the number of private car entering to campus was only 2530 vehicles between 08:00 and 17:00. Today, this number rises to approximately 8500 private cars at these hours and results in 216% increase in carbon emissions, which is extremely high increasing percentage. That is why developing sustainable campus transportation is important for METU campus.

6.5.2 Campus Emission Cost of Private Car Use by Students

The vehicle-km by undergraduate and graduate students (excluding the research assistants that have academic permits) constituted approximately 30% of the daily vehicle-km. The emission cost of private car use by students was found by performing a traffic assignment with students and without students for every three period (see Table 6.11). Then, the change in vehicle-km and change in carbon emissions were calculated. For example, with the student O-D the off-peaks of vehicle-km was found as 31406 whereas, without student O-D the total vehicle-km was determined as 21092.8. Similarly, with the student O-D data, off-peak CO_2 emission was found as 7433.4kg, but without student travels, this amount fell to the 4978.8 kg. The difference between the old value and the new one gives the emission cost of the students at off-peak hours, which is 3027.1 kg CO_2. Finally, without student travels, daily car-based vehicle km was reduced to 29665.8, which correspond to 29.4% reduction and CO_2 emission was reduced by 30.1%.

Table 6.11 Carbon emissions without student demand

Speed km/h	Vehicle-km	(%)	CO_2 (kg)	CO (kg)	ΔVehicle-km	ΔCO_2 (kg)	ΔCO_2 (kg)
	Off-peak emissions w/o student cars					**Emission Cost**	
0-5	547.8	2.6	374.1	1.3	-319.4	-218.2	-0.8
5-15	2262.1	10.7	730.7	5.0	-1124.1	-363.0	-2.4
15-30	10306.6	48.9	2246.8	21.6	-4571.8	-996.7	-9.6
30-50	7976.3	37.8	1627.2	14.4	-4297.9	-876.7	-7.7
Total	**21092.8**	**(100.0)**	**4978.8**	**42.3**	**-10313.2**	**-2454.6**	**-20.5**
	Morning Peak Emissions w/o student cars						
0-5	121.5	2.5	83.0	0.3	-164.9	-112.6	-0.4
5-15	962.4	19.5	310.9	2.1	-46.7	-15.0	-0.2
15-30	1996.9	40.5	435.3	4.2	-390.6	-40.8	-1.0
30-50	1845.1	37.5	376.4	3.3	-335	-109.9	-0.6
Total	**4925.9**	**(100.0)**	**1205.6**	**9.9**	**-937.2**	**-278.3**	**-2.2**
	Evening Peak Emissions w/o student cars						
0-5	95.3	2.6	65.1	0.2	-29.1	-19.9	-0.1
5-15	383.1	10.5	123.7	0.8	-404	-130.5	-0.9
15-30	1783.3	48.9	388.8	3.7	-275.5	-59.9	-0.6
30-50	1385.6	38.0	282.7	2.5	-410.3	-83.7	-0.7
Total	**3647.3**	**(100.0)**	**860.3**	**7.2**	**-1118.9**	**-294**	**-2.3**
	Daily Emissions w/o student cars (sum of off-peak and peak hour emissions)						
0-5	764.4	2.6	522.1	1.8	-513.7	-350.8	-1.3
5-15	3607.6	12.2	1165.3	7.9	-1574.8	-508.5	-3.5
15-30	14086.8	47.5	3070.9	29.6	-5237.9	-1097.4	-11.1
30-50	11207.0	37.8	2286.2	20.2	-5043.2	-1070.4	-9.0
Total	**29665.8**	**(100.0)**	**7044.5**	**59.5**	**-12369.5**	**-3027.1**	**-24.9**

6.5.3 Campus Emission Cost of Short Stay Trips

As explained in Section 5.1.4, 45% of trips to METU campus, have a stay time of less than 15 minutes. Furthermore, majority of these trips happen between 08:15-09:15 and between 17:15-18:15 hours. As congestion is observed during the peak hours only, if the short trips during the peak hours can be decreased, so can the emission be. The O-D analysis of these trips showed that they could be from and to the same gate, such as A4-A4, or a travel from one major gate to another, such as A4-A7.

While it may not be feasible to keep such shuttle services all day long, the policy may focus on providing such services intensely during the peak hours. A traffic assignment without short trips from/to A1, A4 and A7 (except A7 to A7 and Technopolis workers) during the peak hours showed that CO_2 cost of these short stays was 413.4 kg CO_2. Finally, total CO_2 reduction was found as 18.4% and 12.1% for the morning and evening peak hours, which would be equal to a reduction in daily emissions by 3.7% (see Table 6.12).

Table 6.12 Carbon emission cost of short stay trips during peak hours

	Vehicle-km	**Δ (%)**	**CO_2 (kg)**	**Δ (%)**	**CO (kg)**	**Δ (%)**
Base Case Results						
Total	**42035.3**	**---**	**10071.6**	**---**	**84.4**	**---**
am-peak	*5863.1*	---	*1483.9*	---	*12.1*	---
pm-peak	*4766.2*	---	*1154.3*	---	*9.5*	---
Results w/o short stay trips during peak hours						
Total	**40647.3**	**---**	**9658.2**	**---**	**81.3**	**---**
am-peak	*4941.3*	---	*1210.2*	---	*9.9*	---
pm-peak	*4300.0*	---	*1014.6*	---	*8.6*	---
Cost of short stay trips during peak hours						
Total	**1388.0**	**3.3**	**413.4**	**4.1**	**3.1**	**3.7**
am-peak		*15.7*		*18.4*		*16.0*
pm-peak		*9.8*		*12.1*		*10.7*

CHAPTER 7

ASSESSMENT OF SUSTAINABLE TRANSPORTATION SCENARIOS FOR METU

Once the base case is determined with insights on campus travel characteristics, it is possible to develop sustainable transportation policy scenarios and estimate their impact on carbon emissions numerically. Looking at the policy tools, one can focus on plans to regulate private car usage by different traveler groups. Students are expected to be the least sensitive ones to private car usage restrictions, as other travelers have higher probability of trip chaining (leaving children to school or nursery, attending meetings at other locations, etc.) before or in the campus. Though it is not possible to eliminate all private car access for students, it is possible to manage this demand by pricing to some extent. Before focusing on the demand management scenarios, it is important to understand the need for private car use by students. A survey among the student sticker holders showed that the main motivation factors to come by car were late stay on campus (due to studio studies in planning and architecture departments) and poor or non-existence of campus access via public transit of certain neighborhoods. Restricting private car use for students in campus and encouraging them to use public transportation would require better accessibility to- and within- the campus via transit modes, such as, public bus services and shuttles. Furthermore, it may be necessary to support the students with biking options, especially from main gates to the core campus.

As a second tool of demand management, one can focus on the travel demand during the peak hours; especially the very short stay trips (stay time less than 15 minutes). Before developing any policy to eliminate them, it is important to understand the nature of them: They may be drop-off/pick-up trips for METU students/workers by other family members; or they are simply Technopolis workers entering from A7 and A4. Though it is not that easy to forbid such short trips for everyone, they can be discouraged by providing better in-campus shuttle services from the two main gates of A1 and A4 to the academic units.

Furthermore, the literature of sustainable campus transportation plans show that many universities try to support bicycle as a non-motorized mode. Creating a bicycle network with defined bikeways and storage areas, and providing a bike share service are very crucial to encourage this mode. However, when introducing this mode to a community for the first time, major concerns arises on the safety issues. As biking has not been used as a travel mode in Turkey, and especially in Ankara, it is very crucial to design bike lanes either physically separate or as a separate lane on the road, if not via totally segregated lanes, at the beginning.

7.1 Scenario Development

After considering the policy tools discussed above, a series of sustainable campus transportation scenarios (see Table 7.1) is developed for METU campus. The first scenario focused on the impact of road capacity reduction due to introduction of bicycle lanes with the current private car demand (Scenario 1). The second scenario focused on analyzing the impact of reducing private car use by students (Scenarios 2.a, 2.b and 2.c). Since the response to any sticker price change is not studies, student response to modeled with two stage: a) a low reduction in private car use (20%) for a low increase in student sticker price, and b) a high reduction in private car usage (40%) for a significantly high increase in price (but, in order to achieve such a big reduction, we assume that in-campus shuttle connections from the main gates to the academic units needed to be improved). Even a 50% reduction in student private car demand is foreseen if the in-campus biking lanes are introduced as Scenario 2.c.

The third scenario targeted no reduction in demand but merely redirecting Technopolis workers to A7; thus, this scenario simply aims to reduce congestion along the main axes of the road network. Finally, impact of opening of the metro station at the A1 gate, which will greatly change the commute behavior of some of the METU campus users, is studied. While Scenario 4.a assumes a small reduction (20%) in private car usage for all traveler groups, a more substantial change in student (Scenarios 4.b) and administrative personnel (Scenario 4.c) private car usage. As a more comprehensive plan, after the opening of the metro a low increase in student sticker prices with improved in-campus shuttle services is assumed to reduce student demand up to 50% in Scenario 4.d, which is further assumed introduction of biking lanes in Scenario 4.e.

Table 7.1 Scenarios and reduction in private car demand information for different travelers

#	Scenario	% Reduction in private car demand			
		Student	Admin.	Academic	Others
1	Introduction of bicycle lanes with the current demand	---	---	----	---
2.a	Low increase in student sticker price	20	---	---	----
2.b	High increase in student sticker price with improvement of in-campus shuttle	40	---	---	----
2.c	High increase in student sticker price, improvement of in-campus shuttle and introduction of bicycle lanes	50	---	---	----
3	Redirecting Technopolis workers to A7 during peak hours	---	---	---	---
4.a	A small modal shift after the opening of metro station	20	20	20	20
4.b	Modal shift after the opening of metro station w/ a stronger usage by students	40	20	20	20
4.c	Modal shift after the opening of metro station w/ a stronger usage by students and administrative personnel	40	40	20	20
4.d	Modal shift after the opening of metro station, low increase in student sticker price, improvement of in-campus shuttle	50	20	20	20
4.e	Modal shift after the opening of metro station, high increase in student sticker price, improvement of in-campus shuttle, and bicycle lanes	50	20	20	20

In evaluating all these scenarios, first, demand matrices for the selected traveler groups at the defined reduction rates and/or redirections are created and assigned to the network via PTV VISUM. The vehicle-km and speed profiles on the road segments are used to calculate emissions as discussed above. The total change in daily and/or peak-hour vehicle-km and emissions is obtained to assess the scenario. The results of these assessments are given in detail in the following sections.

7.2 Scenario 1: Impact of Road Capacity Reduction due to Introduction of a Bike Lane Network

We assume a bicycle network as shown in Figure 7.1: the proposed bikeways start from A1 to A4 with two sides of the road, and A1 to Demiraylar dormitories, and A4 to Demiraylar dormitories. As the campus road widths are around 3.6 m, it is possible to use narrow lanes of 2.7 and create a 0.9-1m (with some sidewalk alterations) bike lanes. Though this policy is not related to reduction of private car usage, it is important to see its impact on the road capacity and congestion under the base case private car demand.

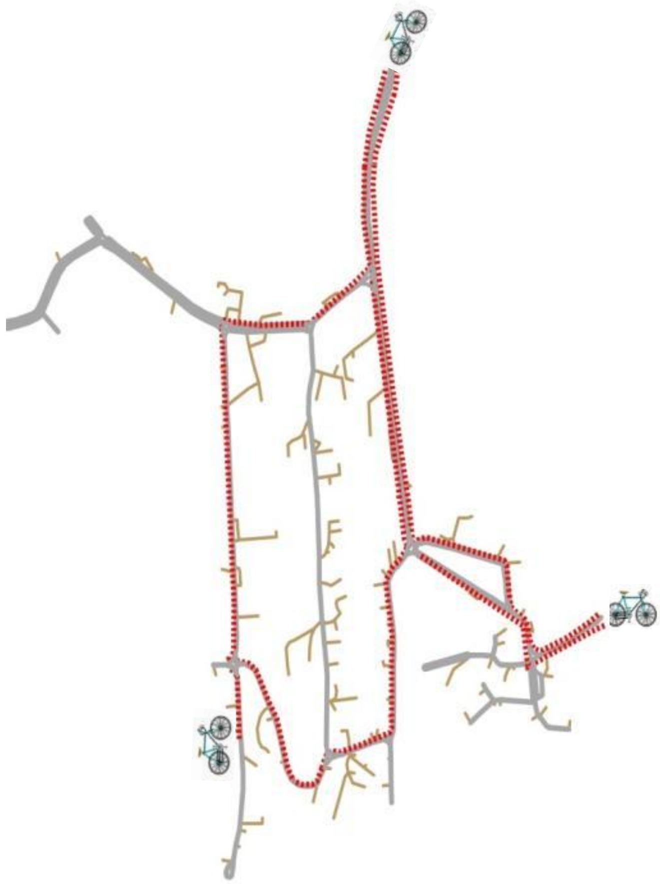


Figure 7.1 Proposed bike lane network for METU campus

To model this in PTV VISUM, campus network link attributes were changed as follows:

i) Link speed limits were reduced by 10 km/h as recommended by Highway Capacity Manuel (2000)
ii) Due to speed limit decrease, the link hourly capacities were reduced from 600cars/h/lane to 400cars/h/lane.

A proposed campus bike network is presented in Figure 7.1. Under the current demand levels, the off-peak and peak hour assignments were repeated with this new campus road network. The encouragement of biking with such a network is expected to decrease the speeds, thus increase the emissions. However, the small level of congestion on campus, wherever it occurs, showed only a 10.7% increase in daily emissions (see Table 7.2). During peak periods, this increase was found as 27.6% for morning and 24.5% for evening peak. However, besides their small impact on the private car congestion and emissions, it is important to see that majority of these bike lanes will be flowing through campus corridor segments most commonly used by cars. Especially intersections must be designed and signalized with separate bike phases, wherever necessary.

