# Managing campus parking demand through course scheduling – an approach to campus sustainability

Sumei Zhang
*Department of Urban and Public Affairs, University of Louisville, Louisville, Kentucky, USA, and*

Emmanuel Frimpong Boamah
*Department of Urban and Regional Planning, University at Buffalo, Buffalo, USA*

Received 30 November 2020
Revised 5 January 2021
5 February 2021
10 March 2021
Accepted 12 March 2021

## Abstract

**Purpose** – The purpose of this study is to use the optimization modeling method to explore whether there is an ideal arrangement of course enrollments that can yield optimal parking demand and supply on college campuses.

**Design/methodology/approach** – Using the University of Louisville as a case study, this study deploys a three-step analytical process to examine the correlation between parking demand and course enrollment, estimate parking demand based on course enrollment with regression analyses and embed this estimated relationship in an optimization model that minimizes on-campus parking demand and supply.

**Findings** – The correlation analyses suggest significant correlations between course enrollments and on-campus parking. The correlation patterns are different between students and university employees. The optimization results indicate that coupling parking supply and course scheduling decisions can reduce parking supply by 30%.

**Originality/value** – Voluminous studies on sustainable campus transportation have focused on transportation demand management strategies. The relationship between course-scheduling and parking demand was not explicitly accounted for in most studies. This study's results reveal that parking demand on campus depends on the number of courses offered across time. Thus, factoring and optimizing course schedules in campus parking decisions remains a viable and essential option to reduce on-campus parking demand.

**Keywords** Sustainability, Parking supply, Transportation demand management, University course scheduling, University of Louisville

**Paper type** Research paper

## 1. Introduction

Parking management and, generally, transportation demand management (TDM) are central issues in planning for a sustainable campus. As colleges' population grows, the demand for and supply of parking spaces on college campuses become crucial TDM considerations (Brown-West, 1996; Inci, 2015; Shoup, 2017). For college campuses, parking spaces are competing with other land uses as the college population grows, which sometimes translates into a loss of surface parking lots for new teaching, research and on-campus housing buildings (Millard-Ball *et al.*, 2004). Thus, the shortage of parking spaces is often an inevitable issue. However, adding more parking facilities increases financial and environmental costs (Riggs, 2014; Shoup, 2017). Hence, universities and researchers are

International Journal of Sustainability in Higher Education
Vol. 22 No. 4, 2021
pp. 909-930
© Emerald Publishing Limited
1467-6370
DOI 10.1108/IJSHE-11-2020-0461

continually exploring TDM strategies to encourage less parking demand or redistribute parking demand over time and space (Aoun *et al.*, 2013; Bamberg *et al.*, 2011; Gärling and Schuitema, 2007; Proulx *et al.*, 2014; Riggs, 2014; Stasko *et al.*, 2013; Yan *et al.*, 2019).

In an auto-dependent society like the USA, the size of on-campus activities determines parking demand. Course-taking and course-teaching are major trip purposes among the university population (Daisy *et al.*, 2018; Kamruzzaman *et al.*, 2011; Khattak *et al.*, 2011), implying that changes in course scheduling could potentially impact on-campus traffic and parking demand. Several studies have focused on university course scheduling or what some refer to as the university course timetabling problem (UCTP) (Al-Betar and Khader, 2012; Babaei *et al.*, 2015; Kostuch, 2004). Most of these studies focus on algorithms to address the UCTP and are yet to recognize the connection between course scheduling and on-campus parking demand. Our study aims to fill this gap by exploring how course scheduling can be leveraged as a tool for transportation demand management using the University of Louisville (UofL) as a case study.

The remainder of the paper is organized as follows. Section 2 provides a review of the literature on transportation demand management, university parking demand and course scheduling. Section 3 introduces the case study, the UofL. Section 4 explains the data collection process and presents a descriptive analysis of course offerings and on-campus parking. Section 5 explores whether there is a relation between course-taking activities and on-campus parking demand and Section 6 proposes a regression model to estimate parking demand based on course-enrollment information. Section 7 presents an optimization approach to search for a set of course scheduling that yields an optimal parking demand and Section 8 concludes the paper with discussions on the policy implications of the findings.

## 2. Literature review

Parking remains vital to the sustainability of college campuses. Studies have discussed the negative impacts of parking, such as increased impervious surface and the associated increase in stormwater runoff, as well as increased vehicle-miles traveled and the related traffic congestion, air pollution and greenhouse gas emissions (Chester *et al.*, 2011; Riggs, 2014; Shoup, 2011). Well-designed parking policies can serve as effective TDM strategies to reduce traffic congestion and associated pollution (Hess, 2017; Shoup, 2011).

### *2.1 Transportation demand management strategies for parking management on campus*

TDM strategies encompass a wide range of transportation and non-transportation efforts to influence travelers' behaviors and promote a more efficient use of existing resources (Ewing and Sarigöllü, 1998; Dalton *et al.*, 2018; Ferguson, 1990; Gärling and Schuitema, 2007; Litman, 2003). These strategies include ridesharing programs, transit/shuttle subsidizations, non-motorized infrastructure improvements, incentives to encourage alternative travel modes, parking pricing policy, public awareness programs and social nudge incentives. Several studies suggest that these strategies directly or indirectly influence travel behaviors, often reducing the number of automobile trips over time (Riggs, 2017; Meyer, 1999; Batur and Koç, 2017;) Göçer and Göçer, 2019).

A university consists of the following two distinct groups of population: students and employees. College students have more compact travel patterns, while employees' travel behaviors are more constrained by their residential locations (Delmelle and Delmelle, 2012; Dalton *et al.*, 2018; Zhang *et al.*, 2020). College students represent a population subgroup with unique demographic attributes and their travel behaviors are different from the general population. The survey data of four universities in Virginia reveals that college students have a higher-than-average daily trip frequency. Nevertheless, they are less dependent on automobiles because of their willingness to use alternative travel modes, such as walking, biking and public transit (Khattak *et al.*, 2011). This finding is supported by other studies in the USA (Akar *et al.*, 2012; Zhang *et al.*, 2020).

Universities use various TDM strategies related to both parking and transit to address parking demand and supply issues. Some suggest that parking and transit policies are the key areas where TDM strategies are used the most on campuses (Aoun *et al.*, 2013). TDM strategies used by universities include parking permitting, carpooling and ridesharing, shared use of private and municipal parking, technology-aided parking and parking pricing (Aoun *et al.*, 2013; Caicedo, 2010; Daggett and Gutkowski, 2003).

Shoup (2008) categorizes some of these TDM measures broadly into parking policies' political and economic sides. The politics-side involves using rules and regulations, while the economics-side relies on market principles to manage campus parking demand and supply. The use of minimum parking requirements is one such politics-side measure to manage parking on campus. Shoup (2011) refers to minimum parking requirements as the "great planning disasters" because such requirements increase auto-dependency, which, in turn, contributes to an increase in developmental cost, sprawl and low-density (Hess, 2017; Shoup, 2011). These parking requirements are often complemented by different forms of parking permitting measures. Existing research shows that most universities use parking permits for multiple user groups (faculty, staff, students and visitors) through a combination of methods such as parking scratch cards, permit lotteries and annual or semester parking fees (Daggett and Gutkowski, 2003; Filipovitch and Frimpong Boamah, 2016).

On college campuses, the impacts of minimum parking requirements and associated permitting measures result in what Shoup (2005) discusses as "feudal hierarchy" (i.e. the ranking of parking permits), parking anxiety among permit holders and misalignments between parking demand and supply, often resulting in parking shortages or excesses and unfair permit pricing (Aoun *et al.*, 2013; Filipovitch and Frimpong Boamah, 2016). Hess (2001, 2017) discusses the benefits of removing minimum parking requirements, but removing these politics-side measures often demands political action mostly from the public and special interest groups.

Emerging TDM strategies on campus are combining economic-centric measures with mode-shift alternatives. Specifically, universities are increasingly using ridesharing and other mobility options (e.g. cycling and walking). Existing studies have evaluated the relationship between parking and rideshare (or other mobility options except driving alone). For instance, to reduce parking demand on campus, a study at the University of California, Berkeley, looked at the role of a targeted and customized marketing campaign in mode-shift among campus users (Riggs, 2016; Riggs and Kuo, 2014). The carpool program at the University of California, Santa Barbara, also reduced campus parking demand by increasing carpooling among students and staff (Cherry *et al.*, 2018). Other studies have also looked at the role of campus bike-sharing and e-bikes programs in reducing campus parking demand (Kaplan and Knowles, 2015; Langford *et al.*, 2013).

