The Application of Queueing Theory in the Parking Lot: a Literature Review

MAI Nguyen Thi1 and CUONG Duong Manh2*

1,2School of Economics and Management, Hanoi University of Science and Technology, Hanoi, Vietnam

*Corresponding author: cuong.duongmanh@hust.edu.vn

Abstract
Waiting lines or queues are common in life, we often encounter a lot of queueing systems to wait for service regarding both crowd-based and random. Indeed, queueing system is ubiquitous from customers queueing to pay at the supermarket, customers coming to make transactions at banks or customers waiting for medical examination at the hospital, etc. Queueing theory is the mathematical study of waiting for lines or queues and is one of the most commonly used mathematical tools for the performance evaluation of systems. Applications of queueing theory are increasing in various fields of life for example the banking sector, healthcare, traffic control, and computer science. This paper reviews the contributions and applications of queueing theory in parking lots. Applications of queueing theory in modeling parking lots processes are reviewed and categorized.

Research purpose:
This paper reviews the contributions and applications of queueing theory in parking lots. Applications of queueing theory in modeling parking lots processes are reviewed and categorized. Our purpose was to identify the leading areas of parking problems as modeled by queueing theory.

Research motivation:
In order to understand the importance, the application of queueing theory in parking lot, this paper aims to investigate research papers to gain insights into queueing theory and queueing models in parking lots.

Research design, approach and method:
This paper is designed as follows. Section 1 of this paper presents the research background. The search approach and papers selection are described in Section 2. In Section 3, we provide the different classifications in using queueing theory in parking lot management. Section 4 includes the list of literature on simulation-based queueing models in the parking lot. In Section 3, a descriptive analysis of the review is presented. Finally, Section 6 presents the summary and conclusions. We presented a review of 65 papers searched in the database of Google scholar. We collected high-quality papers that were peer-reviewed and published between 1972 and 2021 using structured keywords search and cross-referencing.

Main findings:
In this paper, applications of queueing theory in modeling parking processes have been reviewed and categorized. This paper reviewed the use of queueing theory for the analysis and design of different types of parking systems. Also, we have reviewed the simulation-based queueing models that have been presented. From this review, we found that most queueing theory application articles in parking management were published after 2000. A possible reason for the upward trend since 2000 is the advancement in computational power and software availability.

Practical/managerial implications:
Since parking is an essential component of today’s transportation system, improving the system performance is a very important goal. Queueing theory provides an effective and powerful modeling technique that can assist managers in achieving the aforementioned goal.

Keywords: queueing theory, waiting line, parking lots, queueing model
1. RESEARCH BACKGROUND

1.1. Queueing theory overview

1.2.1 History

The history of queueing theory goes back more than one hundred years. The first person to put forth research on queueing theory was Agner Krarup (A. K) Erlang (1/1/1878 – 3/2/1929) - a Danish mathematician, statistician, and engineer who in 1909 published “The Theory of Probabilities and Telephone Conversations”, (Erlang, 1909), introduced the world to the concept of telephone queueing theory. In 1917, he published his most important work (Sztrik, 2010), “Solution of some Problems in the Theory of Probabilities of Significance in Automatic Telephone Exchanges”, (Erlang, 1917) which contained his classical formulas for call loss and waiting time. Another important contributor to Queueing Theory was David George (D. G) Kendall (15/1/1918 – 23/10/2007) – a British statistician and mathematician, who in 1951 published an article “Some Problems in the Theory of Queues”, (Kendall, 1951). In this paper, he refers to a “simple queueing system”. Despite there were a huge number of articles on the subject much earlier. However, the research of D. G. Kendall has given a systematic and mathematical approach to the problem of the queue (waiting line). In 1953, D. G. Kendall introduced the A/B/C type queueing notation. Queueing theory has been further developed to this day and various aspects of the queueing theory were discussed by many authors, so much so that it has generated numerous review papers over the years, for example, Saaty (1966), Bhat (1969), Koenigsberg (1982), Bitran & Dasu (1992), Medhi (1997), Worthington (2009), Mandelbaum & Hlynka (2009), Wang et al. (2010), C. Lakshmi & Appa Iyer (2013).