Table 7.2 Increase in carbon emissions due to the bicycle lanes

	Vehicle km	**Δ (%)**	**CO_2 (kg)**	**Δ (%)**	**CO (kg)**	**Δ (%)**
Base Case Results						
Total	**42035.3**	**---**	**10071.6**	**---**	**84.4**	**---**
am-peak	*5863.1*	---	*1483.9*	---	*12.1*	---
pm-peak	*4766.2*	---	*1154.3*	---	*9.5*	---
off-peak	*31406.0*	---	*7433.4*	---	*62.8*	---
Scenario #1 Results						
Total	**42069.9**	**0.1**	**11153.8**	**10.7**	**86.2**	**2.1**
am-peak	*5906.0*	*0.7*	*1894.0*	*27.6*	*12.7*	*7.1*
pm-peak	*4773.1*	*0.1*	*1436.9*	*24.5*	*10.1*	*5.6*
off-peak	*31390.8*	*0.1*	*7822.9*	*5.2*	*63.4*	*0.9*

Figure 7.2 indicates the daily speed profile of the campus roads after the proposed bike network implementation. With the same demand, the critical road segments were found "*A4 to b*" and" *j to i"* "which speed decreased below 15 km/h. However, the other parts of the campus roads did not effect as much as these road segments. On the other hand, For the morning peak (see Figure 7.3), after the bike network implementation the critical road segments were starting from "*A4 to d"*, "*d to A4","d to g"," n to k"," j to i"," i to j"*. For the evening peak(see Figure 7.4), the critical ones were *"A to d", "d to A4", "d to g", "j to i", "i to j", i to h".*

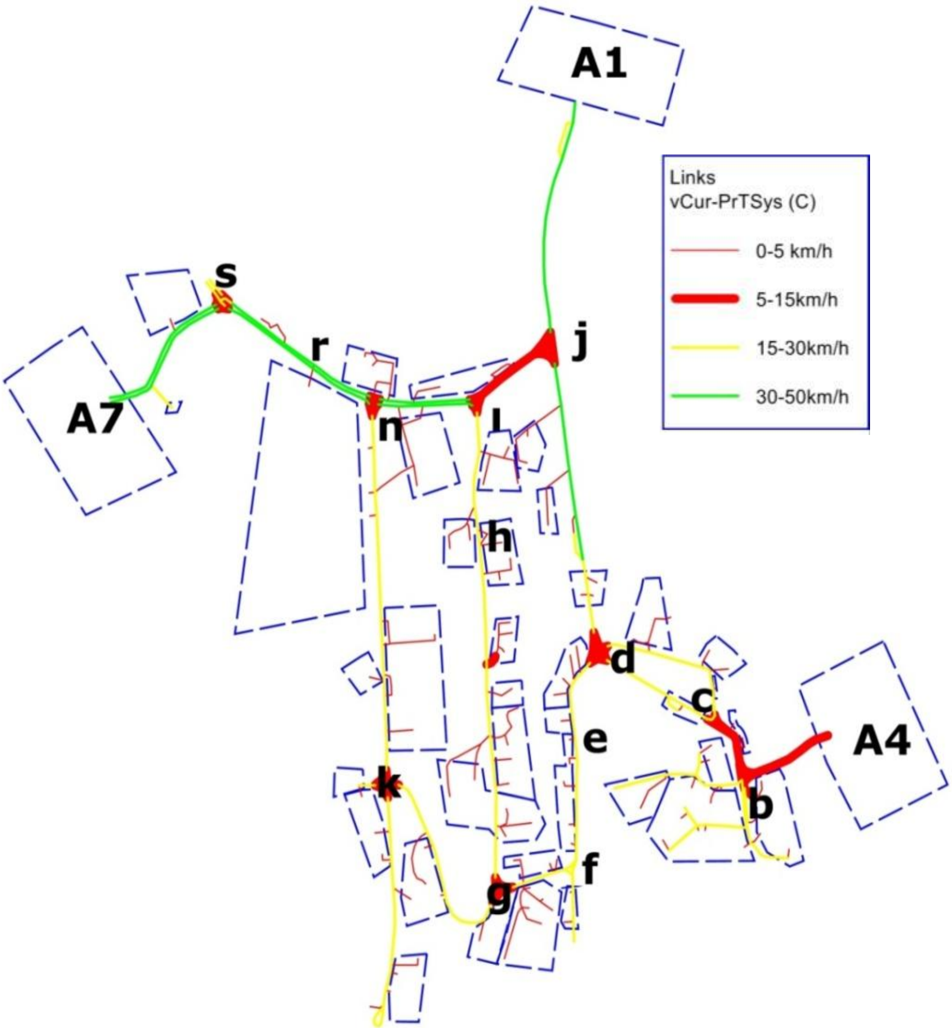


Figure 7.2 Speed profile of METU campus roads after purposed bike network implementation

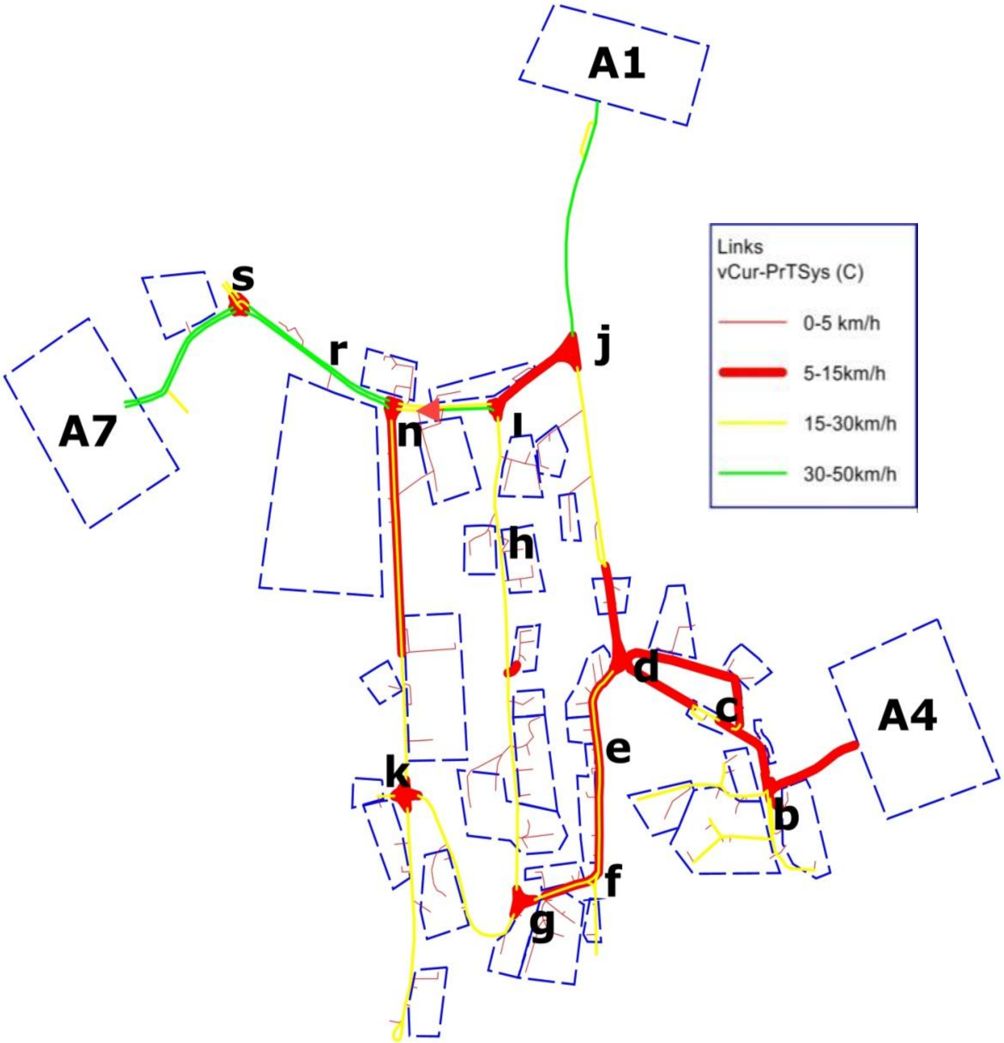


Figure 7.3 Speed profile of METU campus at the morning peak after proposed bike network implementation

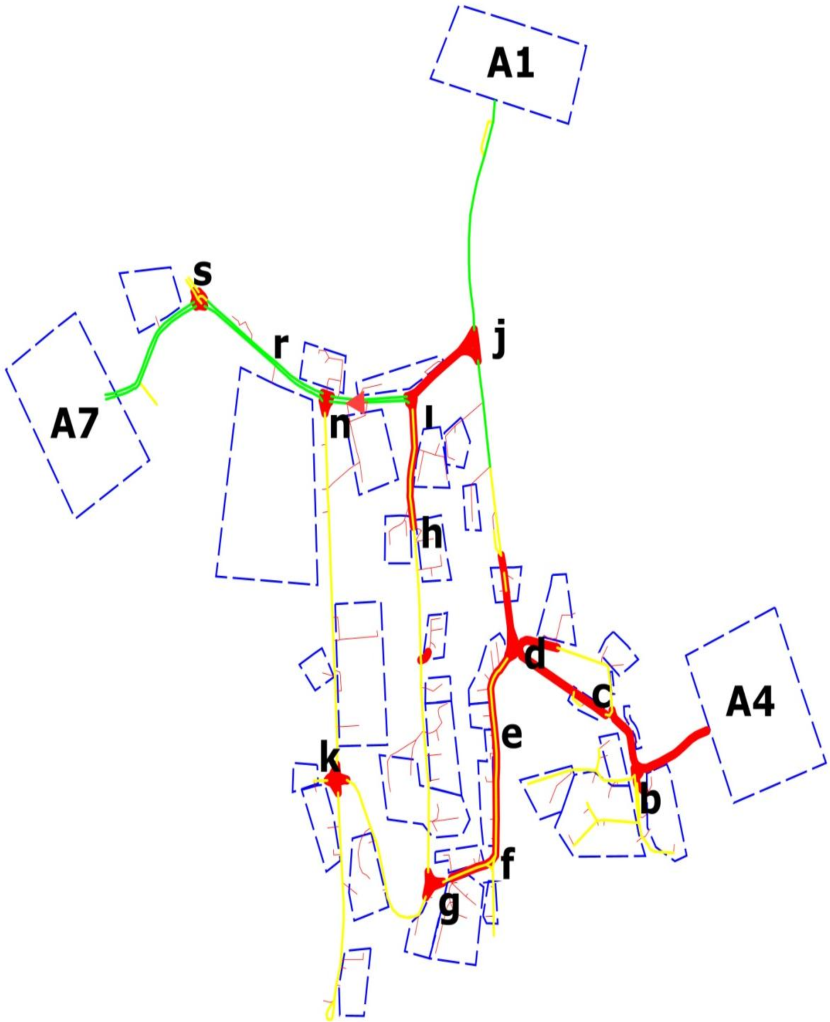


Figure 7.4 Speed profile of METU campus at the evening peak after proposed bike network implementation

7.3 Scenario 2: Reducing of Private Car Use in Campus by Students

Assumed student demand reductions in Scenarios 2.a to 2.c are studied producing the emission values presented in Table 7.3 For the first scenario, if low increase in student price caused 20% reduction in current private car demand, the results showed that the reduction in vehicle-km is 6.2% and carbon emission reductions are 6.1% and 5.9% (see Table 7.3). For the second scenario, high increase in student sticker price and implementing in-campus bus shuttle was assumed to reduce the current demand 40%, and these resulted in 12.2% reduction in total vehicle-km, and 12.0% and 11.9% reduction in CO_2 and CO, respectively. For the third scenario, besides these two TDM implementations, if biking system was implemented and student private car demand was reduced 50%, daily vehicle-km was reduced 15.2%. Since narrow lanes create congestion at peak hours, although the vehicle-km was reduced, CO_2 emission increased 15.0% and 5.5% at morning and evening peak hours. Finally, daily emission reductions were found as 8.3% for CO_2 and 13.6% for CO.

Table 7.3 Carbon emission reductions by implementing TDM strategies for student private car users

	Vehicle km	Δ (%)	CO_2 (kg)	Δ (%)	CO (kg)	Δ (%)
Base Case Results						
Total	**42035.3**	**---**	**10071.6**	**---**	**84.4**	**---**
am-peak	*5863.1*	---	*1483.9*	---	*12.1*	---
pm-peak	*4766.2*	---	*1154.3*	---	*9.5*	---
off-peak	*31406.0*	---	*7433.4*	---	*62.8*	---
Scenario #2.a Results						
Total	**39421.0**	**6.2**	**9461.6**	**6.1**	**79.4**	**5.9**
am-peak	*5715.2*	***2.5***	*1449.5*	***2.5***	*11.9*	***2***
pm-peak	*4526.3*	***5.0***	*1096.2*	***5.0***	*9.0*	***5.1***
off-peak	*29179.5*	***7.1***	*6915.9*	***7.0***	*58.5*	***6.8***
Scenario #2.b Results						
Total	**36909.1**	**12.2**	**8859.8**	**12.0**	**74.3**	**11.9**
am-peak	*5482.4*	***5.4***	*1392.2*	***5.8***	*11.4*	***5.9***
pm-peak	*4306.3*	***9.6***	*1037.7*	***10.1***	*8.6*	***9.8***
off-peak	*27120.4*	***13.6***	*6429.9*	***13.5***	*54.4*	***13.4***
Scenario #2.c Results						
Total	**35661.6**	**15.2**	**9238.6**	**8.3**	**72.9**	**13.6**
am-peak	*5428.2*	***7.4***	*1709.2*	***-15.0***	*11.6*	***2.3***
pm-peak	*4173.1*	***12.4***	*1218.4*	***-5.5***	*8.8*	***8.7***
off-peak	*26060.3*	***17.0***	*6311.0*	***15.1***	*52.5*	***16.6***

7.4 Scenario 3: Redirecting Technopolis Workers to A7 Totally

As explained in Section 5.2.2, there were many numbers of trips starting from A4 and destined to Technopolis in the morning. Similarly, there were many numbers of trips starting from Technopolis to A4 in the evening. To prevent these vehicles from crossing the campus, and to decrease congestion on certain roads especially at peak hours, if all Technopolis workers are directed to A7 gate, which is the closest gate to Technopolis and vehicles do not have a chance to cross the campus, the potential emission reduction was searched. Developed O-D matrix was assigned to the network and vehicle-km reduction and emission results are presented in Table 7.4. Redirecting Technopolis workers from A4 to A7 gates during peak hours reduced the vehicle-km by 4.9% and 1.8% at peak hours and daily reduction was 0.9%. Moreover, CO_2 emission reduction rate for morning and evening peak hours was 8.3% and 2.0% and daily CO_2 reduction was found as 1.4%.

Table 7.4 Carbon emissions reduction by redirecting Technopolis workers to the A7 gate

	Vehicle km	Δ (%)	CO_2 (kg)	Δ (%)	CO (kg)	Δ (%)
Base Case Results						
Total	**42035.3**	**---**	**10071.6**	**---**	**84.4**	**---**
am-peak	*5863.1*	---	*1483.9*	---	*12.1*	---
pm-peak	*4766.2*	---	*1154.3*	---	*9.5*	---
Scenario #3 Results						
Total	**41665.3**	**0.9**	**9925.9**	**1.4**	**83.4**	**1.2**
am-peak	*5578.2*	***4.9***	*1360.8*	***8.3***	*11.2*	***5.2***
pm-peak	*4681.1*	***1.8***	*1131.7*	***2.0***	*9.4*	***1.9***

7.5 Scenario 4: Modal Shift after Metro Station Opening

The analysis of scenarios based on metro opening is summarized in Table 7.5. Firstly, with the opening of the metro line, it was assumed that reduction in private car demand for all traveler groups was 20% and these resulted in 21.1% reduction in vehicle-km and 21.5% CO_2 and 20.9% CO reduction in a day. Secondly, with the opening of the metro line and low increase in student price; the current private car demand of students was reduced 40% and the travel demand of other traveler groups was reduced 20%. As a result, daily vehicle-km reduced 27.1%, CO_2 emission reduced 27.4%, and CO emission reduced 26.9% in a day.

Thirdly, it was assumed that if 40% of the administrative personnel use metro and again low increase in student sticker prices (assumed 40% reduction in student private car demand) and the remaining groups were reduced 20%. The assignment results showed that 28.9% reduction in daily vehicle-km and 29% reduction in daily emissions, which are slightly high emission reduction than the second scenario. Fourthly, if the student private car demand reduced 50% and the other different travelers reduced 20%, because of the opening of metro station, high increase in student sticker price and in campus bus shuttle implementation, the results showed that 30.1% reduction in daily vehicle-km, and 26.7% and 29.1% reduction in CO_2 and CO. Finally, the last scenario was, with the same reduction percentages for different travelers in policy 4.d; if biking network was implemented, the total reduction in vehicle-km was found as 30.1%, and CO_2 emission reduction was 26.7% and CO emission reduction was 29.1%.