At the heart of some of these economic-centric TDM approaches is the use of parking pricing in TDM strategies. Specifically, Shoup advocates for performance-based pricing or the "Goldilocks Principle of parking prices: the price of parking is too high if too many spaces are vacant and too low if no spaces are vacant" (2008, p. 136). This principle uses pricing to signal parking locations with:

- excess of parking spaces (parking price might be too high);
- shortage of parking spaces (price might be too low); and
- few vacant spaces or stable parking vacancy rate of 15% (price is just right) (Shoup, 2011).

An example of performance-based pricing is varying the fees for metered parking spaces based on the facility location and time of day (e.g. peak and off-peak use), especially for metered parking (Pierce and Shoup, 2013).

At the heart of performance-based pricing is information asymmetry or the lemons problem within economic systems. In his famous essay, Hayek (1945, p. 520) notes that because "All economic activity [including parking use] is in this sense planning" and the problem of planning an "efficient economic system [e.g. campus parking system]" is always about "the best way of utilizing knowledge [information] initially dispersed among all the people." Scholars have expanded on this information asymmetry problem within different economic systems such as insurance, automobile, labor and financial capital markets (Akerlof, 1970; Ross, 1973; Spence, 1973; Stigler, 1961). In a way, performance-based pricing brings attention to the information asymmetry between parking suppliers (campus or city parking authorities) and consumers (students, faculty, staff or city residents). Performance-based pricing captures and incorporates multiple information (e.g. location preferences of parking users at different times during the day or weeks and consumers' preferences for alternative transport modes) into parking pricing as a signal to both parking suppliers and consumers.

The literature on campus parking and transportation management is mostly absent on an approach to incorporate information on course schedules into the economics side of parking policymaking. Factoring in course schedules moves us closer to ensuring a useful TDM and parking demand measures that consider both non-coercive (e.g. targeted marketing campaigns, parking-sensitive course schedules on campus, etc.) and coercive (e.g. parking pricing) mean to close the information gap and behavioral issues in planning campus parking systems (Gärling and Schuitema, 2007; Litman, 2010).

### *2.2 Parking demand estimates and campus activities*

Various methodological approaches are used to estimate parking demand for campus TDM strategies. These methodological approaches can be grouped into two main categories, namely, behavioral (demand preference) analysis/modeling and optimization/simulation modeling (Table 1). Studies in the behavioral model category are mostly micro-centric in that they focus on factors influencing users' preferences for specific parking choices (Gurbuz and Cheu, 2020; Yan *et al.*, 2019) or the impacts of parking on mode-choices within university campuses (Bridgelall, 2014; Proulx *et al.*, 2014). Many of the studies within this category use discrete choice models, often involving cross-sectional data (i.e. revealed preference surveys) in the analysis.

The second, optimization/simulation-based studies, are mostly macro-centric in that they focus on aggregate demand and supply estimates of campus parking. The earliest of these studies used a binomial probability model to estimate parking usage among different users at the University of Illinois at Urbana-Champaign (Narragon *et al.*, 1974), but later studies have mostly used agent or activity-based simulation models (Huang *et al.*, 2012; Moradkhany *et al.*, 2015). One study in this category used a systems dynamics model to capture the complexity of factors influencing campus parking demand, supply, cost and benefits (Filipovitch and Frimpong Boamah, 2016).

These available studies mainly explore how individual preference and decision-making affect campus parking demand and how universities can develop appropriate TDM programs to influence campus users' parking decisions. In addition to TDM strategies, universities can directly influence the number of on-campus activities through course scheduling. Studies on university students' activity patterns support that class-related activities have a high daily frequency or occupy a significant amount of time within a day

**Table 1.** Existing literature related to parking demand and preference estimates in universities in the USA

| Paper | University | Research focus | Demographic focus | Methods |
|---|---|---|---|---|
| Gurbuz and Cheu (2020) | The University of Texas of El Paso | *Behavioral (demand preference) analysis/modeling*: The study examined the parking choice behavior of students, including determining the parking search times for different parking locations based on users' intelligent transportation systems (ITS) needs and level of service (LOS) expectations | Students | Descriptive statistics |
| Yan *et al.* (2019) | University of Michigan, Ann Arbor | *Behavioral (demand preference) analysis/modeling*: The study uses a revealed preferences survey to examine the interaction between travel mode and parking location choice among campus users | Faculty and staff | Discrete choice model |
| Bridgelall (2014) | North Dakota State University | *Behavioral (demand preference) analysis/modeling*: The study looked at the effect of parking supply and population growth on changes in mode choice among campus users | Students, faculty and staff | Discrete choice model |
| Proulx *et al.* (2014) | University at California, Berkeley | *Behavioral (demand preference) analysis/modeling*: This study focused on how changes in parking prices and transit fares impact mode choices on campus | Students, faculty and staff | Discrete choice model |
| Stasko *et al.* (2013) | Cornell University ad Ithaca College (and other locations in the city of Ithaca) | *Behavioral (demand preference) analysis/modeling*: The study focused on car sharing and its impacts on parking usage | Students | Descriptive statistics |
| Bustillos *et al.* (2011) | The University of Texas of El Paso | *Behavioral (demand preference) analysis/modeling*: The study focused on using trip origin-destination data assigned to various transportation modes to simulate parking lot preferences among students and faculty | Students and faculty | Discrete choice model and simulation modeling |
| Filipovitch and Frimpong Boamah (2016) | Minnesota State University | *Optimization/simulation modeling*: This study focused on simulating the relative impacts of parking prices and other factors on campus parking demand, supply, cost and benefits | Students, faculty and staff | Systems dynamics model |
| Moradkhany *et al.* (2015) | University of Akron | *Optimization/simulation modeling*: The study focused on identifying the class assignment to minimize parking search time for daily campus commuters effectively | Students, faculty and staff | Optimization (activity-based) model |
| Guo, Huang and Sadek (2013) | University at Buffalo | *Optimization/simulation modeling*: The study focused on developing an agent-based model to capture campus users' parking search process and use this information to evaluate the environmental cost (wasted fuel and emissions) from various parking search processes | Students, faculty and staff | Agent- or activity-based model, traffic micro-simulation and project-level emissions model |

(*continued*)

| Paper | University | Research focus | Demographic focus | Methods |
|---|---|---|---|---|
| Huang *et al.* (2012) | University at Buffalo | *Optimization/simulation modeling*: The study focused on estimating a 24-h dynamic demand of campus parking, demonstrating that this estimated demand replicates the observed parking lot occupancies and using the estimated data to show the desirability of different parking lots on campus using data such as class schedules and building occupancies | Students, faculty and staff | Agent- or activity-based model and traffic micro-simulation |
| Narragon *et al.* (1974) | The University of Illinois at Urbana-Champaign | *Optimization/simulation modeling*: The study develops a parking-facility usage model to analyze the factors affecting parking lot usage among campus parking users | Faculty and staff | Binomial-probability model |

**Table 1.**

(Eom *et al.*, 2009; Khattak *et al.*, 2011; Nois, Phihours and Hudson, 2006). Further, according to the activity transition matrix created based on students' observations at the North Carolina State University, 52.6% of respondents indicated that students directly go for school or class activities after sleep (Eom *et al.*, 2009). This finding suggests that course-taking may be a crucial factor that stimulates trips to campus for students.

Course-taking and course-scheduling are highly correlated. The long history of studies looking into the course timetabling problem or UCTP focus on generating an optimal assignment of courses to a limited number of timeslots and classrooms (Al-Betar and Khader, 2012; Babaei *et al.*, 2015; Kostuch, 2004; Pongcharoen *et al.*, 2008; Socha *et al.*, 2003). These existing studies mainly focus on methods or specific algorithms that can efficiently internalize multiple factors and reduce computational efforts. Factors considered in the existing studies include student demand for courses, faculty teaching load agreements, limited resources of time and space, university policies and personal preferences and conveniences of both students and faculty.

The relationship between on-campus parking demand and course scheduling is not well studied in the literature of TDM, parking demand and course scheduling. To the best of our knowledge, Moradkhany *et al.* (2015) may be the only study that aims to influence on-campus parking activities through course scheduling. Our study contributes to this inquiry within the campus TDM literature. Specifically, it contributes to some of the existing studies by incorporating longitudinal data on-campus course schedules to estimate campus parking demand. It pursues this through a three-step process involving:

(1) correlational analyses of parking use and course enrolment;
(2) regression analyses to determine whether one can estimate parking demand based on course enrollment information; and
(3) optimization analysis to determine whether there is an ideal arrangement of course enrollments that can yield an optimal parking demand and parking supply on campus.

Next, we discuss the campus setting for this analysis and the data and methods used.