1.2.2 Definition

The queueing theory is concerned with the mathematical modeling and analysis of systems that serve random demands. Queueing theory is mostly regarded as a branch of applied probability theory, the mathematical study of queues or waiting lines; uses mainly the mathematical models to analyze the relationship between arrival interval, service intensity, queueing time, queue length, and other parameters under specific service regulations in the system (Willig, 1999, Sundarapandian, 2009). Queueing theory is one of the oldest and most commonly used quantitative analysis techniques (Chowdhury, 2013) and an important study in modern society (Aronu et al., 2021).

Waiting lines or queues are a common phenomenon in life, in many fields, for example, in a supermarket, in a hospital, at a petrol station, at computer systems, etc. Waiting is one of life’s most unpleasant experiences (Sztrik, 2012), and queueing theory addresses it. A waiting line (or queue) is a line or list of customers still waiting to receive certain goods or services from a service center. A queue is formed when a system is overloaded, the number of requests received exceeds the number of requests that the system can handle per unit of time (Aronu et al., 2021). Waiting lines (or queues) help establishments or businesses provide services in an orderly manner (Bhat, 2015). Waiting time and queue length are issues problems related to queueing mechanism (Stasiak, 2016). Queueing model is built to be able to predict queue length and waiting time (Sundarapandian, 2009).

1.2.3 Basic queueing model

Figure 1 illustrates the fundamental queueing model. It can be used to model, e.g., machines or operators processing orders or communication equipment processing information (Adan & Resing, n.d., p. 23):

i. The input process is also known as the arrival process. The input process is the process of objects that go to the system and ask to satisfy a certain requirement. The input process can be characterized by the distribution of the

Figure 1: Basic queueing model

The basic queueing model includes three main components: (i) the input process; (ii) the service mechanism; (iii) the queue discipline (Cooper, 1990, Bhat, 2015):

Input process

Queues

Services

Output
interarrival times of the customers. The input process of requests to the system is a stream of random events and follows certain probability distributions such as fixed-length distribution (D), Poisson distribution, Erlang distribution, and other major distributions according to the statistical laws that it obeys under the stable state.

ii. The service mechanism determination of service rules and statistical rules of service time. The service times are usually assumed to be independent of the arrival process and each other, and service times of servers to be identically distributed, which can be divided into fixed-length distribution (D), exponential distribution (M), general shifted distribution (G), Erlang distribution (Ek).

iii. The queue discipline describes the behavior of customers arrive and find all servers busy. They can leave immediately or wait in a queue. When customers are queuing, they are called to serve depending on the nature of the customer. There are different ways in which customers are called to serve: First in First Out/First Come First Served – FIFO/FCFS; Last in First Out/Last Come First Served – LIFO/LCFS; Service in Random Order – SIRO; Priority service – PNPN; Processor Sharing – PS and so on.

The full queueing system consisting of six components as A / B / m / K / n / D, where (Szrik, 2012):

- A: probability distribution function for the arrival process
- B: probability distribution function for the service process
- m: number of channels/number of servers
- K: capacity of the system, the maximum number of customers allowed in the queueing system including either being served or waiting for service
- n: population size, number of sources of customers
- D: service discipline

1.2 Application of queueing theory in parking lot

1.2.1 Parking lot status

Parking areas are an essential component of today’s transportation system. With rapid economic growth, the vehicle in urban areas has increased dramatically around the world, creating a greater demand for parking infrastructure, particularly in megacities (Cherian et al., 2016). The scarcity of parking or jams at the parking lots contributes to traffic congestion, pollution, and dissatisfaction among drivers, degrade the quality of life in a variety of ways (Wu et al., 2014). Therefore, they are a big source of concern for government officials, business people, shoppers, workers, and everybody who drives (Weant, 1978). With the significant expansion in the number of private vehicles, it has become increasingly vital to provide users with appropriate parking spaces, which would prevent vehicles from becoming a hazard on the streets and disrupting people’s transportation and daily lives (Yuan et al., 2018).