Table 7.5 Modal shift scenarios and effect on daily emission

	Vehicle km	Δ (%)	CO_2 (kg)	Δ (%)	CO (kg)	Δ (%)
Base Case Results						
Total	**42035.3**	**---**	**10071.6**	**---**	**84.4**	**---**
am-peak	*5863.1*	---	*1483.9*	---	*12.1*	---
pm-peak	*4766.2*	---	*1154.3*	---	*9.5*	---
off-peak	*31406.0*	---	*7433.4*	---	*62.8*	---
Scenario #4.a Results						
Total	**33150.2**	**21.1**	**7908.2**	**21.5**	**66.8**	**20.9**
am-peak	*4691.1*	***20.0***	*1151.5*	***22.4***	*9.7*	***19.7***
pm-peak	*3810.7*	***20.0***	*899.2*	***22.1***	*7.6*	***20.4***
off-peak	*24648.4*	***21.5***	*5857.5*	***21.2***	*49.5*	***21.2***
Scenario #4.b Results						
Total	**30661.0**	**27.1**	**7315.3**	**27.4**	**61.7**	**26.9**
am-peak	*4460.0*	***23.9***	*1094.8*	***26.2***	*9.2*	***23.7***
pm-peak	*3589.9*	***24.7***	*846.1*	***26.7***	*7.1*	***25.1***
off-peak	*22611.1*	***28.0***	*5374.4*	***27.7***	*45.3*	***27.8***
Scenario #4.c Results						
Total	**29878.9**	**28.9**	**7124.9**	**29.3**	**60.2**	**28.7**
am-peak	*4326.6*	***26.2***	*1062.5*	***28.4***	*9.0*	***25.9***
pm-peak	*3489.9*	***26.8***	*821.9*	***28.8***	*6.9*	***27.2***
off-peak	*22062.4*	***29.8***	*5240.5*	***29.5***	*44.3*	***29.5***
Scenario #4.d Results						
Total	**29367.9**	**30.1**	**7001.8**	**30.5**	**59.1**	**30.0**
am-peak	*4368.4*	***25.5***	*1072.9*	***27.7***	*9.1*	***25.2***
pm-peak	*3457.2*	***27.5***	*814.9*	***29.4***	*6.9*	***27.8***
off-peak	*21542.3*	***31.4***	*5114.0*	***31.2***	*43.2*	***31.2***
Scenario #4.e Results						
Total	**29378.2**	**30.1**	**7381.4**	**26.7**	**59.8**	**29.1**
am-peak	*4387.5*	***25.2***	*1320.7*	***11.0***	*9.5*	***21.6***
pm-peak	*3456.7*	***27.5***	*946.5*	***18.0***	*7.2*	***24.7***
off-peak	*21534.0*	***31.4***	*5114.2*	***31.2***	*43.2*	***31.2***

7.6 Evaluation of METU Campus Scenarios

The assessment of the different scenarios developed for METU campus travel demand showed that significant reduction in daily carbon emissions (up to 30%) can be achieved. Even a low increase in student sticker prices may be an effective way producing a 6% reduction in daily vehicle-km and CO_2 emissions. With a more aggressive approach in pricing and some support in in-campus shuttle services 40% reduction in student private car use can resulted in 12% reduction in daily vehicle-km. Similarly, any change that can reduce private car demand may help reducing in-campus emissions: For example, opening of the metro station at the A1 may cause a reduction in campus access by private car, which will reduce emissions directly.

However, managing demand by academic personnel is somewhat more challenging. Because, these travelers do not necessary have strict work hours, such as 08:30-17:30, they have a more scattered commute times, which may be more difficult to manage by simple regulations. Also, there is still a significant portion of demand under "others" group which include a more diverse group of travelers, and may need different incentives or regulations to reduce their emission costs. Forcing Technopolis workers to use A7 gate does not provide considerable change in daily emissions, but this policy alleviates the current traffic congestion at the peak hours and decreases the current carbon emissions by 8.3% at the morning peak and 2.0% at the evening peak.

At this point, it is important to see the relationship between the vehicle-km and carbon emissions for different scenario results, to clearify the affecting factors in emission reductions. Figure 7.5 shows the the relation between the vehicle-km reduction rates and CO_2 emissions which were obtained from the developed scenarios. The reduction rate of CO_2 emission is almost same value as the reduction rate of vehicle-km at off-peak hours and daily. However, since traffic congestion occurs during peak hours, the reduction rate of CO_2 are not the same as the reduction rate of vehicle-km. It is slightly higher than the reduction rate of vehicle-km. For the bike network scenarios, since the capacity of the links were changed, the change in CO_2 is not always a reduction and caused an increase which is shown with the negative values in the reduction axis. The relation between the vehicle-km and CO showed similar behaviour that is shown in Figure 7.6.

In addition, Figure 7.7 and Figure 7.8 represent the vehicle-km values with the corresponding CO_2 and CO emissions for peak hours and off-peak hours, respectively. There is a linear relationship between the vehicle-km and carbon emissions in both cases; higher vehicle-km resulted in higher carbon emissions. The linearity of the relation show that the main factor of emissions (or reductions in emissions) depends mainly on the vehicle-km generated. The milder slope of the best fit line (0.2975) for the evening (pm) peak suggests that the average gram of CO2 emission is smaller for unit distance, thus, average operating speeds are higher, which means less congestion, in this peak hour. However, this slope is smaller than the off-peak values of (0.244), which mean a smaller carbon emission per unit distance during the off-peak hours. The linearity of the vehicle-km and emission values is stronger with an R^2 value of 0.9886, reminding the fact that if there is no congestion, the emission is simply the function of vehicle-km.

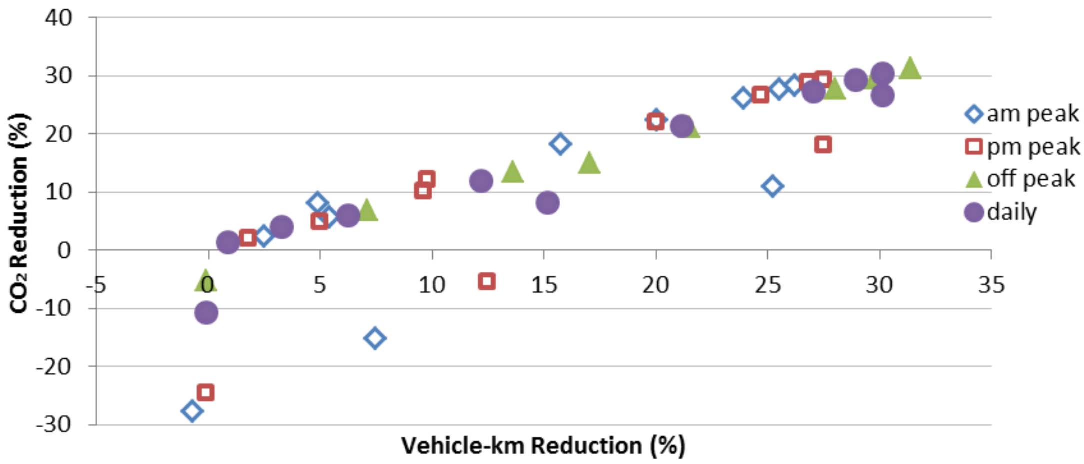


Figure 7.5 Scenario results for vehicle-km reduction versus CO_2 reduction for the different analysis periods

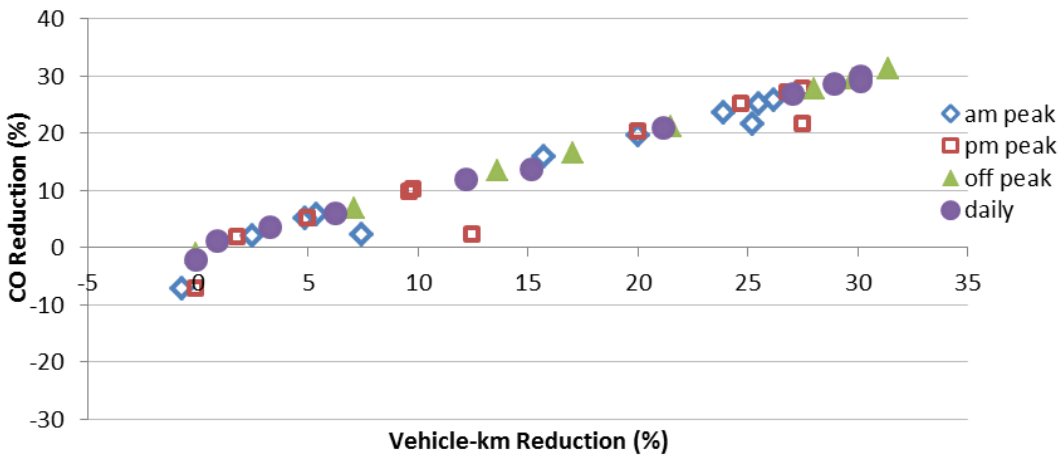


Figure 7.6 Scenario results for vehicle-km reduction versus CO reduction for the different analysis periods

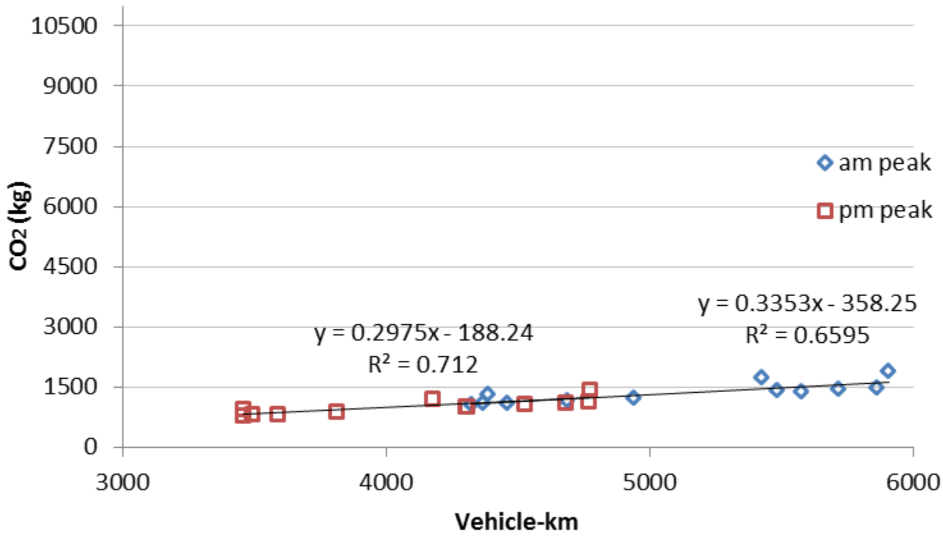


Figure 7.7 Peak hour vehicle-km versus CO_2 emissions for studies scenarios

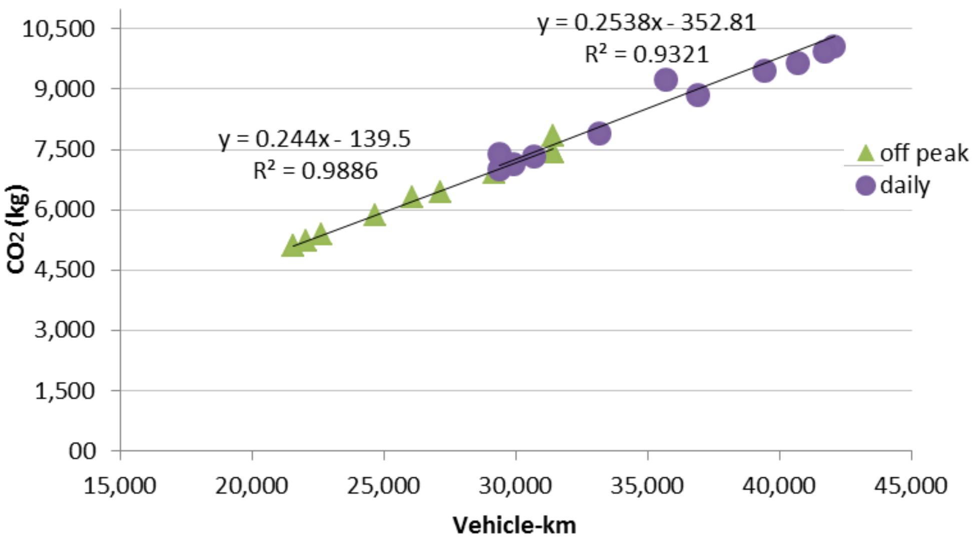


Figure 7.8 Off-peak and daily vehicle-km versus CO_2 emissions for studies scenarios

CHAPTER 8

CONCLUSIONS AND FURTHER RECOMMENDATIONS

8.1 Conclusions

In this study, travel demand characteristics of METU campus have been studied. Travel demand analyses were performed with gate RFID data and video security data from gates and with parking lots. Daily profiles of the all three gates were examined separately. It was found that A1 and A4 gate were most used gates when comparing with A7 gate. Also, the most congested hours were determined as 08.15-09:15 at the morning and 17:15-18:15 at the evening.

Trips detected based on the gate RFID data were further used to determine the travel behavior of different sticker holder types in a day. Each sticker holder type has similar travel behavior that majority of the entries to campus are around 08:00-09:00 and they have a scattered evening peak starting from 15:00 to 19:00. Academic personnel have a more diverse evening departure time pattern compared to administrative personnel that sharply leave between 17:00-18:00. Students entry time start to increase after 08:00 and majority of entries are around 09:00-10:00. The exits of students start from 08:00 and gradually increase up to noontime and they have scattered evening exiting peak starting from 15:00 to 20:00.

Campus stay time analysis showed that there had been a great number of vehicles were staying in campus less than 15 minutes. Especially, these trips were dominant at morning and evening peaks and continued in a day. For the long stay trips, 1 hour to 5 hours stays did not show any dominant entry time interval, but a bit more active in afternoon hours. The entry time of 5 hours to 10hours and more than 10 hours stays were morning hours as expected.

For the traffic assignment part, though there is small traffic congestion only at certain roads during the peak hours, the current travel demand in METU campus showed a daily 42035.3 vehicle-km by private cars with 10071.6 kg CO_2 and 84.4 kg CO. Yearly, METU in-campus private car CO_2 emission was found as 2495.3 ton.

Analysis of different scenarios created based on the traveler characteristics and commute patterns, as well as possible road network and modal changes, showed that the main cause of the in-campus private car emissions is the vehicle-km values. Though, slight congestion during the morning and evening peaks contribute to some increase in the emissions, it is still not that big, thus any traffic management tools such as real-time intersection control, etc. is not necessary at this moment. The policies that would be developed to reduce emissions and increase sustainability in transportation for METU campus must focus on creating modal shift from private car to public or shared-rides. This may probably need integration of approaches developed to manage access-to campus with in-campus accessibility.

Furthermore, introducing bicycle lanes is a common project among sustainable campus transportation programs, but before implementing this system, if the current demand is not reduced, it will simply cause some increase in the emissions. Also, the current private-car demand must be decreased for the safety of biking on campus. Opening of the metro station may be the most effective implementation to reduce private car demand in-campus, but this implementation must be supported with the other "Transportation Demand Management" strategies, such as improving in-campus bus shuttle, introducing bicycle lanes, and increasing in sticker prices to achieve the sustainable campus transportation.

8.2 Further Recommendations

In this study, only private car based travel demand was studied. However, taxi mobility played an important role in campus mobility (over 1100 taxis enter to campus in a day) Estimating the cost of taxi trips in-campus should be studied in future research, in hope to find some insights for improvements for in-campus connectivity.

As a second stage, the emission cost of public transit use should be calculated to find the average emission value per traveler for METU campus. This way, we can produce more scenarios that would consider modal shift from private car to in-campus shuttles and public transit; following that we can calculate the net change of modal shifts in terms of emissions. Eventually, like many universities in the USA, campus carbon emissions should be calculated starting from home to campus. But, this requires comprehensive travel surveys, which should be done in the future. To divert travelers from private car usage, a more comprehensive public transportation planning must be done with the municipality. Additionally, shared-ride modes such as car-pooling and car-sharing must be considered and encouraged by the university administration.

Another aspect of sustainable campus transportation is the encouragement of walking on campuses, this part has not been addressed at all in this study, but should be evaluated separately based on the current levels of motorized traffic, walkway capacities, and their conflict points. For example, the high pedestrian traffic along the mostly used corridors is creating safety problems for pedestrians and congestion for the vehicular traffic.