## 3. The University of Louisville and campus parking supply

The UofL is located in Jefferson County, the most urbanized area in Kentucky. In Fall 2018, the student enrollment was 22,471, and the faculty and staff sizes were 2,540 and 4,444, respectively (UofL, 2021). According to the 2017 American Community Survey five-year estimates, 80.9% of Jefferson County residents commute by driving alone. The 2018 campus transportation survey reveals a similar auto-dependency for the campus population, with 72.4% of students and 83.6% of employees driving alone. Both the campus and the county authorities must factor this auto-dependency lifestyle in their plans, by, for example, providing and maintaining parking spaces.

Table 2 summarizes on-campus parking spaces into three categories for employees, students and visitors, respectively. Figure 1 presents the spatial distribution of on-campus parking spaces.

The first type includes blue and red parking spaces. Only university employees, including graduate research/teaching assistants, are eligible for purchasing these parking permits. Red and blue parking lots are very accessible to classrooms and research buildings. These parking permits are higher-priced than other permits and graduate students are often not motivated to purchase these permits. Instead, they will purchase student permits. Thus, in this study, we assume that red and blue lots are exclusively for faculty and staff.

**Table 2.**
Number campus parking lots by type

| Parking lot type | No. of spaces |
|---|---|
| *Faculty/staffs* | |
| Blue | 890 |
| Red | 863 |
| *Students* | |
| Yellow | 1,688 |
| Green | 1,457 |
| *Visitors* | |
| Miscellaneous | 95 |
| Meter | 82 |
| Visitors | 584 |
| Handicapped | 180 |
| Purple | 3,152 |
| Total | 8,991 |

The second parking type includes yellow and green lots. Students are eligible for these parking permits. Faculty and staff have an option to purchase parking permits for green spaces, but not yellow spaces. Yellow spaces are on the northeast side of the campus. Buildings around these spaces are primarily on-campus student housing. Most yellow spaces are close to the Old Louisville, a large residential community adjacent to the north side of the campus that offers a large stock of apartments to university students. The locations of green spaces are on the south edge of the campus. University employees may not be motivated to purchase these green parking permits because these spaces are less convenient than the locations of red and blue spaces. These green spaces are also less attractive to students because they are not easily accessible to residential and other university buildings. The third category is for campus visitors (e.g. loading zones for facilities and commercial vehicles, metered parking and miscellaneous).

There are 180 handicapped spaces on campus. Every parking lot has a few handicapped spaces. We decided to exclude them from our analysis. Given the small size and even distribution of handicapped spaces, adding or excluding them did not affect our results. All purple parking spaces are in the Cardinal Stadium, located on the north side of the campus. These spaces serve the parking needs of visitors during football seasons. It is inconvenient for people to get to the campus with no direct bus connection after they park their cars at the stadium parking lots. Campus parking lot survey indicates no use or very minimum use of these stadium lots during regular working hours. Therefore, we excluded these purple parking spaces in our analyses.

## 4. Data

This research explores whether there is a correlation between course enrollments and campus parking. Specifically, it examines whether parking demand on campus can be estimated based on course-taking activities and how re-arranging course schedules can optimally minimize on-campus parking demand and supply. To pursue this, we collected three sets of data: course enrollment data, facility information and campus parking lot survey.

Course enrollment data from 2010 to 2016 were obtained from the UofL. This data set provides location, time, course length and enrollment size information for courses offered in the past seven academic years. Table 3 presents the courses offered each day for spring and

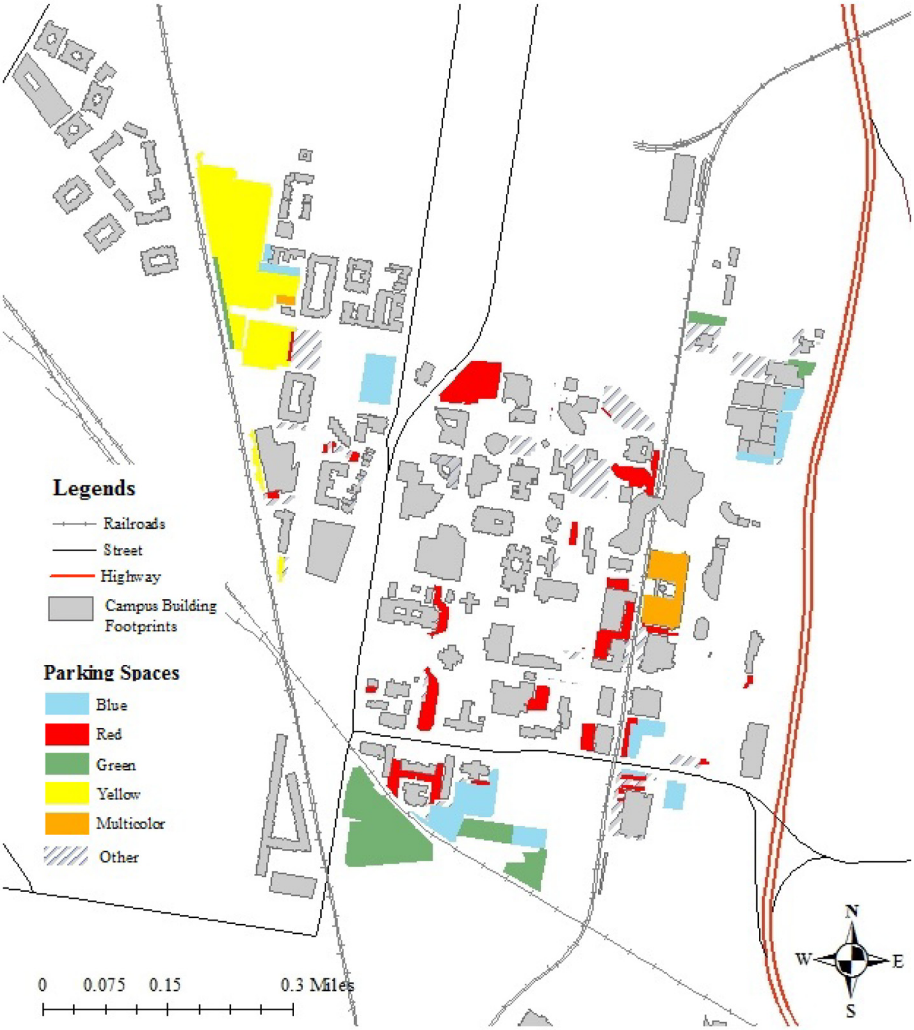


**Figure 1.**
UofL park spaces

| | 2009–2010 | | 2010–2011 | | 2011–2012 | | 2012–2013 | | 2013–2014 | | 2014–2015 | | 2015–2016 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Spring | Fall | Spring | Fall | Spring | Fall | Spring | Fall | Spring | Fall | Spring | Fall | Spring | Fall |
| Monday | 1,034 | 1,141 | 1,051 | 1,173 | 1,059 | 1,160 | 1,046 | 1,155 | 1,058 | 1,199 | 1,113 | 1,276 | 1,180 | 1,316 |
| Tuesday | 969 | 1,046 | 998 | 1,092 | 1,000 | 1,090 | 1,036 | 1,114 | 1,033 | 1,104 | 1,060 | 1,170 | 1,067 | 1,123 |
| Wednesday | 1,093 | 1,190 | 1,127 | 1,209 | 1,130 | 1,212 | 1,110 | 1,223 | 1,121 | 1,263 | 1,160 | 1,280 | 1,199 | 1,325 |
| Thursday | 922 | 1,026 | 967 | 1,096 | 971 | 1,051 | 971 | 1,072 | 1,006 | 1,061 | 1,029 | 1,144 | 1,037 | 1,101 |
| Friday | 553 | 623 | 571 | 636 | 573 | 637 | 575 | 665 | 585 | 671 | 593 | 688 | 622 | 688 |
| Saturday | 35 | 31 | 28 | 28 | 28 | 24 | 24 | 27 | 28 | 30 | 29 | 34 | 22 | 38 |

**Table 3.**
Number of courses by school year, semester and day

fall semesters, with most courses offered on Mondays and Wednesdays, followed by Tuesday and Thursday. Few courses were offered on Fridays and even fewer on Saturdays

Figure 2 illustrates the percentage distribution of start times for the courses. The distribution pattern is very consistent over time and across semesters. Most courses were offered between 9 a.m. and 10 a.m., 11 a.m. and 12 p.m. or 1 p.m. and 3 p.m. There are several possible reasons for this pattern. An instructor may personally prefer these times to avoid potential conflicts with other responsibilities or personal schedules. In this sense, early morning, late afternoon and evening times may not be preferred. A specific course time could also be selected to deal with such conflicts for students, thereby increasing course enrollment. For instance, if most potential students of a program have full-time jobs, the program may purposely arrange their courses in the evenings to allow students the flexibility to balance their daytime jobs and academic work. Curriculum needs are another factor in determining courses' times. A program may offer a class immediately after another on the same day to obtain the best educational outcomes. For example, in an urban planning program, theory and practice courses may be offered consecutively to allow students the opportunity to apply their learned theories to real-world practice scenarios. The length of a class has been very consistent, around 95–98 min on average, over 2009-2016.