To optimize the traffic organization of the parking lot plays a positive role in alleviating traffic congestion and parking difficulties. Lots of scholars have researched the optimization design of parking facilities and traffic organization. Many models have been developed to evaluate the performance of parking lots, analyze parking systems, and design parking systems for different purposes. In 2003, Sattayhatewa & Smith (2003) developed parking choice models for special events by using the logit function and based on three major factors—driving time, parking cost, and walking time. Benenson et al. (2008) presented a model of parking – PARKAGENT, to study residential parking in the evening hours. In 2013, Wilson proposed a 12-step toolkit for reforming parking requirements, and this toolkit a very useful to parking requirements for multifamily housing, workplaces, and mixed-use developments (Wilson, 2013). Ji et al built up a short-term APS forecasting model based on the wavelet neural network (WNN) to forecast available parking spaces (Ji et al., 2015). Cai et al. suggested a parking space allocation method (PSAM) at the network level to allocate the parking demand to a specific parking lot and then the parking space (Cai et al., 2018). Shao et al., (2019) studied parking availability prediction with the Long Short Term Memory model (LSTM) in their paper. However, the queueing theory was not used in the above-quoted works.

1.2.2 The usefulness of queueing theory in the parking lot

The queueing theory is a tremendously useful tool because queueing models require relatively little data and are simple and fast to use. The modelers can be used to swiftly analyze and compare numerous options for providing service due to this simplicity and speed. Queuing models can be useful in gaining insights into the appropriate degree of specialization or flexibility to use in organizing resources, as well as the impact of various priority schemes for determining service order among patients, beyond the most basic issue of determining how much capacity is needed to achieve a specified service standard. With the rising power of information technology, numerical approaches and simulation models...
can be utilized alongside classical queueing theory to gain a better understanding of real-world queueing systems (Shortle et al., 2018).

The parking systems can be analyzed as mass service systems (Krpan et al., 2017) due to which have key features are occupancy, turnover, duration of stay per user, acceptability of parking charges, as well as potential identification of the modal split across alternative means of transportation (Basarić et al., 2013). At the same time, the arrivals of vehicles and length of parking time can be seen as random (stochastic). Corresponding theoretical distributions can be applied for studying the arrivals of vehicles and the parking duration. For that reason, it is possible to apply the analytical approach, i.e. using formulas set out by the queuing theory to calculate the parking functioning ratio (Basarić et al., 2013, Maršanić et al., 2011), to analyze the problems of waiting lines at a parking system entrance, with the cars that arrive at random and ask for parking tickets (Maršanić et al., 2010). The use of queueing theory is an attempt to save costs by reducing inefficiencies and delays. There are many problems in parking systems that can be solved using queueing theory in operational research. The parking area is a complex system, which represents a queueing system with the following structure: vehicles form a waiting line or not (depending on the current situation) to be served (parked) in a parking section and after the service has been completed (certain length of parking time), they exit the system.

The application of queueing theory to parking problems has not yet been thoroughly explored and presented to the public in the international scientific and professional literature. In the existing literature, the application of queueing theory focuses to reduce the construction cost, evaluate and improve the garage performance, optimize the use of parking space, estimate the appropriate parking price, availability of the parking, and parking demand.

1.3 Summary

Understanding the importance the application of queueing theory in parking lot, this paper aims to investigate research papers to gain insights into queueing theory and queueing models in general in parking lots. The rest of this paper is laid out as follows. The search approach and papers selection are described in Section 2. In Section 3, we provide the different classifications in using queueing theory in parking lot management. Section 4 includes the list of literature on simulation-based queueing models in the parking lot. In Section 5, a descriptive analysis of the review is presented. Finally, Section 6 presents the summary and conclusions.

2. RESEARCH METHODOLOGIES

Different research papers on the topic published between 1972 and 2021 have been reviewed. In the initial stage, all articles (except for literature review papers) were reviewed relating to the application of queueing theory in parking lots searched in the database of Google Scholar. The keywords applied to search for the articles were Queueing Theory (or Queuing Theory), Queue Model or Queueing Model, Queue (or Queueing, Waiting line), Parking Lots or Parking or Parking Spaces. During the second stage, the articles on queueing models and their applications in parking lot management were studied. Most collected articles were related to the stated criteria. After the collection of the initial set of papers, there have been works of classification, titles, abstracts, and conclusions screening to choose the appropriate papers to review. The reviewed articles are (directly or indirectly) related to queueing theory and its applications research in parking lots. We selected and reviewed 65 papers reported during 1972 – 2021.