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APPENDIX A

OVERVIEW OF SUSTAINABLE CAMPUS TRANSPORTATION PROGRAMS IN THE USA AND CANADA

Table A.1 Sustainable campus transportation implementations in universities

Drake University				
Campus Size: 5,217 students ; 362 staff ; Urban: 150 acres				
S**CT Goals/Measures:** Decrease the use of personal cars to reduce vehicle emissions				
Sustainable Transportation Implementations				
Biking	**Pedestrian**	**Ride-sharing**	**Public Transit**	**Parking Policy**
Encourage Bikeways		Purchasing vehicles	Free Bus system	
Drury University				
Campus Size: 5474 students, Urban: 88 acres				
S**CT Goals/Measures:**				
Sustainable Transportation Implementations				
Biking	**Pedestrian**	**Ride-sharing**	**Public Transit**	**Parking Policy**
Encourage Bikeways	Improve Walking Paths	Car-pooling	Mass transit	
Emory University				
Campus Size: 12,736 students, Suburban: 631 acres				
S**CT Goals/Measures:**				
Sustainable Transportation Implementations				
Biking	**Pedestrian**	**Ride-sharing**	**Public Transit**	**Parking Policy**
Bike program plans		Shuttle system Car-sharing	Encourage transit system	
Florida Gulf Coast University				
Campus Size: 10,221students, 681 staffs, Suburban:760acres				
S**CT Goals/Measures:**				
Sustainable Transportation Implementations				
Biking	**Pedestrian**	**Ride-sharing**	**Public Transit**	**Parking Policy**
Bike program plans	Improve Walking Paths	Ride sharing plans		

Table A.1 Sustainable campus transportation implementations in universities (cont'd)

Florida State University				
Campus Size: 40,255 students, 6,129 staffs 2,150faculty membersUrban:395,15 acres **SCT Goals/Measures:** To reduce carbon emissions of vehicular traffic				
Sustainable Transportation Implementations				
Biking	**Pedestrian**	**Ride-sharing**	**Public Transit**	**Parking Policy**
Bike program plans	Improve Walking Paths		Fare-free transit services for all students, faculty, and staffs	Parking management
Brown University				
Campus Size: 8,000 students, Urban:143 acres **SCT Goals/Measures:**				
Sustainable Transportation Implementations				
Biking	**Pedestrian**	**Ride-sharing**	**Public Transit**	**Parking Policy**
	Pedestrian Friendly environment	Promote Car-pooling & Ride-sharing	Encourage Public Transit	Parking Management programs
Arizona State University				
Campus Size: 4 campuses; 68,000 students, 2800 faculty, Urban: Tempe: 631.6 acres Polytechnic: 612.99 acres, West: 277.92 acres, Downtown Phoenix: 27.57 acres **SCT Goals/Measures:** Minimize 100% of its carbon emission from transportation by 2035				
Sustainable Transportation Implementations				
Biking	**Pedestrian**	**Ride-sharing**	**Public Transit**	**Parking Policy**
Bicycle co-op	Pedestrian-Friendly environment	Car-pooling Intercampus shuttles	Encourage Public Transit	
Ball State University				
Campus Size: 5474 students, Urban: 88 acres **SCT Goals/Measures:**				
Sustainable Transportation Implementations				
Biking	**Pedestrian**	**Ride-sharing**	**Public Transit**	**Parking Policy**
Encourage Bikeways	Improve Walking Paths	Car-pooling	Mass transit	
Georgia Tech				
Campus Size: 20,291 students, 912 staffs, Urban: 400 acres. **SCT Goals/Measures:**				
Sustainable Transportation Implementations				
Biking	**Pedestrian**	**Ride-sharing**	**Public Transit**	**Parking Policy**
Bike paths/ bikeways	Pedestrian friendly	Van-pooling Car-pooling	Encourage mass transit	Parking transportation plan/ smart parks

Table A.1 Sustainable campus transportation implementations in universities (cont'd)

Carleton University				
Campus Size: 23,000 students, 2,000 staff				
SCT Goals/Measures:				
Sustainable Transportation Implementations				
Biking	**Pedestrian**	**Ride-sharing**	**Public Transit**	**Parking Policy**
Enhance bicycle commuting	Safe paths for pedestrians	Car-pooling programs	Encourage Public Transit	Parking permit program
Colorado College				
Campus Size: Urban: 90 acres				
SCT Goals/Measures:				
Sustainable Transportation Implementations				
Biking	**Pedestrian**	**Ride-sharing**	**Public Transit**	**Parking Policy**
Bike co-op	Pedestrian friendly	Car-sharing programs	Encourage Public Transit	
Clarion University				
Campus Size: 6,583 students, 286 staff, Rural Pennsylvanya				
SCT Goals/Measures: Reduce air pollution and carbon emission				
Sustainable Transportation Implementations				
Biking	**Pedestrian**	**Ride-sharing**	**Public Transit**	**Parking Policy**
Encourage Bikeways	Pedestrian friendly			
Harvard University				
Campus Size: 21,125 students, 12,000 staff, Urban: 380 acres				
SCT Goals/Measures:				
Sustainable Transportation Implementations				
Biking	**Pedestrian**	**Ride-sharing**	**Public Transit**	**Parking Policy**
Strong Bike commuting system	Pedestrian friendly	Zipcar/ Car-pooling	Passenger transport services/mass transit/public transit	
Pennsylvania State University				
Campus Size: 94,301students, 8,626 staff.(5 special campuses) 18,370acres				
SCT Goals/Measures:				
Sustainable Transportation Implementations				
Biking	**Pedestrian**	**Ride-sharing**	**Public Transit**	**Parking Policy**
Strong Biking system	Pedestrian Friendly campus		Design of efficient transit system	Parking plans

Table A.1 Sustainable campus transportation implementations in universities (cont'd)

Portland State University				
Campus Size: 24,284 students, 2,248staff, Urban: 49 acres **SCT Goals/Measures:**				
Sustainable Transportation Implementations				
Biking	**Pedestrian**	**Ride-sharing**	**Public Transit**	**Parking Policy**
Bike improvement	Pedestrians	Car-pooling Van-pooling	Subsidized Transit passes	
Michigan State				
Campus Size: 47,278 students, 6355 staff. Suburban:21km^2 USA **SCT Goals/Measures:** MSU is committed to reducing its carbon footprint by using energy efficient transportation.				
Sustainable Transportation Implementations				
Biking	**Pedestrian**	**Ride-sharing**	**Public Transit**	**Parking Policy**
Bikeway	Pedestrian safety	Zipcar Car-pooling	Mass transit	
Northern Arizona University				
Campus Size: 21,413 students, 2,248 staff. 740 acres **SCT Goals/Measures:** Decrease greenhouse emissions from commuting each year				
Sustainable Transportation Implementations				
Biking	**Pedestrian**	**Ride-sharing**	**Public Transit**	**Parking Policy**
İmprove bicycle access	Pedestrian friendly	Car-pooling Ride-sharing	Improve Public Transit	
SUNY Buffalo				
Campus Size: 28,192 students, 2,667 staff Suburban:1347 acres **SCT Goals/Measures:** Smaller environmental footprint				
Sustainable Transportation Implementations				
Biking	**Pedestrian**	**Ride-sharing**	**Public Transit**	**Parking Policy**
Encourage Bikeways	Pedestrian friendly			
UC Berkeley				
Campus Size: 35,800 students, Urban:6,651 acres California USA **SCT Goals/Measures:** By 2014, reduce fuel use by commuters and campus fleet to 25% below 1990 levels				
Sustainable Transportation Implementations				
Biking	**Pedestrian**	**Ride-sharing**	**Public Transit**	**Parking Policy**
Bicycle access planning	Strategic Pedestrians improvement plans		Transit subsides	Parking discounts for commuters who use alternative transportation

Table A.1 Sustainable campus transportation implementations in universities (cont'd)

UMACS

Campus Size:
SCT Goals/Measures:

Sustainable Transportation Implementations

Biking	Pedestrian	Ride-sharing	Public Transit	Parking Policy
Bike share program	Walking Paths	Car-sharing		

University of British Columbia

Campus Size: 51,700 students, Urban:402 ha
SCT Goals/Measures: Reduce GHS to 33 percent below 2007 levels by 2015. Provide a wide range of transportation choices for everyone at UBC

Sustainable Transportation Implementations

Biking	Pedestrian	Ride-sharing	Public Transit	Parking Policy
Cycling	Walking Paths	Car-pooling	Public transit	Parking management

University of Colorado

Campus Size: 30,196 students, 1,075 faculty. Urban: 786 acres USA
SCT Goals/Measures:

Sustainable Transportation Implementations

Biking	Pedestrian	Ride-sharing	Public Transit	Parking Policy
Biking	Walking Paths	Car-pooling	Bus program	

University of Florida

Campus Size: 50,691 students, 4,534 faculty. Urban 2,000 acres
SCT Goals/Measures: To reduce carbon emissions by purchasing alternative fuel vehicles

Sustainable Transportation Implementations

Biking	Pedestrian	Ride-sharing	Public Transit	Parking Policy
Bikeway	Walking Paths	Car-pooling Zipcar Motor-pool	Bus services	

University of Virginia

Campus Size: 20,102 students. Urban 1,682 acres
SCT Goals/Measures: To reduce carbon emissions by purchasing alternative fuel vehicles

Sustainable Transportation Implementations

Biking	Pedestrian	Ride-sharing	Public Transit	Parking Policy
Bikeways		Car-pooling Car-sharing service		Parking permit program

Table A.1 Sustainable campus transportation implementations in universities (cont'd)

UC Santa Barbara				
Campus Size: 20,559 students 1,054faculty. Suburban:1,055 acres California USA **SCT Goals/Measures:** By 2011, 75% of fleet purchases will be alternative fuel or ultra-efficient vehicles				
Sustainable Transportation Implementations				
Biking	**Pedestrian**	**Ride-sharing**	**Public Transit**	**Parking Policy**
Bicycle program	Walking Paths	Car-pooling Car-sharing	Bus programs	
University of Michigan				
Campus Size: 41,674 students, 6,238 staff. 3campuses 20,965 acres USA **SCT Goals/Measures:** By 2014, reduce fuel use by commuters and campus fleet to 25% below 1990 levels				
Sustainable Transportation Implementations				
Biking	**Pedestrian**	**Ride-sharing**	**Public Transit**	**Parking Policy**
Bicycles/ motorcycles	Walking Paths	Car-pooling Ride-sharing	Free bus services for faculty members and students	
University of NC				
Campus Size: 28,916students, 2,395 staff. Urban: 729 acres USA **SCT Goals/Measures:**				
Sustainable Transportation Implementations				
Biking	**Pedestrian**	**Ride-sharing**	**Public Transit**	**Parking Policy**
Bikeways	Walking Paths	Car-pooling Van-pooling Car-sharing Campus vehicles	Fare-free transit	
University of NH				
Campus Size: 14,752 students+586 staff Rural USA **SCT Goals/Measures:** Reduce greenhouse gas emissions: %50 by 2020				
Sustainable Transportation Implementations				
Biking	**Pedestrian**	**Ride-sharing**	**Public Transit**	**Parking Policy**
Bikeways	Walking Paths	Ride-sharing Car-pooling	Alternative fuel vehicles	
University of Oregon				
Campus Size: 22,386 students+1,666staff. Urban: 295acres USA **SCT Goals/Measures:**				
Sustainable Transportation Implementations				
Biking	**Pedestrian**	**Ride-sharing**	**Public Transit**	**Parking Policy**
Bikeways	Walking Paths	Car-pooling		Alternative fuel vehicles/ Parking policy

Table A.1 Sustainable campus transportation implementations in universities (cont'd)

University of Washington				
Campus Size: 42,907students ,16,174 staff, 5,803 faculty. Urban: 643acres **SCT Goals/Measures:**				
Sustainable Transportation Implementations				
Biking	**Pedestrian**	**Ride-sharing**	**Public Transit**	**Parking Policy**
Bikeways	Walking Paths	Car-pooling Van-pooling UW shuttles	U-PASS	Parking enforcement
University of Wisconsin				
Campus Size: 42,059students, 2,054faculty. Urban:933 acres Madison USA **SCT Goals/Measures:** To encourage and support comprehensive and compatible mixture of modes of transportation conducive to the health, safety, and well-being of all those living and working in and around the university				
Sustainable Transportation Implementations				
Biking	**Pedestrian**	**Ride-sharing**	**Public Transit**	**Parking Policy**
Safety bikes routes	Pedestrian routes	Car-pooling Van-pooling Ride-sharing	Encourage public transit	
University of Toronto				
Campus Size: 45,000students, 4,735 staffs, 2,551 faculty. Urban:176 acres **SCT Goals/Measures:** Reduce emissions, fossil fuel consumption, the consumption of agricultural land, park land and wildlife habitat				
Sustainable Transportation Implementations				
Biking	**Pedestrian**	**Ride-sharing**	**Public Transit**	**Parking Policy**
Bicycle facilities	Walking Paths	Car-sharing Car-pooling Van-pooling	Public transit use	Parking Management
Washington State				
Campus Size: 26,101 students+1,304 faculty Rural: 640acres **SCT Goals/Measures:** Reduce greenhouse gas emissions: %50 by 2020				
Sustainable Transportation Implementations				
Biking	**Pedestrian**	**Ride-sharing**	**Public Transit**	**Parking Policy**
Bicycle	Walking Paths	Car-sharing Car-pooling	Encourage public transit	
Cornell University				
Campus Size: 20,633 students, Small city 745 acres. 3 campuses in different country **SCT Goals/Measures:**				
Sustainable Transportation Implementations				
Biking	**Pedestrian**	**Ride-sharing**	**Public Transit**	**Parking Policy**
		Car-pooling Ride-sharing	Encourage public transit	Individual parking limits land use policies

Table A.1 Sustainable campus transportation implementations in universities (cont'd)

Yale University				
Campus Size: 11,593 students, 3,619 staffs. Urban 837 acres **SCT Goals/Measures:** A greenhouse gas reduction target of 43% below 2005 levels by 2020 by investigating sustainable fuel options				
Sustainable Transportation Implementations				
Biking	**Pedestrian**	**Ride-sharing**	**Public Transit**	**Parking Policy**
Enhance bicycle facilities	Walking Paths	Car-sharing Ride-sharing Van-pooling	Public transport shuttle services	
University of Kentucky				
Campus Size: **SCT Goals/Measures:**				
Sustainable Transportation Implementations				
Biking	**Pedestrian**	**Ride-sharing**	**Public Transit**	**Parking Policy**
Safety bikes routes	Pedestrian friendly		Encourage public transit	
New College of CA				
Campus Size: **SCT Goals/Measures:**				
Sustainable Transportation Implementations				
Biking	**Pedestrian**	**Ride-sharing**	**Public Transit**	**Parking Policy**
Bike network	Walking Paths		Encourage public transit	
Duke University				
Campus Size: 14,300 population **SCT Goals/Measures:**				
Sustainable Transportation Implementations				
Biking	**Pedestrian**	**Ride-sharing**	**Public Transit**	**Parking Policy**
	Walking Paths		Encourage public transit	

APPENDIX B

PARKING LOT SURVEY RESULTS

Table B.1 The capacities and distribution of parking lots in CTAZ

CTAZ	ID	Cap.	Description	CTAZ	ID	Cap	Description
I	65	60	Health Center	VI	17	60	Presidency
	66	10	1st Dormitory		19	80	Department of Physics
	67	35	2nd Dormitory		20	40	Department of Statistics
	68	20	Baraka Gym.		21	70	Cafeteria
	69	10	Swimming Pool		22,23	75	Engineering Science
	70	15	3rd Dormitory		24	50	Industrial Engineering
	71	15	Dorm. Territory	VII	25	70	Computer Center
	72	10	7th Dormitory		26,27	120	Dept. of Elect. and Electronics
	73	10	8th Dormitory		28,29,30	115	Civil Engineering
	74	10	Parlar Vakfı		31	15	Central Laboratory
	75	15	6th Dormitory		32,33,51,52	165	Mechanical Engineering
	76	30	Sami Kırdar Dorm.		34	50	Hydromechanics Lab.
	77	70	Faik Hızır. Dorm.		35,36	65	Chemical Engineering
	78,79	55	Guest House	VIII	37	50	Coastal And Harbor Eng.
II	58	25	Housing Territory4		38	30	Dept. of Environmental Eng.
	62	25	Housings Territory 3		39	100	Dept. of Metal. and Materials Eng.
	63	25	Housings Territory 2	IX	40	55	Geological Eng.
	64	25	Housings Territory 1		41	45	Mining Eng.
III	59	30	Shopping Center		45,46	50	Dept. of Petrol. and Natural Gas E
	60	20	Bank Territory		47,48	45	Dept.of Food Eng.
	61	45	Gymnasium	X	42,43,44	60	Dept. of Aerospace Eng.
IV	18	20	Social Building	XI	49,50	70	ODTUKENT Guest House
	56	320	Cult.and Conv. Center	XII	53	150	Tubitak
	57	50	Tennis Courts		54	55	Informatics Institute
V	8,9	60	Fac.of Economics		55	50	ODTUKENT Gymnasium
	10,11	160	Fac. of Arch.	XIII	1,2	80	Faculty of Education
	13	100	Kinder garden		3	35	Psychological Counseling Center
	14	30	Human Sciences		4,5	105	School of Foreign Languages
	15	45	Dept. of Math.		6,7	130	Fac. of Economic and Administ. Sciences-II
	16	70	Dept. of Biology	**Total Capacity**		**3614**	
	12	115	Library				

Table B.2 The occupancy values of each parking lot for different time periods, Nov 10, 2010