Facility data includes building and room names and maximum room occupancies. This data reflects the 2018 facility inventory. We expect this to be stable over 2009-2018 because most facility additions during this period were mainly sports facilities, parking spaces and student housing, rather than facilities for teaching and research activities.

The last dataset collected was the 2016–2017 campus parking lot survey, which provides parking lot occupancies and vacancies over time (from 8:30 a.m. to 7:30 p.m.) from Monday to Friday. The parking occupancy rates for each parking space were computed. Table 4 presents the descriptive statistics of parking occupancy rates for different parking spaces. Yellow lots have the highest mean and median occupancy rates and the lowest standard deviation, followed by blue, green and red lots.

Course enrollment information enabled us to calculate the number of students (i.e. total enrollments) expected to be on campus across certain times and days. Figure 3 compares enrollment information with parking lot usage for Fall 2016. Course enrollment peaks on Tuesdays and Thursdays in the morning around 10 a.m.–12 p.m. for both fall and spring semesters. Parking occupancy patterns follow, but not exactly, these enrollment patterns.

## 5. Course enrollments and campus parking demand

This section examines the relationship between the total course enrollment and the campus parking lot usage over time. The enrollment sizes at a time are the expected number of students on campus for course-taking. As supported by the trip chaining patterns of Eom *et al.* (2009), students may come to campus earlier before class or stay on campus after class for various reasons, such as meeting with other students, using professors' office hours or using the library. Similarly, it is unlikely for an instructor to be present on campus only during the teaching time. In this sense, parking lot usage could relate strongly with the total course enrollment within a time window rather than a single course enrollment at a specific time. We examine the relationship between course enrollment and parking usage by defining:

$P_t$ = The parking lot usage at time $t$; and

$E_t$ = The total course enrollment on campus at time $t$.

Then, the total course enrollment with $k$-hour time window (i.e. before and after $k$ hours of time $t$) can be calculated as:

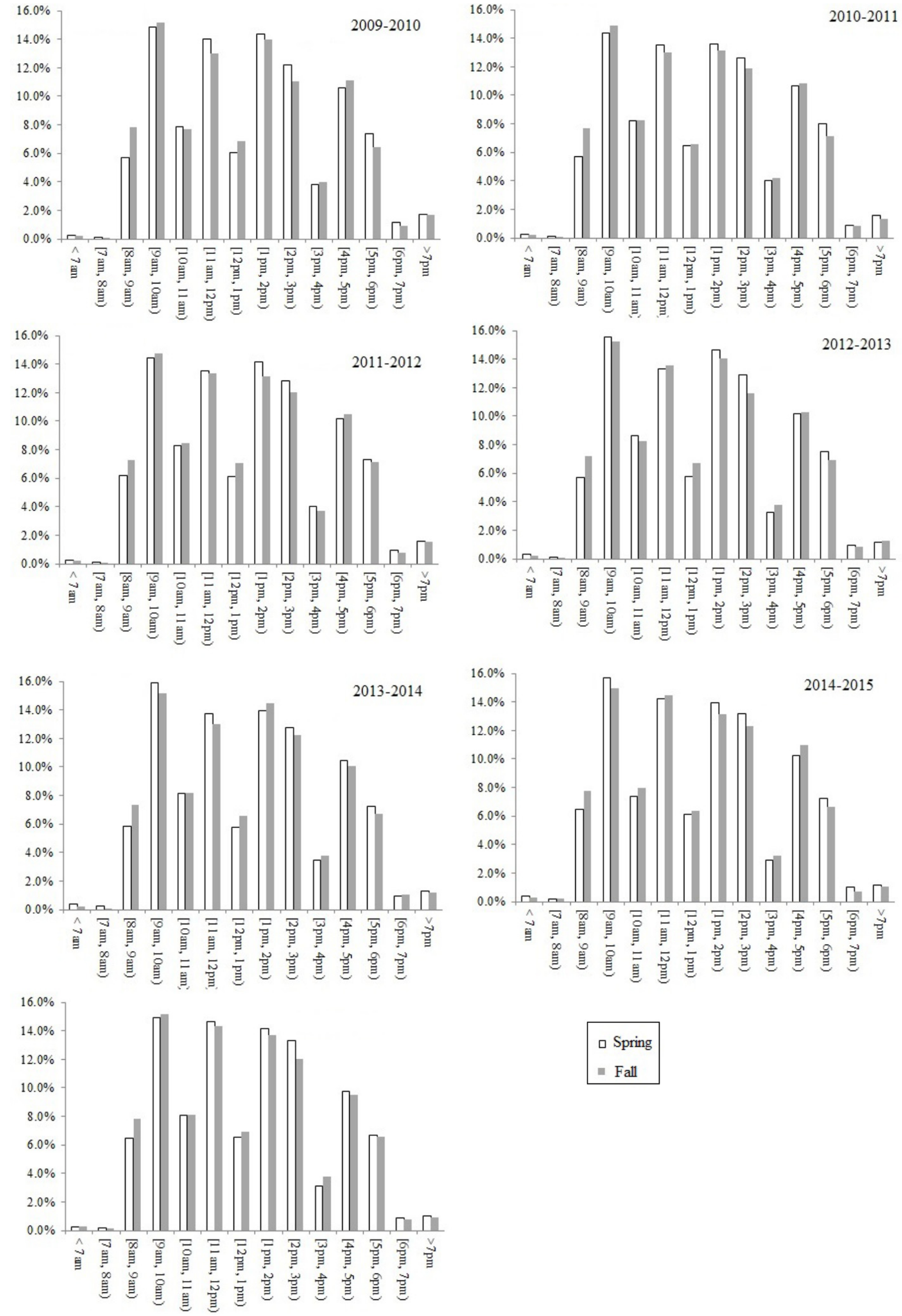


**Figure 2.**
Percentage distribution of course sessions by course starting time

$$EE_{(t,k)} = \sum\nolimits_{(T=t-k)}^{(t+k)} E_T.$$

Table 5 presents the correlation coefficients between parking lot usage ($P_t$) and the number of enrollments within different $k$-hour windows ($EE_{t,k}$) for the parking lots for faculty/staff (blue and red), students (yellow and green) and visitors (meter, visitors and miscellaneous). With an increasing course enrollment, we expect more students on campus and a higher level of parking lot demand from students. There are consistently positive and significant correlations between yellow parking lot usage and course enrollment over different time windows. The correlation coefficient peaks at the 2-h time window ($k$ = 2) for calculating course enrollment size. This peak time correlation suggests that when students come to campus for their classes, they are likely to arrive two hours early or stay for an extra two hours after class for various course-related or social reasons. For green parking lot usage, such correlations are positive but insignificant for most time windows. This result may be

**Table 4.** Descriptive statistics of parking lot occupancy rates

| Parking lot type | $n$ | Min (%) | Mean (%) | Median (%) | Std (%) | Max (%) |
|---|---|---|---|---|---|---|
| Blue | 477 | 0 | 77 | 84 | 25 | 100 |
| Red | 677 | 0 | 63 | 68 | 27 | 100 |
| Yellow/orange | 208 | 32 | 90 | 97 | 13 | 100 |
| Green | 187 | 0 | 66 | 82 | 34 | 100 |
| Miscellaneous | 190 | 0 | 52 | 59 | 36 | 100 |
| Meter | 241 | 0 | 60 | 63 | 34 | 100 |
| Visitors | 225 | 0 | 50 | 50 | 28 | 100 |