3. RESEARCH VARIETIES AND CLASSIFICATION

In the existing literature, various queueing models have been studied for parking systems, among which the M/M/s queue is the most widely used model. In this section, the classification methods are classified into two parking groups: parking systems design and parking system analysis. These works are studied and implemented in the parking problem.

3.1 Parking systems design

3.1.1 Automated parking system

Li & Miao (2020) proposed a parking system - automated stereo-garage to reduce the construction cost and improve the garage performance. To achieve the goal, they designed two scheduling strategies: garage efficiency-oriented strategy and customer waiting time-oriented strategy. The queueing theory used to analyzed service performance after the operation processes of the garage during busy periods is simulated. Senapati & Khilar (2020) proposed an automated parking service with the help of vehicles and the Road Side Unit (RSU). The M/M/1 queueing model was used to compute total service time (TST) for the overall parking service. Total service time is the total searching time, parking fee collection time, and vehicle entry time into a predefined parking spot. Pypno & Sierpi (2013) presented the issues of parking in the cities and proposed the idea of a multi-story, overground garage - Modeling of The Operation of The Multi-Story Automated Garage with A
Big Capacity. The queueing theory has been used in the modeling process of the operation of the vehicle, description of the process of entering and exiting. From there, the efficiency of the parking operation in a multi-story garage was assessed. Min & Shidong (2015) constructed a mathematical model on queueing theory for a lift-sliding solid garage, and some important performance parameters are analyzed based on the queuing model. They analyzed the performance of the garage by a $M / M / n / \infty / FCFS$ queuing model. The purpose was the planning and designing a reasonable and efficient garage. The authors also conducted studies and made a comparison the system's operation strategies in order to achieve an optimized operating strategy. The entire analysis and conclusions are important for solid garage design as well as improving the garage's service performance.

3.1.2 Smart parking

Lu et al. (2009, 2010) proposed a new VANET-based intelligent parking scheme for large parking lots. They analyzed performance through extensive simulations which demonstrate the efficiency and practicality of the proposed scheme. They used the $M/G/c/c$ queuing model to estimate the blocking probability $B$. The blocking probability $B$ is a stable statistic, which denotes the probability that a vehicle could be blocked, i.e., the parking lot is full when the vehicle arrives. As so as, the parking lot’s capacity and blocking probability can be disseminated to the vehicles that run on the road. Geng & Cassandras (2011, 2012, 2013) proposed a dynamic resource allocation model based on queuing theory and user objective function of destination distance and parking cost, but various uncertainties in the real environment may impair system performance. Belkhala et al. (2019) studied and set up a smart parking system. Queue modeling helped them to test the performance of the system and its ability to manage requests. Du & Gong (2016) proposed a decentralized and coordinated online parking mechanism. Mitigated the competition among vehicles helps alleviate parking congestion at numerous parking facilities. They modeled the service of the parking facility as an $M/M/c$ queuing model. Nugraha & Tanamas (2017) designed a new reservation parking system and built a simulator to test that system performance and compare it to conventional parking systems and conventional reservation parking systems based on queueing theory. Sutjarittham et al. (2019) outlined experiences in designing and deploying a monitoring system for a real car park at their university campus. They developed a car park model to determine the potential of new offerings. Given the rate of arrival and departure, they model the car park as an $M/M/1/C$ queue and simulator in R to quantify the probability of rejection considering a futuristic scenario. The primary aim would be to optimize the use of parking space for generating revenue from shared cars with minimal impact on private car users.