ID	10 November 2010			ID	10 November 2010			ID	10 November 2010		
	10:30	13:30	15:30		10:30	13:30	15:30		10:30	13:30	15:30
1	5	7	7	**28**	1	8	8	**55**	5	6	9
2	68	69	93	**29**	45	55	57	**56**	162	256	146
3	26	40	36	**30**	59	48	46	**57**	35	65	42
4	40	42	38	**31**	23	22	18	**58**	18	27	14
5	60	62	49	**32**	57	44	59	**59**	27	30	25
6	69	69	51	**33**	21	28	18	**60**	16	16	27
7	---	---	---	**34**	49	51	41	**61**	34	54	50
8	26	32	49	**35**	4	11	8	**62**	14	8	14
9	18	17	35	**36**	43	59	59	**63**	13	9	14
10	72	74	61	**37**	37	28	32	**64**	13	9	14
11	10	24	19	**38**	24	28	25	**65**	36	20	19
12	120	144	129	**39**	114	84	92	**66**	2	5	3
13	40	80	74	**40**	50	63	63	**67**	23	27	17
14	58	16	24	**41**	25	17	34	**68**	24	38	33
15	45	48	33	**42**	4	5	2	**69**	3	13	13
16	53	59	62	**43**	16	5	16	**70**	---	---	---
17	63	46	59	**44**	15	17	21	**71**	10	15	13
18	19	16	21	**45**	5	10	4	**72**	3	4	7
19	108	101	96	**46**	10	12	7	**73**	9	5	6
20	17	17	19	**47**	18	7	18	**74**	---	---	---
21	56	71	61	**48**	13	5	20	**75**	11	4	13
22	43	38	46	**49**	---	---	---	**76**	22	38	36
23	39	40	39	**50**	22	11	14	**77**	30	24	46
24	30	40	39	**51**	57	36	38	**78**	11	16	8
25	81	57	59	**52**	29	31	26	**79**	4	16	8
26	76	80	76	**53**	79	83	75	**TOTAL**	**2645**	**2837**	**2718**
27	36	36	29	**54**	21	40	36				

Table B.3 Occupancy values of each parking lot for different time periods, May 4, 2011

ID	Sessions				ID	Sessions			
	08:30	10:30	12:30	16:30		08:30	10:30	12:30	16:30
1	6	8	2	10	**41**	14	34	32	31
2	39	59	67	59	**42**	2	7	4	3
3	25	14	30	3	**43**	14	10	12	10
4	40	30	35	9	**44**	20	11	16	6
5	51	41	48	12	**45**	3	11	15	5
6	35	67	68	43	**46**	1	13	5	2
7	---	---	---	---	**47**	10	19	13	13
8	5	16	17	18	**48**	8	16	14	13
9	6	9	7	14	**49**	9	6	6	10
10	13	66	51	34	**50**	37	22	22	21
11	8	11	30	34	**51**	21	33	39	18
12	22	118	122	79	**52**	11	41	32	20
13	16	38	50	51	**53**	135	134	121	122
14	4	10	8	11	**54**	2	36	32	34
15	26	47	40	36	**55**	2	19	24	27
16	7	40	48	52	**56**	107	240	312	208
17	35	58	48	28	**57**	36	59	49	48
18	17	16	22	10	**58**	15	11	12	14
19	25	46	48	32	**59**	27	28	47	31
20	28	43	42	32	**60**	16	15	16	14
21	13	51	52	54	**61**	33	54	67	61
22	14	76	36	36	**62**	---	18	26	18
23	21	12	38	34	**63**	---	19	25	19
24	17	28	37	34	**64**	---	19	25	19
25	36	80	67	59	**65**	36	33	25	5
26	21	69	64	55	**66**	3	5	4	2
27	---	---	---	---	**67**	30	11	11	8
28	2	6	4	4	**68**	6	47	54	22
29	6	50	43	39	**69**	8	16	20	32
30	12	48	49	37	**70**	9	29	23	16
31	8	26	22	27	**71**	4	19	13	16
32	12	31	34	33	**72**	5	6	7	2
33	4	28	30	30	**73**	8	4	5	10
34	3	17	18	11	**74**	9	2	3	5
35	3	7	11	9	**75**	24	10	11	8
36	11	35	24	24	**76**	19	17	17	25
37	---	23	14	19	**77**	45	28	25	64
38	6	13	29	30	**78**	9	11	34	15
39	18	50	69	69	**79**	6	5	12	9
40	18	39	42	30	**TOTAL**	**1376**	**2543**	**2697**	**2206**

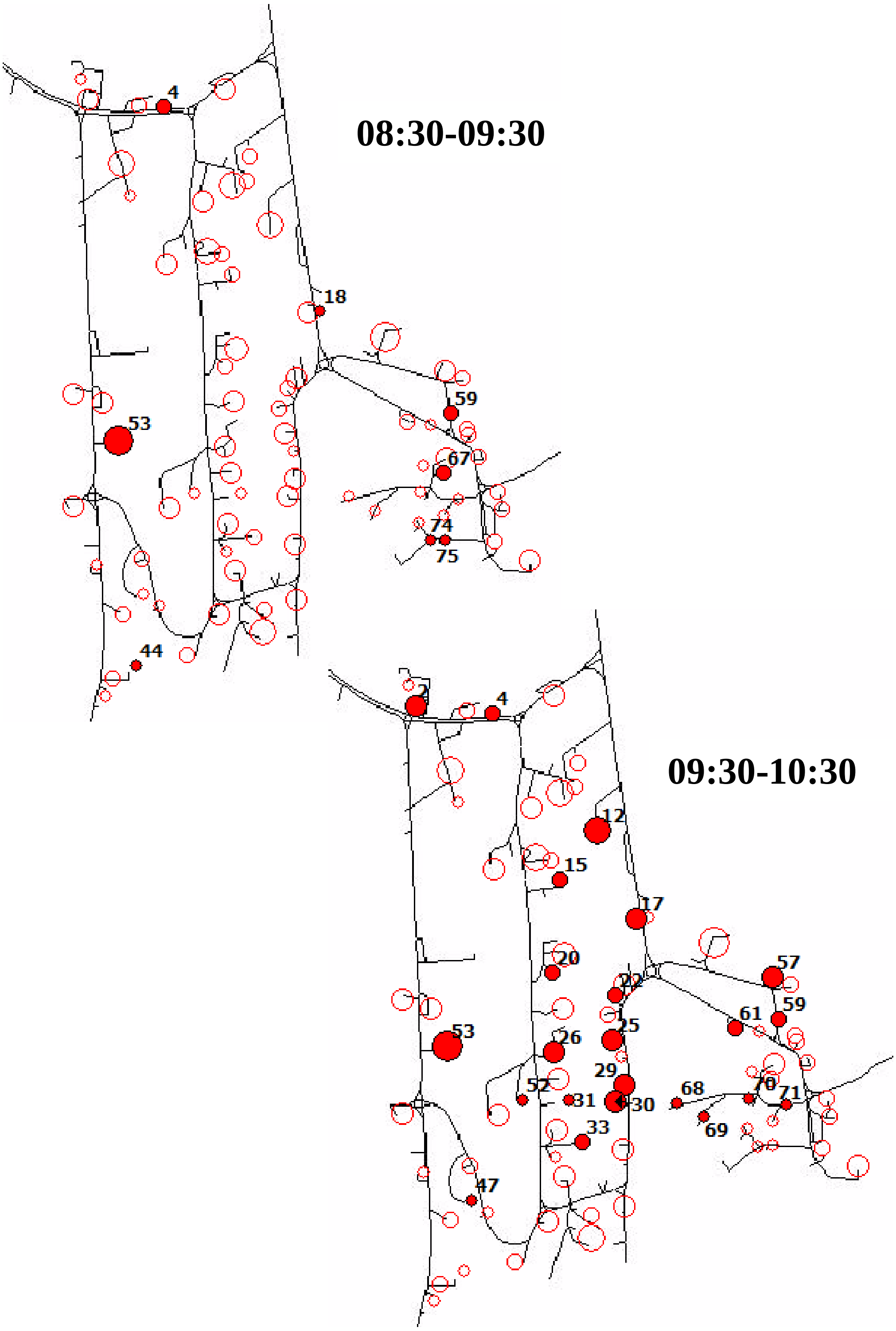

Figure B.1 85+% parking lot occupancy rate of METU campus at 08:30-09:30 and 10:30-11:30 parking surveys, on May 4, 2011

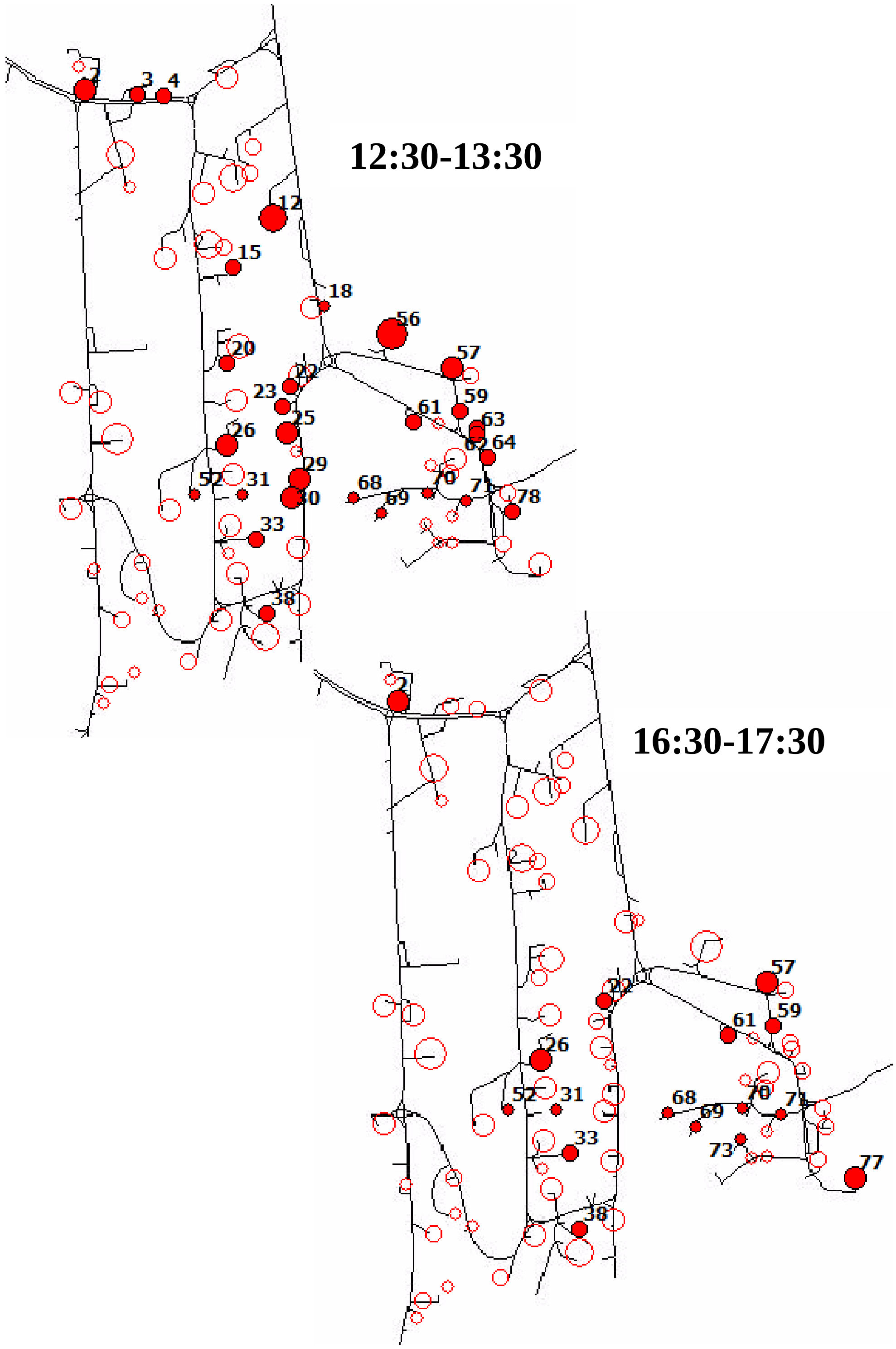

Figure B.1 85+% parking lot occupancy rate of METU campus at 12:30-13:30 and 16:30-17:30 parking surveys, on May 4, 2011 (cont'd)