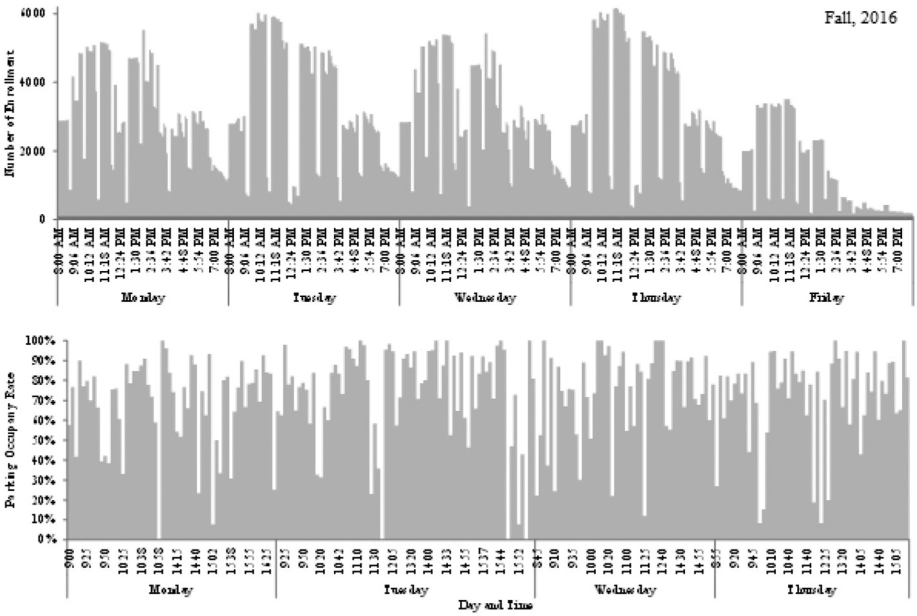


**Figure 3.** Numbers of enrollment and parking occupancy by day and time

because users of green parking spaces include both students and faculty/staff, and these two user groups use parking spaces differently.

With increasing enrollment and a higher number of students on campus, we expect more faculty and staff to teach courses and provide supportive services. There is a positive and significant correlation between the usage of red parking spaces and course enrollment and the correlation level peaks at a time window of $k$ = 4.5 h. The correlation also peaks at $k$ = 4.5 h for blue parking spaces and this correlation is significant at a 5% level.

There is no significant and stable correlation between parking lot usage and course enrollment for the visitors' parking spaces (i.e. visitor, meter and miscellaneous parking lots). This result makes sense because most visitors do not visit the campus for course-related purposes.

## 6. Estimating parking demands

This section explores whether parking demand can be estimated based on course enrollment information. It builds on the significant correlations identified among course enrollment, student parking lot usage (yellow) and faculty/staff parking lot usage (red and yellow) in the previous section. We set the following regression models to estimate parking space demands:

$$S\_OCCU_{d,t,l} = b_0 + b_1 S_l + b_2 EE_{t,2} + b_3 FR_d + \gamma_{d,t,l} \quad (1)$$

$$F\_OCCU_{d,t,l} = a_0 + a_1 S_l + a_2 EE_{t,4.5} + \mu_{d,t,l} \quad (2)$$

where:

$F\_OCCU_{d,t,l}$ = number of occupied faculty/staff parking space at time $t$, in day $d$, in parking lot $l$;

$S\_OCCU_{d,t,l}$ = number of occupied student parking space at time $t$, in day $d$, in parking lot $l$;

$S_l$ = number of parking space available in parking lot $l$;

$EE_{t,2}$ = Total course enrollment within a 2-h time window of time $t$;

$EE_{t,4.5}$ = Total course enrollment within a 4.5-h time window of time $t$;

$FR_d$ = Friday residual; and

$\mu_{d,t,l}$, $\gamma_{d,t,l}$ = Error terms.

Two-hour ($EE_{t,2}$) and four-and-half-hour ($EE_{t,4.5}$) time windows are used to explain student and faculty/staff parking lot usages, respectively, because these are what the correlation analysis results suggest (Table 4). Friday may impact a student's or a faculty/staff's

| | Time window size ($k$) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 0.5 | 1 | 1.5 | 2 | 2.5 | 3 | 3.5 | 4 | 4.5 | 5 |
| Red | 0.09* | 0.09** | 0.14*** | 0.09* | 0.10* | 0.10** | 0.16*** | 0.13*** | 0.17*** | 0.18*** | 0.17*** |
| Blue | −0.01 | −0.04 | 0.06 | 0.02 | −0.01 | 0.10* | 0.10** | 0.10* | 0.11** | 0.13*** | 0.12** |
| Green | 0.11* | 0.03 | 0.05 | 0.02 | 0.02 | 0.05 | 0.10 | 0.07 | 0.08 | 0.07 | 0.05 |
| Yellow | −0.08 | 0.16** | 0.20*** | 0.20*** | 0.24*** | 0.23*** | 0.18** | 0.21*** | 0.21*** | 0.18** | 0.19** |
| Visitor | −0.04 | −0.17** | −0.07 | 0.01 | −0.03 | −0.03 | 0.06 | 0.07 | 0.01 | 0.06 | 0.03 |
| Meter | 0.08 | 0.06 | 0.05 | 0.09 | 0.07 | 0.01 | 0.08 | 0.04 | 0.07 | 0.06 | 0.10 |
| Miscellaneous | 0.03 | 0.00 | 0.09 | 0.11 | −0.04 | 0.00 | 0.04 | 0.00 | 0.06 | 0.00 | 0.06 |

**Notes:** ***Significant at 1% level; **significant at 5% level; *significant at 10% level

**Table 5.** Correlation coefficients between parking lot usage and course enrollment activities

decision to visit the campus and impact course scheduling. To avoid the multicollinearity issue, we regressed a Friday dummy variable on course enrollments and used the residual ($FR_d$) to capture the Friday effect. This Friday residual variable does not have a significant impact on the faculty/staff model, and therefore is not included in equation (2).

Table 6 present the regression results. For student parking space usage, the results suggest that for every additional parking spot supplied, 0.9053 units will be used. For every course enrollment within a 2-h window, parking space demand increases by 0.0048 units. The Friday residual variable has a strong and negative impact, suggesting a lower parking demand level from students on Fridays. All these effects are significant at the 1% significance level. The faculty/staff model results indicate that with an additional parking space supply, the demand from faculty/staff increases by 0.8196 units. With every additional enrollment in a 4.5-h window, parking demand from faculty/staff increases by 0.0004 units.

The high $R^2$, 0.9897 for the student model and 0.9280 for the faculty/staff model, suggest both models' high explanatory power. Hence, these models can be used to predict parking space usage based on parking facility information and course enrollment information.

## 7. The optimized campus parking demand

The regression analyses suggest that course enrollment is a key determinant of on-campus parking demand for students and faculty/staff. This section uses the optimization modeling method and explores whether there is an ideal arrangement of course enrollments that can yield an optimal parking demand and supply. The analysis focuses on the Fall semester of 2016. The university, in this semester, offered 3,032 courses, with a total course enrollment of 74,248. Our analysis excludes distance learning classes and short courses [1]. These classes do no generate significant and long-term impacts on on-campus parking. For simplicity, the optimization model only focuses on the 2,401 courses that ended in November and December, which were offered weekly throughout the semester. Since the usages of yellow, red and blue parking lots are more correlated with course enrollment (Table 5), the optimization analysis focuses on these three types of parking spaces. We set up the optimization model based on the existing algorithm of university course timetabling (Babaei *et al.*, 2015), with extensions to consider the impacts of course scheduling on parking demand and to search for a set of course scheduling that yields an optimal peak parking demand.

### *7.1 The optimization model*

An optimization model consists of an objective function and a set of constraints. Our objective function is to minimize the total student and employee parking supply on campus.

**Table 6.** Regression results of student and faculty/staff parking space usage

| | Student model | | Faculty/staff model | |
|---|---|---|---|---|
| | Estimate | $p$-value | Estimate | $p$-value |
| Intercept | −67.2046 | <0.0001 | −12.2369 | 0.0005 |
| Number of parking spots of a parking lot (S) | 0.9053 | <0.0001 | 0.8196 | <0.0001 |
| 2-h window course enrollment ($EE_{t,2}$) | 0.0048 | <0.0001 | | |
| 4.5-h window course enrollment ($EE_{t,4.5}$) | | | 0.0004 | 0.0088 |
| Friday residual | −76.1268 | 0.017 | | |
| $n$ | 157 | | 798 | |
| $R^2$ | 0.9897 | | 0.9280 | |

We set up this objective to promote a more sustainable campus. Almost all parking supplies on the UofL campus are asphalt parking lots. This type of parking facility requires a large land area, increases the impervious surface areas on campus and contaminates surface runoffs due to the chemicals (e.g. polycyclic aromatic hydrocarbons) contained in the coal-tar emulsion seal coat used in asphalt parking lots (Greenstein *et al.*, 2004). Surface parking lots also raise security, aesthetics and cleanliness concerns (Mendat and Wogalter, 2003), are costly to build and maintain. Shoup (2017) finds that the average cost of a parking space at the University of California, Los Angeles is $22,500, and this cost is higher for structured parking facilities (Riggs, 2014). Further, routine maintenance and periodic repair are necessary to keep parking facilities clean and secure (Gooranorimi and Shiu, 2018).