3.1.3 Normal/another parking system

Maršanić et al. (2010) applied queueing theory to defined the optimal number of servers (ramps) and the required capacity (number of parking spaces) in closed parking areas. Yan et al. (2015) used an $M/M/c/c$ queuing model to estimate the availability of the parking spots in the parking lot, model this factor based on the arrival and service rate of the cars and the capacity of the parking lot. Larson & Sasanuma (2007) developed an $M/M/1$ queueing model of the parking problem after reviewed various road pricing (RP) and parking pricing (PP) schemes for implementing congestion pricing (CP). Hauer & Templeton (1972) presented queueing model in parking system analysis for applied to a parking lot design problem. Guo (2020) optimized of traffic organization of a parking lot; proposed improvement measures from three aspects of parking lot entrance and exit, internal traffic organization, and external traffic organization. The parking lot's entrance and exit were regarded as a queueing model. To measure the entrance and exit queueing model, the authors used the queueing model parameters. Caliskan et al. (2007) built a parking model based on queueing theory and used a continuous-time homogeneous Markov model to estimate the future occupancy of parking lots to enable each vehicle to choose an appropriate parking lot. Zhu et al. (2018) presented a method to optimize the speed of vehicle access for three-dimensional garage used queueing model $M/M/s$.

3.2 Parking system analysis

Queueing models are used to gain information about activities within a parking system. We classified these into three subareas: availability of parking and parking demand, parking performance, appropriate parking price estimation.

3.2.1 The availability of parking and parking demand

Abdeen et al. (2021) used an $M/M/c/c$ queuing model to estimate the availability of the parking spots in the parking lot. They model this factor based on the arrival and service rate of the cars and the capacity of the parking lot. Kawakami et al. (1994) proposed a method for forecasting parking demand at individual parking lots by traffic assignment model used $M/M/s(\infty)$ to estimate...
the parking waiting time. The proposed model can be used to forecast parking demand for each parking lot, as well as to assess the effect of parking policies. Jung & Lee (2014) conducted parking demand-supply status of attached car parks analysis of 13 big discount stores’ in Busan based on queuing theory and simulation using Arena 10.0. Chiara & Cheah (2017) described the parking facility at a mall as a queuing system. Millard-Ball et al. (2014) derived an empirical relationship between average occupancy and the probability that a driver finds a block full, as well as between average occupancy and the number of blocks cruised, using queuing theory as a foundation. Sukmana & Lesmono (1999) built the M/M/29/29 model that describes the stochastic nature of the parking situation to determine the probability that all parking bays are occupied. Pel & Chaniotakis (2017) proposed a G/G/c queuing model for computing endogenous parking probability, as well as admissible maximum search times. They used simulation to approximate the parking probability for any particular parking site. Klappenecker et al. (2014) proposed a method to predict the availability of parking resources based on the M/M/n/n queueing model. Xiao et al. (2018) suggested a model-based practical framework for predicting future occupancy based on historical occupancy data. They used to M/M/C C queueing model to describe the stochastic occupancy change of a parking facility. Atif et al. (2020) used M/M/C model to the estimated arrival times are used to predict the current parking lot states to infer the future parking state, considering the expected arrival time to each parking lot. B. Li et al. (2017) proposed a smart parking guidance algorithm by considering various preferences of drivers and three representative decision factors: walk duration, parking fee, and the number of vacant parking spaces. They used to queue model to quantity the availability degree of vacant parking spaces in a parking facility. Debnath & Serpen (2015) presented a study for the development of a real-time scheduling algorithm for a multi-story and fully automated parking structure with a group of elevators. They used to queueing model of the queuing theory to calculate elevator count and parking spaces on each floor under an assumed customer arrival rate and mean service rate. Ma et al. (2017) introduced a smart on-street parking system to predict parking occupancy and provide a routing strategy using cloud-based analytics. They developed a prediction algorithm based on transient queuing theory and Laplace transform to predict parking occupancy thus predicting open parking locations. The queuing model was applied to predict the probability of finding a parking space as well as the future occupancy level based on historical arriving rate data and parking rate for each bay. Mohd Bukari et al. (2019) identified the availability of parking spaces to produce a quantitative assessment of parking and to analyze the sufficiency of parking spaces in Muar town’s chosen area. They used Erlang’s loss model to calculate the likelihood that a client may abandon the system or facility due to insufficient parking lots.