APPENDIX C

METU CAMPUS TRAVEL DATA ANALYSIS

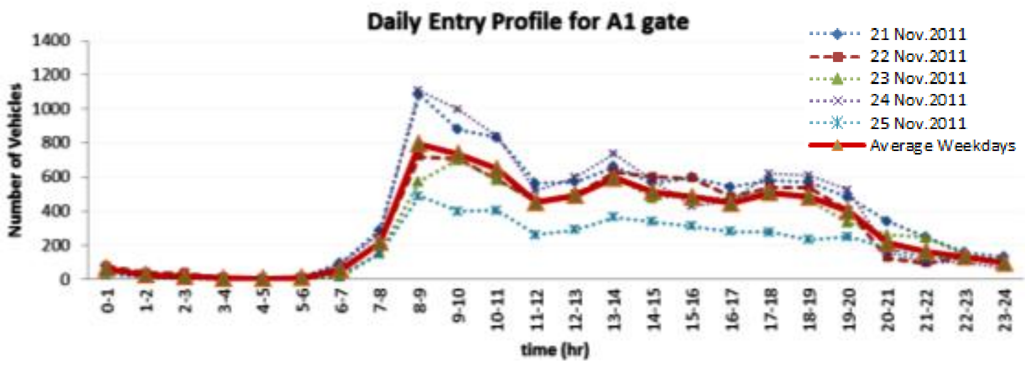

Figure C.1 Daily entry profile of METU campus from A1 main gate

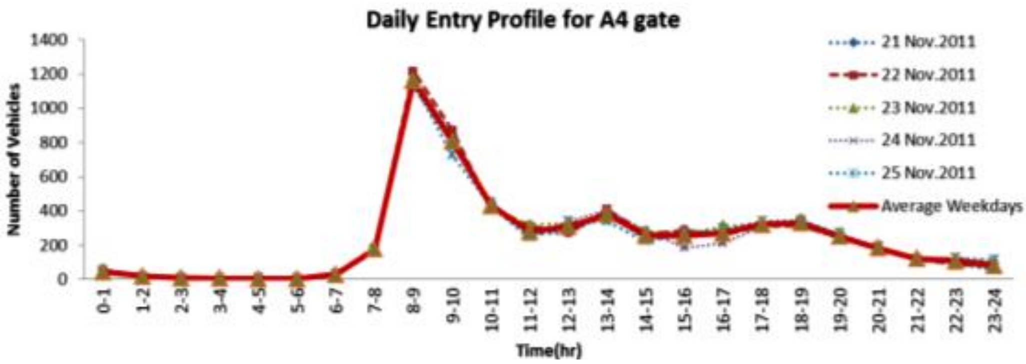

Figure C.2 Daily entry profile of METU campus from A4 main gate

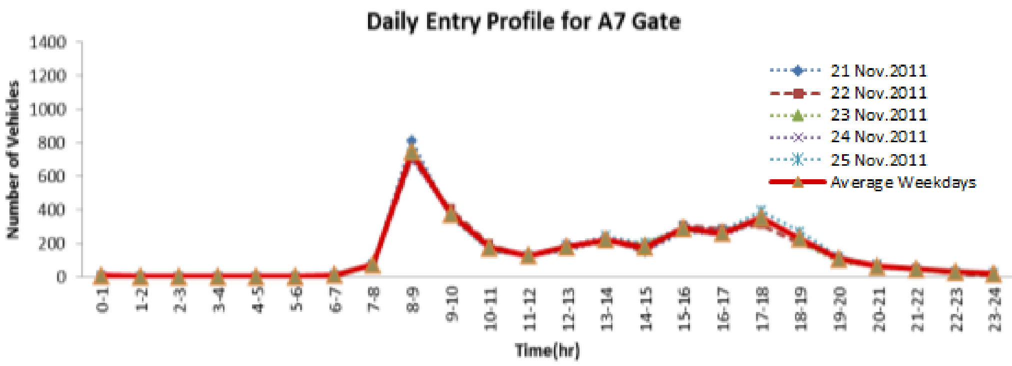

Figure C.3 Daily entry profile of METU campus from A7 main gate

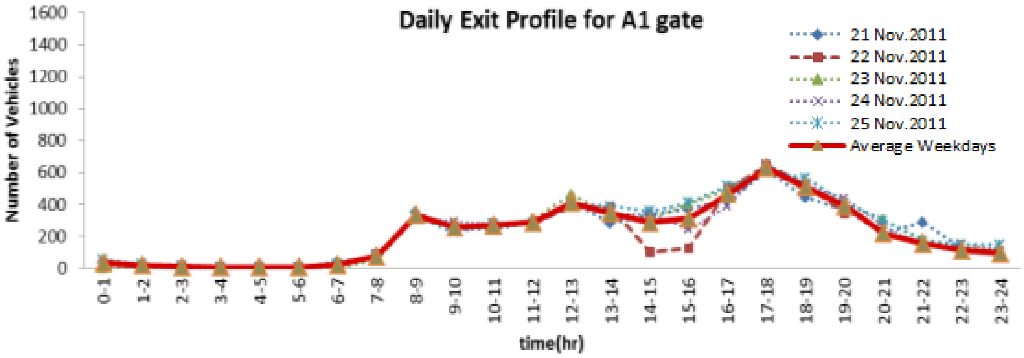

Figure C.4 Daily exit profile of METU campus from A1 main gate

Figure C.5 Daily exit profile of METU campus from A7 main gate

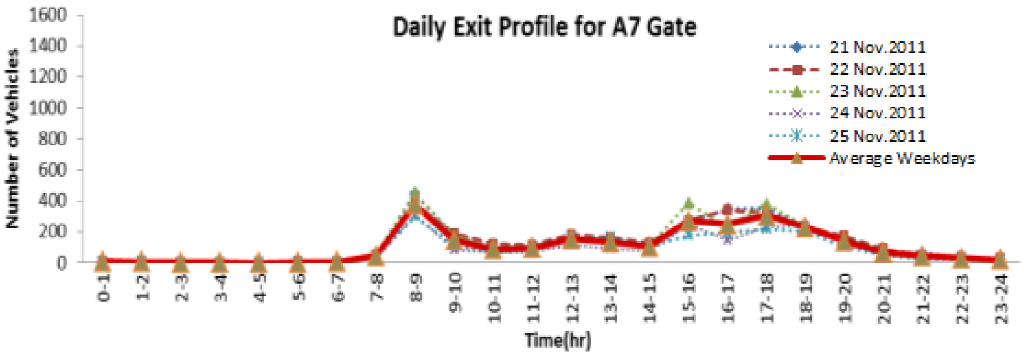

Figure C.6 Daily exit profile of METU campus from A7 main gate

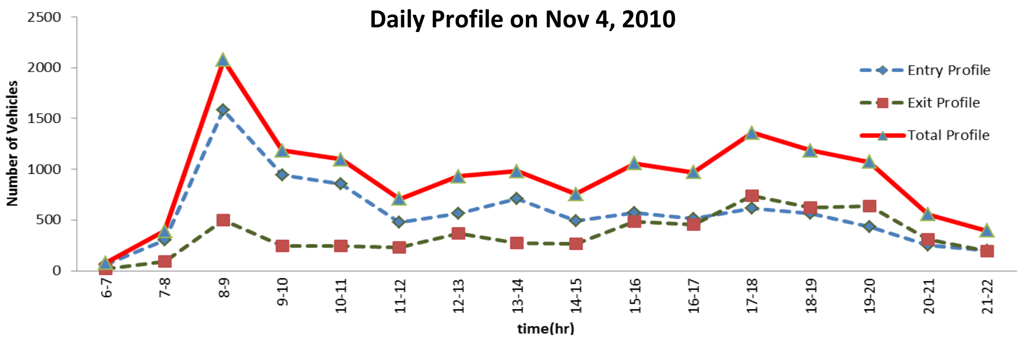

Figure C.7 Daily entry-exit and total profile of all gates on November 10, 2010

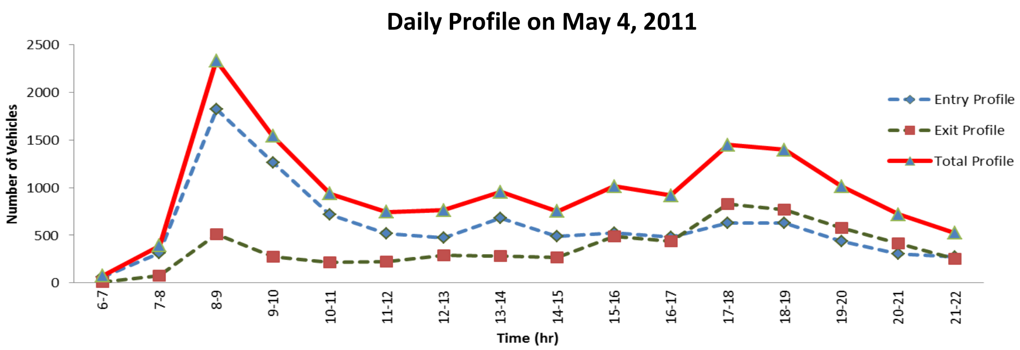

Figure C.8 Daily entry-exit and total profile of all gates on May 4, 2011

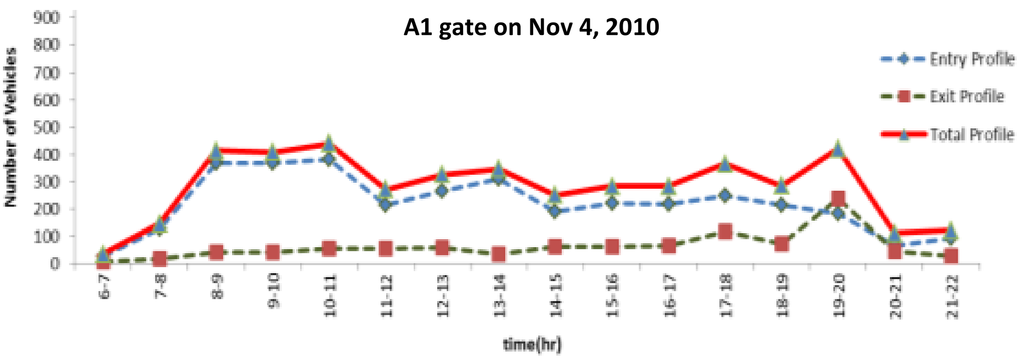

Figure C.9 Daily entry-exit and total profile of A1 gate on Nov 4, 2010

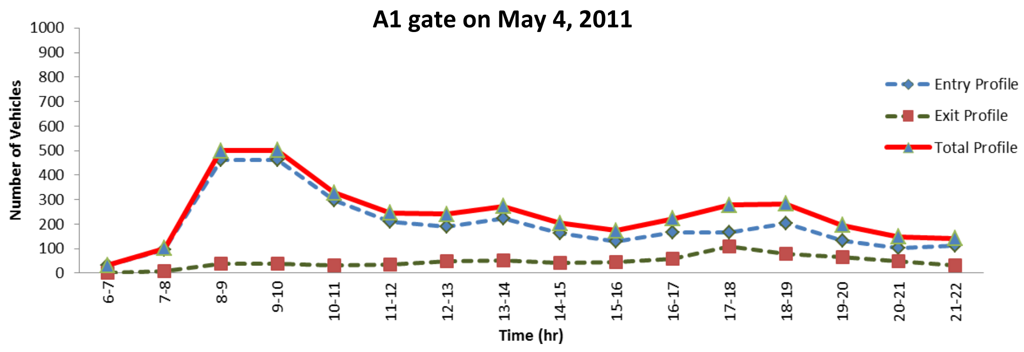

Figure C.10 Daily entry-exit and total profile of A1 gate on May 4, 2011

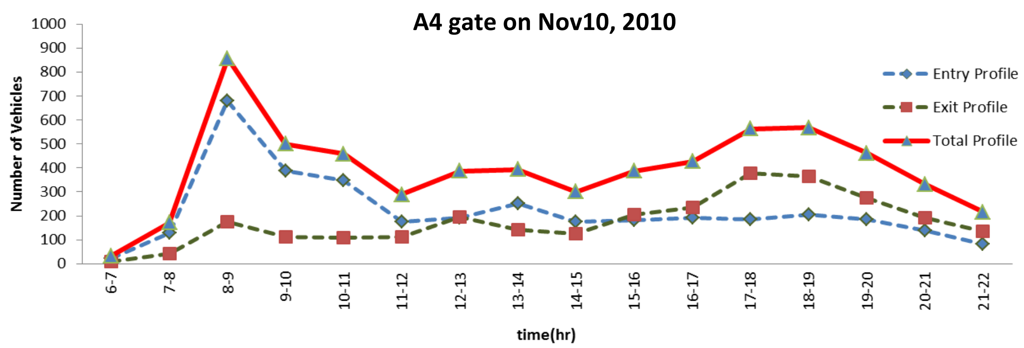

Figure C.11 Daily entry-exit and total profile of A4 gate on Nov 10, 2010

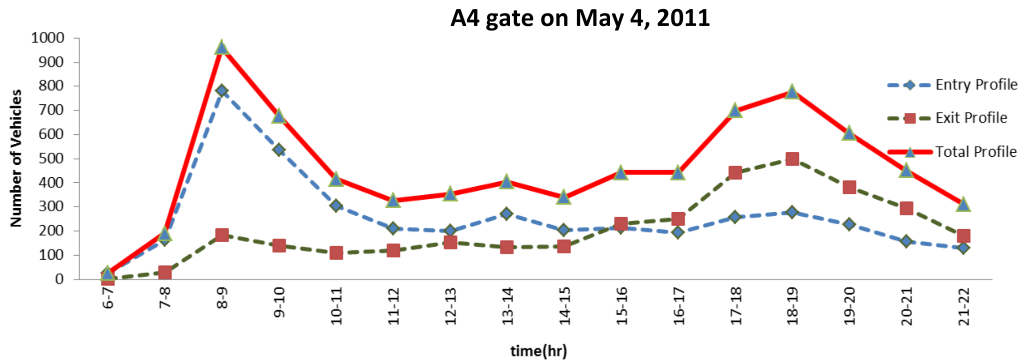

Figure C.12 Daily entry-exit and total profile of A4 gate on May 4, 2011

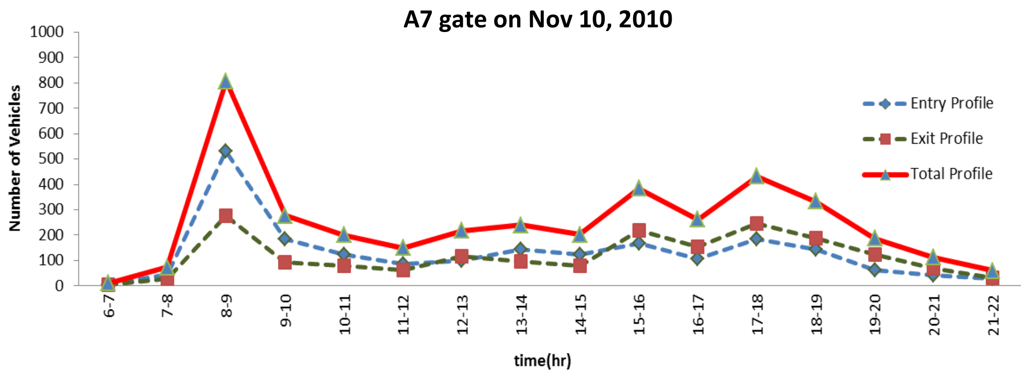

Figure C.13 Daily entry-exit and total profile of A7 gate on Nov 10, 2010

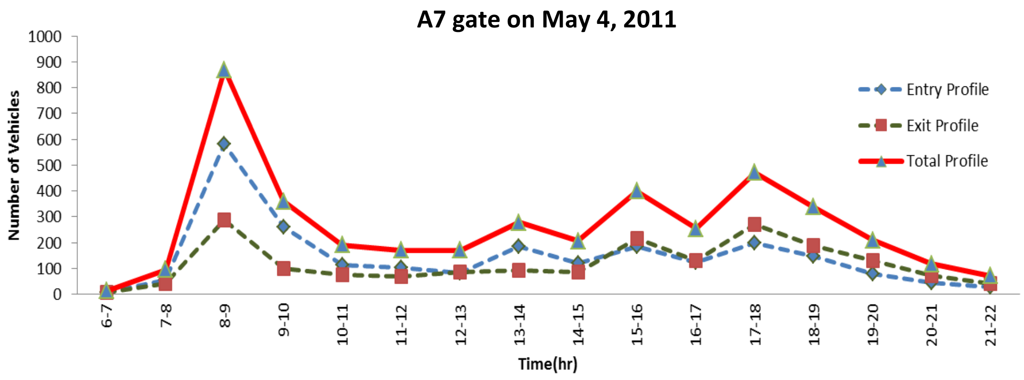

Figure C.14 Daily entry-exit and total profile of A7 gate on May 4, 2011

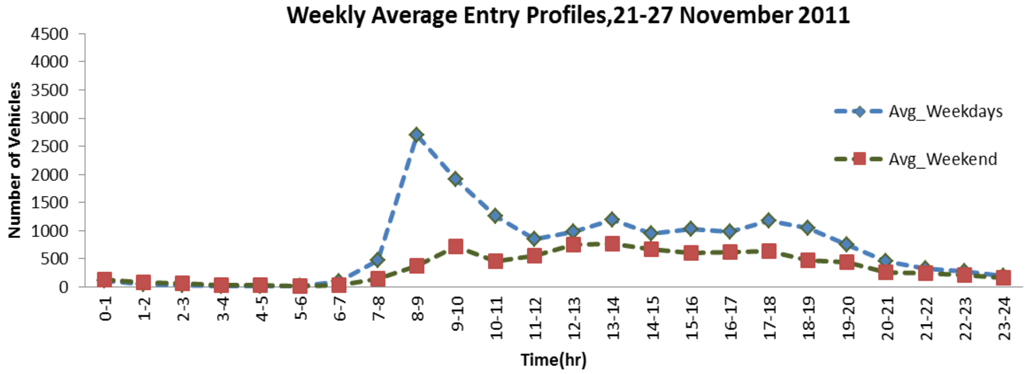

Figure C.15 Weekly Average Entry Profile of METU campus on November 21-27, 2011

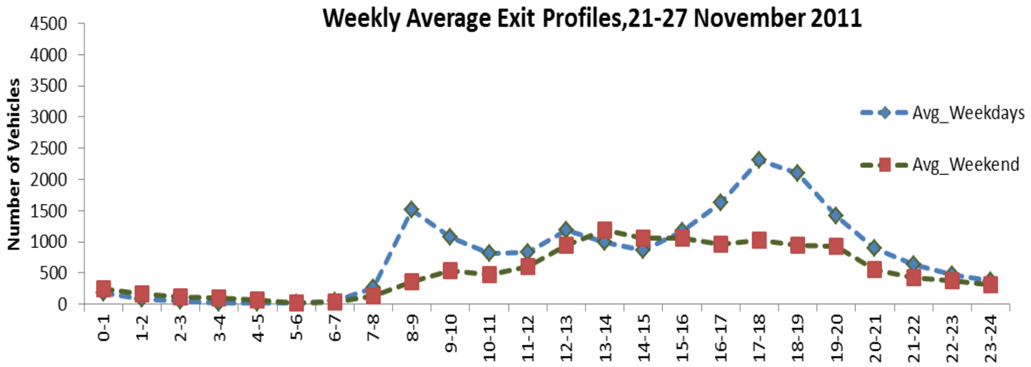

Figure C.16 Weekly Average Exit Profile of METU campus on November 21-27, 2011

APPENDIX D

CAMPUS ORIGIN-DESTINATION MATRIX ESTIMATION

The assumptions used in estimating O-D matrix of METU campus are as follows:

- Firstly, if a vehicle had a recorded entry time and gate, and captured in parking lot surveys then, the origin of the trip is "gate," and destination of the trip is the "parking lot," and entry time of a vehicle was taken as the start time of a trip. Similarly, if a vehicle captured at parking lot and had a recorded exit then, origin of the trip is "parking lot" and the destination of the trip is "gate."
- Secondly, same vehicle is captured many times at different parking lots in a day. In this time, origin of the trip is the first captured parking lot and the destination of the trip is the second captured parking lot.