The objective of minimizing the on-campus parking supply has to be constrained by campus operational needs, the limitation of facilities, personal preferences and parking demand.

The first two sets of constraints are extensively addressed in the literature (Badri *et al.*, 1998; Pongcharoen *et al.*, 2008). Universities must offer all required courses. For instance, an English department may have to offer the required English 101 with students meeting three times a week for fifty minutes per session. The optimization model must ensure that:

- there are three class sessions;
- every class session is on a different weekday;
- every session must be 50 min; and
- every session takes place in continuous 50 min.

As for facility limitation constraint, every course session has to occur in only one classroom. Every classroom can accommodate at most one class at a given time, implying that the number of courses offered at a given time cannot be more than the number of classrooms available on campus. Further, every room must be able to accommodate the course's maximum enrollment size assigned to this room.

We introduce a constraint to account for instructors' time preferences. After examining the start times of courses offered in the past years, the data revealed that the preferred start time for a class is between 6:55 a.m. and 6:05 p.m.

A key contribution of this research is the introduction of a parking demand constraint. The supply of parking must meet the demand from students and university employees across time and days. According to the regression results estimated in the previous section, time-specific parking demand can be estimated based on course enrollment information. The supply of on-campus parking spaces must exceed or equal the peak-time demand.

Figure 4 summarizes the basic idea of the optimization model. Every university has control over course scheduling throughout a semester. Course scheduling decisions are constrained by the existing facility, course attributes and faculty members' preferences when offering their courses, as discussed previously. At the same time, a university's course scheduling decisions determine the size of enrollments on campus across time and days; that is, the number of students are expected to be on campus for classes. Based on the regression results about the relationship between parking demands and course enrollment activities, we can estimate the parking demand for a given course arrangement decision as an optimization goal. This optimization analysis aims to find a set of course scheduling that yields an optimal level of parking demand. We used the general algebraic modeling system (GAMS) to program our optimization model.

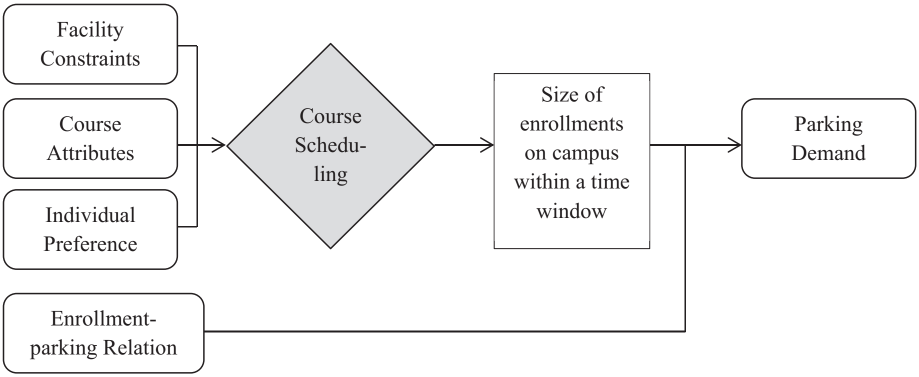


**Figure 4.**
Basic idea of the optimization analysis

*7.2 Optimization results*

The optimization results suggest offering 20.11%, 19.18%, 20.05%, 20.49% and 20.17% of course sessions on Monday, Tuesday, Wednesday, Thursday and Friday, respectively. As a comparison, currently, there are more courses offered on Mondays and Wednesdays and much fewer courses offered on Fridays (Table 3). A more even course distribution across weekdays can effectively reduce the peak-time parking demand, and therefore, on-campus parking supply.

Different from the existing distribution of course times (Figure 1), which peaks around mid-morning and mid-afternoon times, the optimization results suggest concentrating courses in the early morning, noon and late afternoon times (Figure 5). This distribution of start times reflects the correlations between parking demand and course enrollment activities, as presented in Table 5. The correlation results suggest that students and instructors may not stay on campus for the whole day to attend or teach a class. Instead, they stay during a time window of their class times. Considering these specific time windows (4.5 h for faculty/staff and 2 h for students) in course arrangement decisions reduces peak time parking demand and creates a more even distribution of parking demand over day and time (Figure 6).

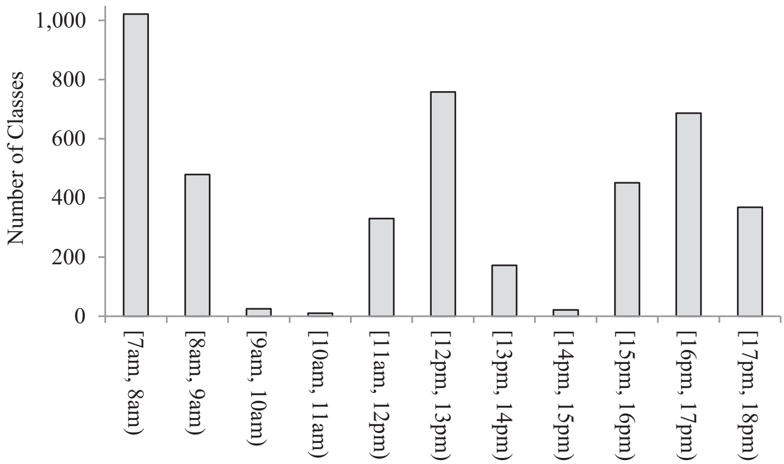


**Figure 5.**
Optimal distribution of course start time

More importantly, by considering the relationship between course-taking and parking demand, the optimization results suggest that 2,398 yellow/blue/red parking spaces will meet the parking demand from students and university employees. For comparison, the university currently has 3,441 such spaces. Thus, the optimal demand reflects a 30.3% of reduction in the existing parking supply on campus.

## 8. Conclusions

Studies focus on campus TDM strategies have proposed measures to influence individuals' travel decisions (Aoun *et al.*, 2013; Kaplan and Knowles, 2015; Riggs and Kuo, 2014; Shoup, 2005, 2008). The relationship between course-scheduling and parking demand was not explicitly accounted for in most studies. This study reveals that course scheduling remains vital in campus parking demand and supply predictions and policies. Thus, an optimized course schedule remains a viable and essential option to reduce on-campus parking demand.

This study uses the UofL as a case study to demonstrate how campus parking demand and supply could be optimized by carefully considering course arrangement decisions. First, correlation analysis results supported the hypothesis that on-campus parking is significantly correlated with course-taking activities. Second, regression analyses enabled estimating on-campus parking demand based on existing parking supply and course-taking activities. Finally, an optimization model, incorporating the regression results, was set up to find a set of course scheduling that minimizes total on-campus parking supply given the constraints of university operations, personal preferences, facility limitations and the relation between parking demand and course-taking activities. The optimization model suggested that the university's parking supply could be reduced by 30.3% by coupling and optimizing campus course scheduling and parking supply decisions.

The results from this research offer an additional tool for campus authorities to consider when thinking about sustainable TDM options on campus. While many studies and campus policies have suggested innovative TDM strategies related to transit (shared mobility, informational campaigns) and parking (performance-based pricing), this study adds a layer to the policy options available to campus authorities. Course scheduling is a fundamental function performed by all colleges, and this ubiquitous function drives who, when and what activities flow in and out of campuses. While some of the emerging TDM strategies aim toward changing travel behavior on campus, this study suggests the need to tackle the fundamental decision that drives why most people travel and stay on campuses in the first place.