3.2.2 The parking performance

Kokolaki et al. (2012) used queueing models for the analytical investigation of the parking system’s performance to assess the effectiveness of the parking search process such as the parking search time and route length, and the proximity of the found/assigned parking spot. Bajpai & Maneesha (2015) assessed the situation and made recommendations to reduce the queue in the parking areas lots of one of Dubai’s major shopping malls using Little’s Theorem, the M/M/s queuing model along with simulation software to prepares for expo 2020. According to the simulation results, increasing the number of servers (entry points) to at least three times present capacity reduces the wait time to under a minute during peak hours. The parking lot will be even less congested as a result of this. Maršanić et al. (2011) presented the application of the queuing theory in the optimal dimensioning of parking areas. They have calculated the number of parking spaces and therefore defined the required parking area capacity. The objective of the paper was to demonstrate that by applying the queuing theory the optimal number of servers (ramps) and the required capacity (number of parking spaces) in closed parking areas can be defined. Abhishek et al. (2021) proposed a queueing model for an urban parking system consisting of delivery bays and general on-street parking spaces. They obtained the performance measures from the analysis of the queues. Cechka & Šedivý (2021) analyzed car park occupancy based on queuing theory to investment decision-making. Abdas et al. (2019) focused on analyzing the implementation of Active RFID as an effort to reduce queues and waiting times. Fuentes et al. (2017) used the queue model in analysis evaluates the measures of performance for parking spaces of parking by visitors in a national park. The managers, then, can facilitate utilization estimates based on visitor changes and different seasons, and make decisions relating to the expansion of parking facilities or management of parking. Tamber (2015) optimized the queuing system of a fast-food restaurant. The author analyzed this restaurant under a queuing model to assess the behavior of the system for improving its performance. Parking was also part of the queuing system at this restaurant. Abdel-Aal (2020) researched to calibrate a mathematical
The authors proceeded with calibration average service time (one of the queue model's important parameters) for the M/D/1 queueing model. The result showed that when the application of the calibrated M/D/1 model, its performance measures are significantly better than those of the original model that wasn't calibrated. Setiawani et al. (2020) determined the queuing model, measures the performance of the queue model, and determine whether or not this model's application was effective in a motorcycle parking area.

### 3.2.3 Estimate the appropriate parking price

Given that the arrival rate and staying time are dependent on the parking fee, Keren & Haddad (2021) used the M/G/N/N queueing model to estimate the appropriate parking price. Babic et al. (2015) calculated of parking duration at the parking. They used an M/M/c/0 queue with time-varying parameters to model arrival and stay in the parking lot, allowing different timeslots (hours) to have different arrival and service rates. Gong et al. (2013) used a queuing model to predict the PEV flow pattern into the parking lot for the PEV charging control development; estimate the waiting time under a different number of chargers. The charging requirement for the parking lot, then, could be predicted and estimated; providing a way for the transformer capacity design; the charging station design, or as guiding information for the customers.

### 4. SIMULATION-BASED QUEUEING MODELS IN PARKING SPACES

Simulation is an efficient method to solve complicated problems; providing a replica of the exact model with the behavior of the system and helps in delivering some important decisions for the system. Simulation modeling has long been part of queue modeling. Many applications and some research mentioned earlier in this paper have been used in simulation models.

Amari et al. (2019) simulated the proposed parking system using the queuing theory which aims to improve the quality of service of a smart parking. Dowling et al. (2018) simulated curbside parking as a network of finite capacity queues. X. Li et al. (2015) investigated the “non-shaped” tower parking garage's vehicle scheduling strategy. They simulated various access processes based on queuing theory, then thoroughly analyzed the experimental findings of the MATLAB simulation, demonstrating that efficiently enhances the efficiency of the parking garage system. Portilla et al. (2009) applied an M/M/∞ queueing model to simulate the effect of parking on average link journey times due to the presence of parking maneuvers. Xie & Hlynka (2019) built a mathematical model to simulate the parking directions in the parking lot and discuss the relation between parking direction and arrival time and service time. Pandey & Hanchate (2018) proposed an intelligent parking management system using queuing theory and IoT. Simulation in Python to analyze system performance and improve user experience. S. Li et al. (2012) studied the queue system in the vertical circulation-type stereo garage through a queue theory to obtain the management strategy of scheduling optimization for parking and driving. The simulation experiment revealed that applying the optimization method described in this work has various advantages, such as an average short time for parking and taking a car one time, and high efficiency for average service rate. Lu et al. (2009, 2010) proposed a new VANET based mart parking scheme (SPARK) for large parking lots. Its efficiency and practicality are demonstrated by simulation. Guo et al. (2018) made a simulation in advance to evaluate the construction project of a seven-level automated parking lot for a hospital. They proposed and simulated three optimization solutions to mitigate the issue of hospital traffic congestion based on an analysis of hospital traffic characteristics and the estimation of the possible maximum of cars reaching the hospital. The average queue length to estimate the traffic congestion situation was calculated based on queueing model M/M/C.