- Many vehicles have a recorded entry and exits, but they are not captured in parking lot surveys. For example, a vehicle enters from A1 gate and exits from A1 gate. Since A1 to A1 has no mean, these kinds of gate-to-gate trips were divided into two trips; first, gate-to-parking lot and then parking lot-to-gate.

- If a vehicle had recorded entry but did not captured in parking lot surveys and did not have a recorded exit, then the sticker types of this vehicle was searched and if the sticker type was Technopolis, it was assigned to A8. (reading problem was also seen at internal gate) However, if the sticker type is not Technopolis, the assumption was; origin of the trip was the "gate," and destination of the trip was assigned to any parking lot randomly.

- If a vehicle had recorded exit but did not have recorded entry, the origin of the trip was assigned to any parking lot randomly and destination of the trip is the "gate."

- If a vehicle did not have recorded entry and exit, but capture in parking lot survey then, two different assumptions were used to estimate the O-D of this kind of trips: First, this kind of vehicle may come from ODTUKENT and Region II (Faculty member houses). It was assumed that approximately 300 vehicles were coming from ODTUKENT and 70 vehicles were coming from Region II to the campus parking lots. (This value was obtained from the number of houses, which are located in ODTUKENT, and every family has one private car). Second, this kind of vehicle may be non-sticker visitors. The trip chaining is; the first trip is gate-to-parking lot, and second trip is parking lot-to-gate. To get more accurate result, video camera record entry-exit ratios for each gate were taken as a reference and assigning gates were selected to catch these ratios.

- If a vehicle had a recorded entry and captured in parking lots, but did not have recorded exit, then exits were assigned to the gate.

- If a vehicle was seen at student dormitory parking lots in the last parking survey hour (16:30-17:30), and did not have recorded exit then this vehicle was assumed as staying in campus and did not take to consideration. If a vehicle was seen at student dormitory parking lots in the first parking survey hour (08:30-09:30), and did not have recorded entry, this vehicle was assumed as left from night and did not take to consideration.

- A vehicle with METU foundation sticker, “High School Zone” was defined this kind of sticker types. If a vehicle had a recorded entry but did not capture in parking lot, the destination of this kind of trips was assigned to “High School Zone.” Similarly, if a vehicle did not have recorded entry but had recorded exit, then, origin of the trip was assigned to “High School Zone.”

- Furthermore, a vehicle with an academic sticker type, entered to campus after 20:00, the destination was assumed as ODTUKENT.

Table D.1 Traffic analysis zones for the campus traffic assignment

CTAZ	ID	Description
1	76	Sami Kırdar Dorm.
	77	Faik Hızır. Dorm.
	78,79	Guest House
2	66	1st Dormitory
	70	3rd Dormitory
	71	Dorm. Territory
	72	7th Dormitory
	73	8th Dormitory
	74	Parlar Vakfı
	75	6th Dormitory
3	68	Baraka Gym.
	69	Swimming Pool
4	65	Medical Health Center
	67	2nd Dormitory
5	62	Housings Territory 3
	63	Housings Territory 2
	64	Housings Territory 1
6	60	Bank Territory
	61	Gymnasium
7	59	Shopping Center
8	57	Tennis Courts
	58	Housing Territory 4
9	56	Cultural and Conv. Center
10	17	Presidency
	18	Social Building
11	21	Cafeteria
	22,23	Engineering Science
12	25	Computer Center
13	28,29,30	Civil Engineering
	34	Hydromechanics Lab.
14	35,36	Chemical Engineering
15	37	Coastal And Harbor Eng.
16	38	Dept. of Environmental Eng.
	39	Dept. of Metallurgy and Materials Eng.
17	40	Geological Eng.
	41	Mining Eng.
18	45,46	Dept. of Petroleum and Natural Gas Eng.
	47,48	Dept.of Food Eng.
19	32,33,51,52	Mechanical Engineering
20	26,27	Dept. of Elect. and Electronics
	31	Central Laboratory
21	24	Industrial Engineering
22	19	Department of Physics
	20	Department of Statistics
23	13	METU Kinder garden
	14	Human Sciences
	15	Dept. of Mathematics
24	16	Dept. of Biology
25	12	Library
26	10,11	Fac. of Architecture
27	8,9	Fac.of Economics I
28	6,7	Fac. of Economic and Administ. Sciences-II
29	3	Psychological Counseling Center
	4,5	School of Foreign Languages
30	1,2	Faculty of Education
31	53	Tubitak
	54	Informatics Institute
32	55	ODTUKENT Gymnasium
33	49,50	ODTUKENT Guest House
34	42,43,44	Dept. of Aerospace Eng.
90	-	ODTUKENT
91	-	METU High School

APPENDIX E

CAMPUS TRAFFIC ASSIGNMENT RESULTS

Table E.1 Morning peak O-D matrix between 08:15-09:15

40x40		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	90	91	A1	A4	A7	A8
	Sum	30	24	15	52	24	58	29	48	140	62	75	50	47	29	9	54	46	32	65	46	22	59	71	20	44	41	13	55	124	115	164	8	15	20	20	116	287	237	341	262
1	23																																					9	6	8	
2	18																																					9	4	5	
3	14																																					8	3	3	
4	20																																					9	5	6	
5	17																																					8	4	5	
6	15																																					7	4	4	
7	16																																					7	4	4	1
8	17																																					7	5	5	
9	32																																					8	9	10	5
10	20																																					8	5	6	1
11	23																																					9	6	7	1
12	16																																					8	4	4	
13	23																																					9	6	8	
14	17																																					8	4	5	
15	14																																					8	3	3	
16	21																																					9	5	7	
17	19																																					9	4	6	
18	18																																					9	4	5	
19	23																																					9	6	8	
20	22																																					10	5	7	
21	15																																					8	4	3	
22	19																																					9	5	5	
23	25																																					9	8	8	
24	19																																					9	5	5	
25	21																																					9	6	6	
26	24																																					9	7	8	
27	15																																					8	4	3	
28	23																																					9	7	7	
29	21																																					9	6	6	
30	67																																					8	49	9	1
31	27																																					8	8	10	1
32	13																																					7	4	2	
33	13																																					7	4	2	
34	13																																					7	4	2	
90	116							1		2	1	1	3	2				3	1	3	6	2	5	5			1	1	3	5	4	2						3	18	44	
91	103																																							103	
A1	611	7	4	2	18	7	20	9	26	55	24	23	12	13	10	2	17	11	12	21	13	6	20	26	6	15	15	4	22	47	19	82	2	6	7	7					21
A4	902	16	15	10	23	13	25	15	17	63	27	39	28	18	13	4	22	20	12	24	15	9	26	24	11	22	18	8	22	46	73	50	5	8	11	5	2			1	142
A7	525	7	5	3	11	4	12	4	5	19	10	12	7	14	6	2	15	11	7	16	12	5	8	16	3	7	7		8	25	19	30	1	1	2	8	114				89
A8	9						1			1						1		1		1										1									2	1	

Table E.2 Evening peak O-D matrix between 17:15-18:15

40x40		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	90	91	A1	A4	A7	A8
	Sum	28	31	34	13	18	32	16	10	24	8	29	16	24	11	4	13	9	9	23	21	34	13	22	10	10	12	3	26	12	47	31	19	21	3	102	32	629	650	247	66
1	33																																					7	21	5	
2	32																																					13	16	3	
3	46																																					33	10	3	
4	19																																					2	13	4	
5	26																																					3	17	5	1
6	51																																					35	12	4	
7	29																																			1		13	11	2	2
8	20																																					2	14	3	1
9	163																																			1		111	38	9	4
10	41																																			2		17	13	8	1
11	79																																			3		44	24	7	1
12	49																																			4		19	18	7	1
13	54																																			7		17	20	10	
14	31																																			3		8	13	6	1
15	18																																			2		2	10	3	1
16	71																																			2		35	22	12	
17	43																																			2		17	20	4	
18	29																																			2		9	14	4	
19	54																																			3		21	22	8	
20	57																																			6		19	21	11	
21	25																																			1		9	10	5	
22	37																																			5		7	19	6	
23	64																																			2		27	23	10	2
24	41																																					19	17	5	
25	65																																			1		40	18	6	
26	59																																			2		29	20	7	1
27	26																																			3		8	12	3	
28	42																																			1		13	14	12	2
29	26																																			2		3	14	7	
30	82																																			3		20	43	15	1
31	64																																			1		15	31	15	2
32	19																																			1		4	11	3	
33	14																																					1	9	4	
34	19																																			2		4	10	3	
90	6	1																		1																		1	1	2	
91	24																																							24	
A1	266	8	12	18	6	7	15	8	6	8	4	10	7	10	5	2	5	4	4	9	6	18	6	7	4	3	4	2	13	3	8	13	11	7	1	5	1				6
A4	235	11	16	13	3	7	9	3	2	5	1	11	5	7	3		3	2	2	5	5	8	3	8	3	3	4		7	5	32	8	5	7		13	2				14
A7	228	8	3	3	4	3	6	3	2	7	3	7	3	7	3	2	5	3	3	7	10	5	4	5	3	4	4	1	6	4	6	9	2	6	1	22	29				25
A8	75					1	2	2		4		1	1							1		3		2							1	1	1	1	1			2	49	2	

Table E.3 Off-peak O-D matrix

40x40		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	90	91	A1	A4	A7	A8
	Sum	281	145	185	121	157	199	100	131	633	159	316	139	290	113	56	251	168	125	311	278	107	156	263	136	266	263	94	214	179	481	318	106	200	91	351	176	3198	2928	1240	793
1	286		1	1				1	4	3	1	4		1					1	3		1	1	2	2	6	7		6	1	2	1	1	3		2		83	107	37	4
2	193					1		1		1							1	1						1		2					1							81	74	26	3
3	210	2				1		1		2	2							1		1						4	1			1	3			1	1	1		115	61	11	1
4	190	1		1			1				1	2																	2				1	2		1		77	71	26	4
5	188	1	1	1			1					1		2			2	2	1	1					1				1					1				81	63	25	3
6	262	2		1		1	2					1	1	2				3	1	1	1	1	1	1		2	2				2	1		1				141	68	20	6
7	155	1	1	2	1					1	1	1	1		1					2	1			2					2	1	2	4						88	31	11	1
8	204	12					1	1		1		1	1			1			1	1	1					2				3	1		1	2	1			101	47	20	5
9	569	5	4	3	1		2	1				1	1	6	1	1	6	2		2	1	1	4	2		2	1	1	1	3	3	2	3		3			251	187	61	7
10	201	3	1	2		2		1	1	1		3	1										1						2		1		1	2		2		83	65	26	3
11	332	3	2	2		7	3	1	2	5	1	1		2	5		1	4		1	2	1			1	1	1				2		2	5	3	4		124	106	36	4
12	180	3	4	1				2		1	1			1	1				1		1					1				1		3				2		64	70	21	2
13	303	2	1	2		1	3		1	5				1		2		2				1				4							3	2		4		111	116	38	4
14	155		1						1	1		2	1				2	1	1																	3		65	56	19	2
15	94									2		1								1				1								3				1		47	29	9	
16	245					4			1	8		1							1	1			1			2										2		81	97	40	6
17	202	2		2		4	3	1		3		5		2	1			1	1		1			4					1	1			1	1		4		65	66	28	5
18	168	2	1	2		1	1			3		4	1		1		2			2						2	1						1			1		55	61	24	3
19	336	12	2	4		1	2	3		6	1	4			1		2	1				3	2	3		3			1					3	3	4		108	120	40	7
20	297		1				1			3			1	1						1						2					1		1	3		3		139	86	49	5
21	174	1	1			1		3		1				2	1				1	1	2											2				7		82	45	21	3
22	208			1	1	1	2	1	1		1	1	1				4		1		1			1										1	1	4		76	67	39	3
23	299		1	1	1	1	1			2	2		1							3		2	1	1		1	1			1		1	1	2		3		111	102	54	5
24	152	2		3						2										1													1	4		1		62	49	23	4
25	259	5	2	6		2	1			5	1	3		3			2	1	1	5							1			1				1		1		95	90	30	3
26	255	8		1			2	1		4		1							1							2			1						1	1		92	95	40	5
27	125			1	1																			1			2						1			1		52	46	18	2
28	251	5				2	1	3	1	3	1													1		3	1	1						1		1		96	86	39	6
29	299	3	1			2	2		2	6	1	2						1		1		2		4						4			3			21		98	87	53	6
30	500	1		2		2	1	2	1	3	1	2		1					1	2	1	1		1		2								3		2		107	299	57	8
31	372	1				2	1	1		1			2			2					1	2					1						2	1		3		157	115	71	9
32	148		2	1			2			2							1				1			1								2		1				73	41	18	3
33	146	1		1	2	1			1	3	1	2	1	1						4		2	1	1	4		2	1			4	1	1		1			51	45	13	1
34	138						2	1	1	3		5		1	1				1	1						1	1								3	1		56	41	18	1
90	159						1	1	2		4	2	3	4			4	1	1	1	6	3	12	4	2	2		2	4	5	6	1			2			24	24	38	
91	127																																					1	1	125	
A1	2870	77	52	70	51	55	83	35	49	256	67	114	57	117	50	27	105	69	50	120	145	52	63	114	58	96	110	42	74	75	109	114	39	72	37	100					66
A4	2771	92	48	58	39	44	58	22	42	226	46	114	49	106	35	18	88	55	41	111	70	18	42	72	43	95	90	29	71	49	295	101	22	61	18	98	11				294
A7	1479	30	18	14	22	20	22	15	19	64	21	35	16	34	15	5	26	22	19	41	39	14	26	43	25	29	38	17	43	30	46	72	18	27	17	73	165				299
A8	216	4		2	2	1		2	2	6	5	3	1	3			5	1		3	4	3	1	3		2	3	1	5	3	3	10	3					5	114	16	

Table E.4 Daily O-D matrix of academic travelers between 07:00-22:00

40x40		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	90	91	A1	A4	A7	A8
	Sum	45	21	22	31	46	26	18	25	68	48	101	48	93	37	16	80	63	43	79	73	45	90	108	34	41	38	40	69	125	134	66	18	148	25	453	54	702	788	589	104
1	61																								1				2		2			1		2		16	23	13	1
2	37																	1																				17	13	6	
3	33																													1	1					1		15	9	5	1
4	47	1																											2				1			1		19	13	8	2
5	55		1	1										1			1	2	1	1									1					1				17	17	10	1
6	40																	1	1		1	1					1				2							17	10	6	
7	32																			1				1								1				1		16	6	4	2
8	41	4																												1								17	13	6	
9	81															1	1						1							2						1		21	31	19	4
10	57	1		1																									1		1					4		19	17	10	3
11	109			1		2									2			2				1			1						1		1	1	1	6		31	45	12	2
12	60	3		1															1													2				6		18	21	8	
13	98					1			1	1								1								1								1		11		34	31	15	1
14	51											1						1																		6		20	15	8	
15	33									1																						1				3		15	8	4	1
16	90					1																														4		24	34	25	2
17	70					3						3			1									1												6		18	24	11	3
18	57					1				2			1																							3		22	17	10	1
19	85					1					1											2	1													7		21	35	15	2
20	88																																	1		9		20	26	29	3
21	57					1				1					1				1		1															8		15	14	14	1
22	95				1								1				2		1		1														1	9		22	30	26	1
23	120						1			1										1		1	1							1						5		36	39	31	3
24	46			2						1																							1	1		1		18	13	9	
25	53																																			2		20	22	8	1
26	52																												1							3		18	19	10	1
27	53			1																													1			4		22	15	9	1
28	79	2				2					1													1			1	1								2		21	23	20	5
29	135					1	1			2	1	1								1		2		2						2			1			23		21	38	36	3
30	142	1		1		1				2	1	2								1		1		1		1								1		5		31	62	28	3
31	79												1			1																		1		4		24	25	19	4
32	33		1																																	1		15	11	5	
33	40	1				1						1										2			1		1	1			2				1			14	10	4	1
34	41						1			2		2																								3		16	10	7	
90	257	1					1	2	1	2	5	3	6	6			4	4	2	5	12	5	17	9	2	2	1	3	7	10	10	3			2			11	38	83	
91	54																																							54	
A1	660	8	5	2	11	10	8	4	6	18	13	27	13	30	12	2	22	15	8	22	20	12	27	40	8	9	12	13	13	39	27	17	3	57	7	107					13
A4	796	14	8	4	12	13	8	6	10	21	15	49	18	37	13	7	29	23	18	27	17	7	27	29	13	20	12	15	19	36	64	16	5	57	7	105					15
A7	585	7	6	6	7	8	6	4	6	13	10	11	6	18	8	4	19	12	10	18	19	9	15	22	8	8	9	6	20	32	22	24	4	25	6	100	54				23
A8	52	2		2				2	1	1	1	1	2	1		1	2	1		2	2	2	1	2			1	1	3	1	2	2	1	1				1	11	2	