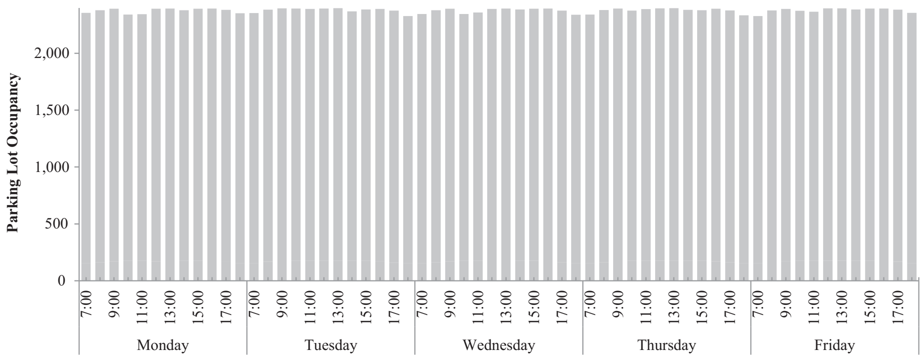


**Figure 6.** Optimal parking demand over day and time

The COVID-19 pandemic has disrupted course-offering schedules across US universities (Johnson *et al.*, 2020). For instance, at the UofL, all in-person classes are offered entirely online or as a hybrid course involving online and in-person teaching components. Universities are exploring strategies to safely reopen campuses during or after the pandemic (Cheng *et al.*, 2020; Harper, 2020). It is expected that some courses will still be online even after the pandemic due to several factors. For instance, some instructors have improved their pedagogical mastery of using online tools for teaching (Rapanta *et al.*, 2020), universities have made significant software and hardware investments to support online teaching (Gardner, 2020) and students are developing positive attitudes toward well-structured online courses (Yang and Tsai, 2008). Consequently, on-campus course-taking activities and related traffic may change over time. Our proposed method can be adapted to this new scenario in finding the optimal level of on-campus parking supply. The current setup does not consider the potential impact of distance learning on on-campus activities. Over the academic year 2015–2016, 7.3% of the courses were offered online at the UofL. These courses did not have detectable impacts on on-campus activities. However, with an increasing number of online classes, the relationship between parking demand and course-taking activities may change. When a student makes a trip for an in-person class, she may stay on campus for a longer time to participate in other online courses. Therefore, online course enrollments should be introduced as another independent variable for explaining on-campus parking demand in the regression analysis. The optimization setup will remain the same, but with an updated relationship between parking demand and course enrollments.

There are two limitations of this research, which should be accounted for in future research. First, there will be an unexpected calculation burden when applying the mixed-integer linear programming to a university course scheduling problem. For instance, in Fall 2016, our optimization program considered 2,401 courses. Each course could have up to 5 weekly sessions. There were 5 days and each day had 69-time slots. The model introduced more than 4 million binary variables (2401 * 5 * 5 * 69). A computer with a lower than 32 GB memory could not accommodate the dimension of this problem. We had to run the GAMS program iteratively, with progressing relative optimality criteria. Future research may explore individual programs' or departments' user equilibrium instead of the university's system optimal. One can split a large optimization program into numerous simultaneous optimization decisions at the program or department level.

Second, this research proposed a method to optimize on-campus transportation behaviors through course-scheduling. The constraint set of the optimization analysis can be expanded to internalize the impacts of many related factors, such as instructors' time preference, curriculum design needs and potential impacts of existing TDM policies. Future policy and research could experiment with combing course scheduling decisions with other TDM strategies (e.g. targeted informational campaign on ridesharing) to evaluate their impacts on-campus parking demand and associated cost reductions in campus parking supply. There are potential cost savings from combining both TDM strategies and course scheduling to minimize parking supply on campus. These savings can be invested in other TDM strategies such as campus biking programs, public transit programs (free bus rides) and increased incentives for those participating in shared mobility programs. The quest for more sustainable college campuses cannot be obtained through panaceas but requires experimentation with and rigorous testing of multiple options by researchers and campus authorities.

**Note**

1. For instance, the MBA program can provide a one-day course from 8 a.m. to 4 p.m.

## References

Akar, G., Flynn, C. and Namgung, M. (2012), "Travel choices and links to transportation demand management: case study at Ohio state university", *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 2319 No. 1, pp. 77-85.

Akerlof, G.A. (1970), "The market for 'lemons': quality uncertainty and the market mechanism", *The Quarterly Journal of Economics*, Vol. 84 No. 3, pp. 488-500.

Al-Betar, M.A. and Khader, A.T. (2012), "A harmony search algorithm for university course timetabling", *Annals of Operations Research*, Vol. 194 No. 1, pp. 3-31.

Aoun, A., Abou-Zeid, M., Kaysi, I. and Myntti, C. (2013), "Reducing parking demand and traffic congestion at the American University of Beirut", *Transport Policy*, Vol. 25, pp. 52-60.

Babaei, H., Karimpour, J. and Hadidi, A. (2015), "A survey of approaches for university course timetabling problem", *Computers and Industrial Engineering*, Vol. 86, pp. 43-59.

Bamberg, S., Fujii, S., Friman, M. and Gärling, T. (2011), "Behaviour theory and soft transport policy measures", *Transport Policy*, Vol. 18 No. 1, pp. 228-235.

Batur, İ. and Koç, M. (2017), "Travel demand management (TDM) case study for social behavioral change towards sustainable urban transportation in Istanbul", *Cities*, Vol. 69, pp. 20-35.

Bridgelall, R. (2014), "Campus parking supply impacts on transportation mode choice", *Transportation Planning and Technology*, Vol. 37 No. 8, pp. 711-737.

Brown-West, O.G. (1996), "Optimization model for parking in the campus environment", *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 1564 No. 1, pp. 46-53.

Bustillos, B.I., Shelton, J. and Chiu, Y.-C. (2011), "Urban university campus transportation and parking planning through a dynamic traffic simulation and assignment approach", *Transportation Planning and Technology*, Vol. 34 No. 2, pp. 177-197.

Caicedo, F. (2010), "Real-time parking information management to reduce search time, vehicle displacement and emissions", *Transportation Research Part D: Transport and Environment*, Vol. 15 No. 4, pp. 228-234.

Cheng, S.Y., Wang, C.J., Shen, A.C.T. and Chang, S.C. (2020), "How to safely reopen colleges and universities during COVID-19: experiences from Taiwan", *Annals of Internal Medicine*, Vol. 173 No. 8, pp. 638-641.

Cherry, C.R., Riggs, W., Appleyard, B., Dhakal, N., Frost, A. and Jeffers, S.T. (2018), "New and unique aspects of university campus transportation data to improve planning methods", *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 2672 No. 8, pp. 742-753.

Chester, M., Horvath, A. and Madanat, S. (2011), "Parking infrastructure and the environment", *ACCESS Magazine*, Vol. 1 No. 39.

Daggett, J. and Gutkowski, R. (2003), "University transportation survey: transportation in university communities", *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 1835 No. 1, pp. 42-49.

Daisy, N.S., Hafezi, M.H., Liu, L. and Millward, H. (2018), "Understanding and modeling the activity-travel behavior of university commuters at a large Canadian university", *Journal of Urban Planning and Development*, Vol. 144 No. 2, p. 4018006.

Dalton, L.C., Hajrasouliha, A.H. and Riggs, W.W. (2018), "State of the art in planning for college and university campuses: site planning and beyond", *Journal of the American Planning Association*, Vol. 84 No. 2, pp. 145-161.

Delmelle, E.M. and Delmelle, E.C. (2012), "Exploring Spatio-temporal commuting patterns in a university environment", *Transport Policy*, Vol. 21, pp. 1-9.

Eom, J.K., Stone, J.R. and Ghosh, S.K. (2009), "Daily activity patterns of university students", *Journal of Urban Planning and Development*, Vol. 135 No. 4, pp. 141-149.

Ewing, G.O. and Sarigöllü, E. (1998), "Car fuel-type choice under travel demand management and economic incentives", *Transportation Research Part D: Transport and Environment*, Vol. 3 No. 6, pp. 429-444.

Ferguson, E. (1990), "Transportation demand management planning, development, and implementation", *Journal of the American Planning Association*, Vol. 56 No. 4, pp. 442-456.

Filipovitch, A. and Frimpong Boamah, E. (2016), "A systems model for achieving optimum parking efficiency on campus: the case of Minnesota state university", *Transport Policy*, Vol. 45, pp. 86-98.

Gardner, L. (2020), "Covid-19 has forced higher ed to pivot to online learning. Here are 7 takeaways so far", *The Chronicle of Higher Education*, Vol. 20.

Gärling, T. and Schuitema, G. (2007), "Travel demand management targeting reduced private car use: effectiveness, public acceptability and political feasibility", *Journal of Social Issues*, Vol. 63 No. 1, pp. 139-153.

Göçer, Ö. and Göçer, K. (2019), "The effects of transportation modes on campus use: a case study of a suburban campus", *Case Studies on Transport Policy*, Vol. 7 No. 1.

Gooranorimi, O. and Shiu, K. (2018), "Maintenance and repair costs for different types of parking structures", *Concrete Repair Bulletin*, pp. 32-38.

Greenstein, D., Tiefenthaler, L. and Bay, S. (2004), "Toxicity of parking lot runoff after application of simulated rainfall", *Archives of Environmental Contamination and Toxicology*, Vol. 47 No. 2, pp. 199-206.

Guo, L., Huang, S. and Sadek, A.W. (2013), "A novel agent-based transportation model of a university campus with application to quantifying the environmental cost of parking search", *Transportation Research Part A: Policy and Practice*, Vol. 50, pp. 86-104.