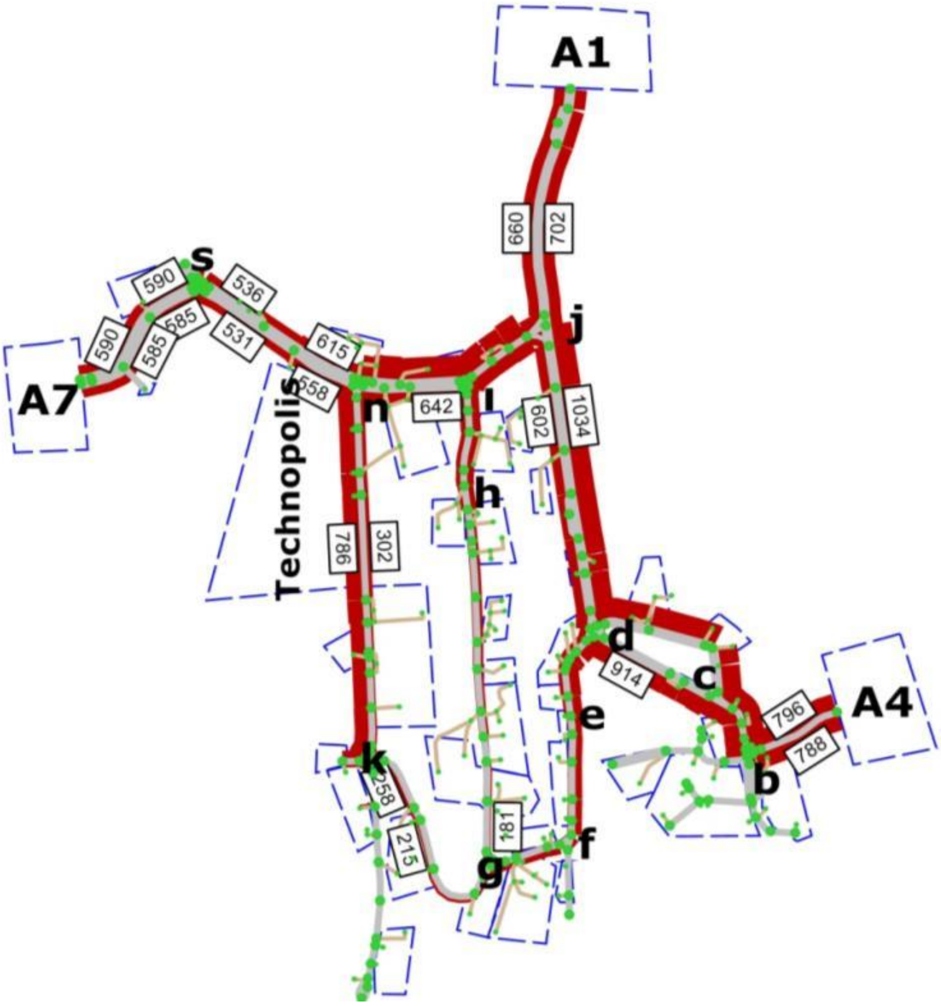

Figure E.1 Campus traffic assignment result for academic travelers

Table E.5 Daily O-D matrix of administrative travelers between 07:00-22:00

40x40		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	90	91	A1	A4	A7	A8
	Sum	35	38	19	44	27	15	13	12	46	64	53	41	30	17	8	29	17	22	30	40	8	23	38	15	25	27	11	23	20	55	33	9	12	7		14	367	329	159	15
1	35		1									1																										13	14	6	
2	40																																					19	14	7	
3	21										2																1											11	7		
4	39			1								1																						1				15	16	5	
5	30											1																										12	11	5	1
6	17																																					9	6	2	
7	15			2							1				1									1					1									7	1	1	
8	16	1																																				8	5	2	
9	44		1	1													1																					16	17	7	1
10	55	2		1		1							1																					1				27	13	9	
11	47		1			3	1					1																										17	14	9	1
12	39		2					1			1																											16	12	7	
13	30																																					13	11	6	
14	19																1																					8	6	4	
15	9																							1														5	2	1	
16	26																																					12	10	4	
17	19													1																								8	6	4	
18	22																			1																		10	8	3	
19	25																																					10	10	5	
20	36																																					14	16	6	
21	11																																					8	2	1	
22	22																																					9	9	4	
23	39										1		1																			1		1				15	15	5	
24	16																																					8	5	3	
25	23	1																		1																		9	8	4	
26	24																																					8	11	5	
27	13																																					7	5	1	
28	22							1																														8	9	4	
29	17																																					7	7	3	
30	50																																					8	33	8	1
31	31																																					9	14	7	1
32	11																																					7	3	1	
33	15																																					7	5	3	
34	10																																					7	2	1	
90																																									
91	14																																							14	
A1	345	12	11	6	18	7	6	4	4	17	26	18	16	13	7	2	14	8	10	12	19	4	7	17	7	11	13	4	9	9	14	11	2	2	2						3
A4	367	12	17	8	16	12	6	4	6	20	21	22	18	12	7	5	9	5	9	11	14	3	11	11	5	10	9	5	8	8	34	12	6	4	4						3
A7	167	7	5		10	4	2	3	2	7	9	9	5	4	2	1	4	4	3	5	7	1	5	8	3	4	4	2	5	3	7	9	1	3	1		14				4
A8	9									2	3																												2	2	

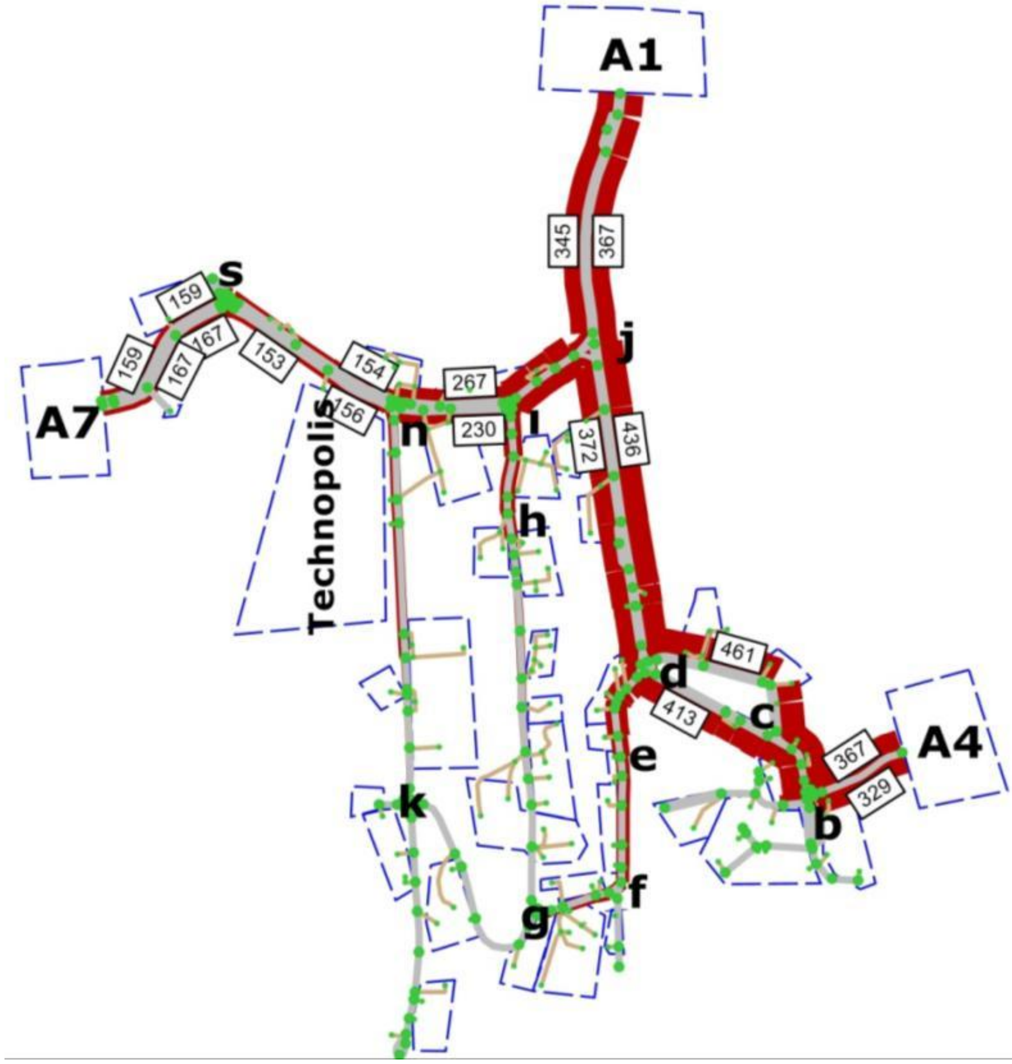

Figure E.2 Campus traffic assignment result for administrative travelers

Table E.6 Daily O-D matrix of other travelers between 07:00-22:00

40x40		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	90	91	A1	A4	A7	A8
	Sum	133	81	113	69	89	171	86	120	284	79	154	56	105	57	26	108	71	42	116	139	73	82	126	65	112	103	41	101	114	284	144	62	45	37	20	243	1781	1444	746	814
1	121							1	4		1	1							1	2		1		1	1	1	5		1	1				2				32	44	20	2
2	89							1		1														1		1												37	33	14	1
3	135	1				1		1		1								1								2					2			1				91	25	9	
4	86						1				1	1																						1				29	36	16	1
5	92	1					1										1								1													39	33	15	1
6	182	1				1	2					1						2					1	1		1								1				116	40	13	2
7	106				1					1		1									1								1	1	2	2						61	22	11	2
8	135	7					1	1		1						1			1	1	1					2				2	1			1				66	31	15	3
9	289	3			1		2	1				1	1	2	1		1						2					1			2	1	3		1			176	57	28	5
10	97		1			1			1	1		3											1						1				1	1				38	32	15	1
11	171	2				2			1	2	1			1	2		1	1		1	1												1	3	2	1		89	39	19	2
12	76		1							1				1	1						1					1				1								28	28	12	1
13	120									1				1		1		1								1							2	1				47	42	21	2
14	76								1	1			1				1		1																			27	29	14	1
15	45									1										1																		14	20	9	
16	124					3			1	2		1											1			2												54	39	20	1
17	92	1		2			2			1		1		1							1													1				31	34	16	1
18	60	1										1			1																							12	30	14	1
19	124	4	1					2		1		2						1					1			1												48	41	21	1
20	163		1				1			1			1							1											1		1					99	37	19	1
21	94	1						3						1							1																	47	27	12	2
22	98			1		1	1	1	1		1	1					2							1										1				40	31	15	1
23	141		1	1	1	1				1	1											1		1									1	1				66	42	22	1
24	83	1		1																														3				32	30	14	2
25	129	2		3		2				1	1			1						1										1								65	34	17	1
26	118	6								2																												45	42	22	1
27	62				1																			1			2											20	26	11	1
28	117	2					1	1		2																1								1				47	39	21	2
29	129	2	1			1	1		2	3														1						2			2					58	36	18	2
30	297			1		1		2	1	1											1													2				71	183	30	4
31	161					2		1														1																83	47	24	3
32	79			1						2							1				1			1										1				33	25	13	1
33	65			1	2					1	1	1		1									1	1	3						2	1	1					16	24	9	
34	58							1				2			1																				1			17	24	11	1
90	9								1																													2	5	1	
91	173																																					1	1	171	
A1	1567	35	35	60	32	38	78	39	59	114	40	60	26	48	29	20	48	34	22	50	79	46	44	60	32	47	42	24	48	54	55	68	29	18	23	5	1				25
A4	1476	38	29	30	18	24	56	17	33	96	22	50	16	26	12	1	37	17	8	38	29	13	19	34	15	37	31	9	31	34	189	42	10	2	4	11	15			1	382
A7	1117	24	11	12	13	11	21	13	14	42	10	25	11	21	10	3	15	14	9	20	22	9	12	22	13	15	22	7	18	16	29	26	11	4	6	3	227				356
A8	180	1					3	1	1	3		2		1			1			1	1	2		1			1		1	2	1	4						4	136	13	

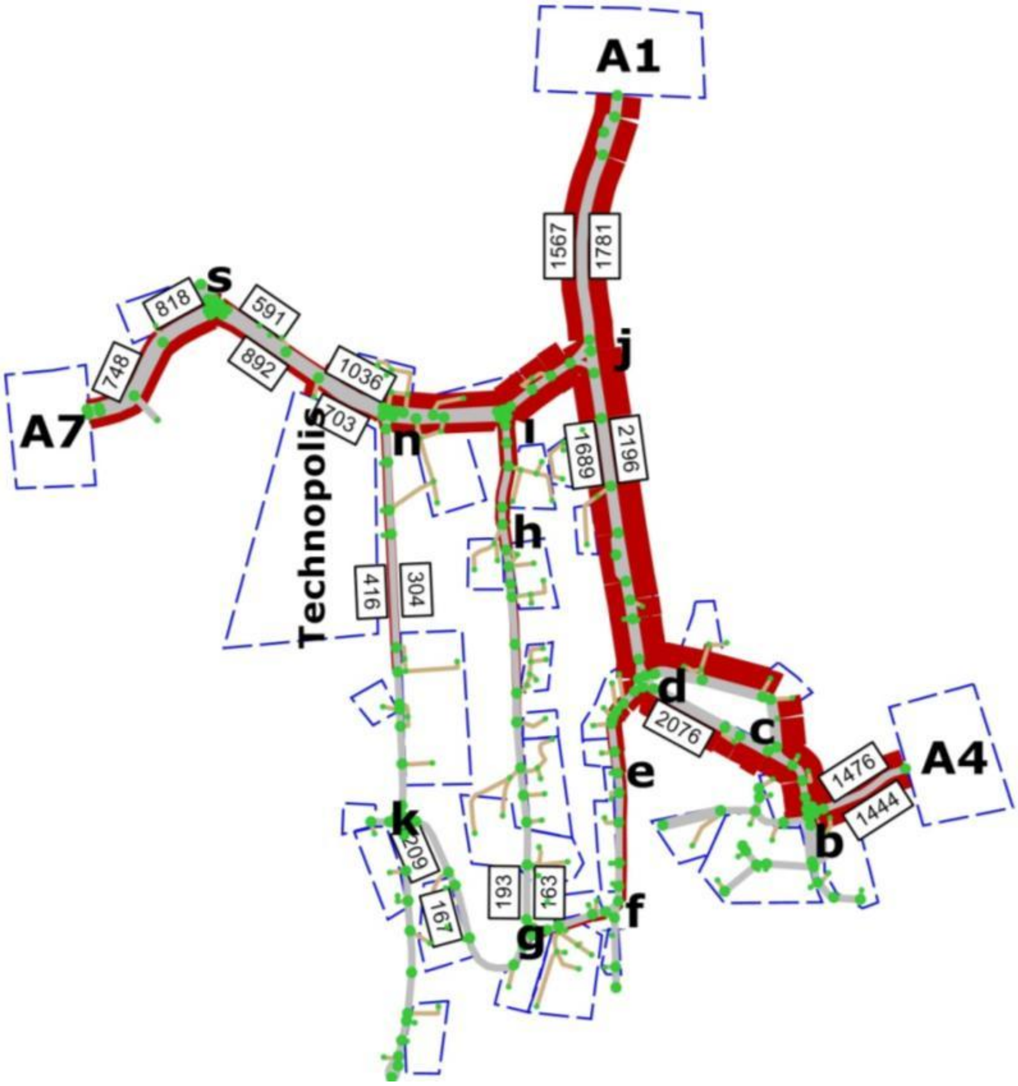

Figure E.3 Campus traffic assignment result for other travelers