Gurbuz, O. and Cheu, R.L. (2020), "Survey to explore behavior, intelligent transportation systems needs, and level of service expectations for student parking at a university campus", *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 2674 No. 1, pp. 168-177.

Harper, S.R. (2020), "COVID-19 and the racial equity implications of reopening college and university campuses", *American Journal of Education*, Vol. 127 No. 1, pp. 153-162.

Hayek, F.A. (1945), "The use of knowledge in society", *The American Economic Review*, pp. 519-530.

Hess, D.B. (2001), "Effect of free parking on commuter mode choice: evidence from travel diary data", *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 1753 No. 1, pp. 35-42.

Hess, D.B. (2017), "Repealing minimum parking requirements in buffalo: new directions for land use and development", *Journal of Urbanism: International Research on Placemaking and Urban Sustainability*, Vol. 10 No. 4, pp. 1-26.

Huang, S., Guo, L., Yang, Y., Casas, I. and Sadek, A.W. (2012), "Dynamic demand estimation and microscopic traffic simulation of a university campus transportation network", *Transportation Planning and Technology*, Vol. 35 No. 4, pp. 449-467.

Johnson, N., Veletsianos, G. and Seaman, J. (2020), "U.S. Faculty and administrators' experiences and approaches in the early weeks of the COVID-19 pandemic", *Online Learning*, Vol. 24 No. 2, pp. 6-21.

Kamruzzaman, M., Hine, J., Gunay, B. and Blair, N. (2011), "Using GIS to visualise and evaluate student travel behaviour", *Journal of Transport Geography*, Vol. 19 No. 1, pp. 13-32.

Kaplan, D.H. and Knowles, M.J. (2015), "Developing a next-generation campus bike-share program: examining demand and supply factors", *Planning for Higher Education*, Vol. 44, p. 63.

Khattak, A., Wang, X., Son, S. and Agnello, P. (2011), "Travel by university students in Virginia: is this travel different from travel by the general population?", *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 2255 No. 1, pp. 137-145.

Kostuch, P. (2004), "The university course timetabling problem with a three-phase approach", *International Conference on the Practice and Theory of Automated Timetabling*, Springer, *Berlin, Heidelberg*, pp. 109-125.

Langford, B.C., Cherry, C., Yoon, T., Worley, S. and Smith, D. (2013), "North America's first e-bikeshare: a year of experience", *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 2387 No. 1, pp. 120-128.

Litman, T. (2003), "Transportation demand management and 'win-win' transportation solutions", *Handbook of Transport and the Environment*, Emerald Group Publishing.

Litman, T. (2010), *Parking Pricing Implementation Guidelines*, Victoria transport policy institute.

Mendat, C.C. and Wogalter, M.S. (2003), "Perceptions of parking facilities: factors to consider in design and maintenance", *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, Sage, *Los Angeles, CA*, Vol. 47, pp. 918-921.

Meyer, M.D. (1999), "Demand management as an element of transportation policy: using carrots and sticks to influence travel behavior", *Transportation Research Part A: Policy and Practice*, Vol. 33 Nos 7/8, pp. 575-599.

Moradkhany, A., Yi, P., Shatnawi, I. and Xu, K. (2015), "Minimizing parking search time on urban university campuses through proactive class assignment", *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 2537 No. 1, pp. 158-166.

Narragon, E., Dessouky, M. and Devor, R. (1974), "A probabilistic model for analyzing campus parking policies", *Operations Research*, Vol. 22 No. 5, pp. 1025-1039.

Pierce, G. and Shoup, D. (2013), "Getting the prices right: an evaluation of pricing parking by demand in San Francisco", *Journal of the American Planning Association*, Vol. 79 No. 1, pp. 67-81.

Pongcharoen, P., Promtet, W., Yenradee, P. and Hicks, C. (2008), "Stochastic optimisation timetabling tool for university course scheduling", *International Journal of Production Economics*, Vol. 112 No. 2, pp. 903-918.

Proulx, F.R., Cavagnolo, B. and Torres-Montoya, M. (2014), "Impact of parking prices and transit fares on mode choice at the University of California, Berkeley", *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 2469 No. 1, pp. 41-48.

Rapanta, C., Botturi, L., Goodyear, P., Guàrdia, L. and Koole, M. (2020), "Online university teaching during and after the Covid-19 crisis: refocusing teacher presence and learning activity", *Postdigital Science and Education*, Vol. 2 No. 3, pp. 923-945.

Riggs, W. (2014), "Dealing with parking issues on an urban campus: the case of UC Berkeley", *Case Studies on Transport Policy*, Vol. 2 No. 3, pp. 168-176.

Riggs, W. (2016), "Cargo bikes as a growth area for bicycle vs. auto trips: exploring the potential for mode substitution behavior", *Transportation Research Part F: Traffic Psychology and Behaviour*, Vol. 43, pp. 48-55.

Riggs, W. (2017), "Painting the fence: social norms as economic incentives to non-automotive travel behavior", *Travel Behaviour and Society*, Vol. 7, pp. 26-33.

Riggs, W. and Kuo, J. (2014), "The impact of a 'soft sell' for parking mitigation on the UC Berkeley campus", Paper presented at the Transportation Research Board 93rd Annual Meeting.

Ross, S.A. (1973), "The economic theory of agency: the principal's problem", *The American Economic Review*, Vol. 63 No. 2, pp. 134-139.

Shoup, D. (2005), "Parking on a smart campus: lessons for universities and cities", in Mitchel, D. (Ed.), *CA Policy Options*, UCLA School of Public Affairs, Los Angeles.

Shoup, D. (2008), "The politics and economics of parking on campus", in Ison, S. and Rye, T. (Eds), *The Implementation and Effectiveness of Transport Demand Measures: An International Perspective*, Ashgate Publishing, Aldershot.

Shoup, D. (2011), *The High Cost of Free Parking*, APA Planners Press, Chicago, IL.

Shoup, D. (2017), *The High Cost of Free Parking*, Routledge.

Socha, K., Sampels, M. and Manfrin, M. (2003), "Ant algorithms for the university course timetabling problem with regard to the state-of-the-art", *Workshops on Applications of Evolutionary Computation*, Springer, Berlin, Heidelberg, pp. 334-345.

Spence, M. (1973), "Job market signaling", *The Quarterly Journal of Economics*, Vol. 87 No. 3, pp. 355-374.

Stasko, T.H., Buck, A.B. and Gao, H.O. (2013), "Carsharing in a university setting: impacts on vehicle ownership, parking demand, and mobility in Ithaca", *Transport Policy*, Vol. 30, pp. 262-268.

Stigler, G.J. (1961), "The economics of information", *Journal of Political Economy*, Vol. 69 No. 3, pp. 213-225.

UofL (2021), "Just the facts 2018-2019", available at: http://louisville.edu/oapa/institutional-research-and-planning/docs/JusttheFacts2019WEBada.pdf

Yan, X., Levine, J. and Marans, R. (2019), "The effectiveness of parking policies to reduce parking demand pressure and car use", *Transport Policy*, Vol. 73, pp. 41-50.

Yang, F.Y. and Tsai, C.C. (2008), "Investigating university student preferences and beliefs about learning in the web-based context", *Computers and Education*, Vol. 50 No. 4, pp. 1284-1303.

Zhang, S., Li, Y., Frimpong Boamah, E. and Mog, J. (2020), "Gender disparity in travel demand management of university students and employees", *Journal of Planning Education and Research*.

## Further reading

Chan, N.D. and Shanheen, S.A. (2012), "Ridesharing in North America: past, present, and future", *Transport Reviews*, Vol. 32 No. 1, pp. 93-112.

Cooper, C. (2007), "Successfully changing individual travel behavior: applying community-based social marketing to travel choice", *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 2021 No. 1, pp. 89-99.

Nonis, S.A., Philhours, M.J. and Hudson, G.I. (2006), "Where does the time go? A diary approach to business and marketing students' time use", *Journal of Marketing Education*, Vol. 28 No. 2, pp. 121-134.

## About the authors

Sumei Zhang (PhD) is an Associate Professor in the Department of Urban and Public Affairs at University of Louisville. Her research interests include urban methods, regional economics, GIS and urban sustainability. Sumei Zhang is the corresponding author and can be contacted at: sumei.zhang@louisville.edu

Emmanuel Frimpong Boamah (PhD) holds a joint faculty appointment with the Department of Urban and Regional Planning and the Community for Global Health Equity (CGHE) at the University at Buffalo. His research focuses on how the built and institutional environments impact communities, both in sub-Saharan Africa and the USA. He uses mixed methods in his work, including social network analysis and modeling.