### 5. DESCRIPTIVE ANALYSIS

In this paper, the simple meta-analysis used only provides descriptive information and does not include any statistics; it is intended to provide a better understanding of the development and evolution of queuing theory research in parking management, as well as to identify potential research areas for future research and improvement. We identified and analyzed the 65 articles related to the application of queuing theory research in parking management by (1) year of publication and (2) using our classification groups.

#### 5.1. Distribution of articles by year of publication

Figure 2 shows that there is limited research output before 2000 and an increasing research trend on queuing
theory application in parking spaces from 2000 onward. Another possible reason for the upward trend since 2000 is the advancement in computational power and software availability.

\[ \text{Figure 2: Distribution of reviewed papers by published year} \]

5.2 Classification groups

5.2.1 Parking system design and system analysis

The following is a classification table of the papers on the application of queueing model in the parking lot (Table 1), which is divided into two groups: parking system design and parking system analysis.

Table 1: Classification scheme: parking system design and system analysis

| Classification methods | References |
|------------------------|------------|
| Automated parking system | Z. Li & Miao (2020), Senapati & Khilar (2020), Pyppö & Sierpi (2013), Min & Shidong (2015) |
| Smart parking system | Lu et al. (2009), Lu et al. (2010), Geng & Cassandras (2011a), Geng & Cassandras (2011b), Geng & Cassandras (2012), Geng & Cassandras (2013), Belkhal et al. (2019), Du & Gong (2016), Nugraha & Tanamas (2017), Sutjarittham et al. (2019) |
| Normal/another parking system | Maršanić et al. (2010), Yan et al. (2015), Larson & Sasanuma (2007), Hauer & Templeton (1972), Guo (2020), Caliskan et al. (2007), Zhu et al. (2018) |
| The availability of parking and parking demand | Abdeen et al. (2021), Kawakami et al. (1994), Jung & Lee (2014), Chiara & Cheah (2017), Millard-Ball et al. (2014), Sukmana & Lesmono (1999), Pet & Chaniotakis (2017), Klappenecker et al. (2014), Xiao et al. (2018), Atif et al. (2020), B. Li et al. (2017), Debath & Serpen (2015), Ma et al. (2017), Mohd Bukari et al. (2019) |
| The performance of the parking | Kokolaki et al. (2012), Bajpai & Maneesha (2015), Maršanić et al. (2011), Abhishek et al. (2021), Cějka & Šedivý (2021), Ahda et al. (2019), Fuentes et al. (2017), Tamber (2015), Abdel-Aal (2020), Setiawani et al. (2020) |
| Estimate the appropriate parking price | Keren & Hadad (2021), Babic et al. (2015), Gong et al. (2013) |

5.2.2 Queueing models in parking

Table 2 is a table that categorizes articles into different queueing models based on whether they use simulation or not. The queueing models are categorized to MM, MG, MD, GM, GG models, and a handful of other models.

Table 2: Classification scheme: queueing models in parking

| Techniques/Method/Model | Simulations | References |
|------------------------|------------|------------|
| MM | Abdeen et al. (2021), Marchi et al. (2018), Amari et al. (2019), Bajpai & Maneesha (2015), Geng & Cassandras (2011a), Geng & Cassandras (2011b), Geng & Cassandras (2012), Geng & Cassandras (2013), Dowling et al. (2018), Belkhal et al. (2019), Ratiliff et al. (2016), Portilla et al. (2009), Babic et al. (2015), Xie & Hlynka (2019), Atif et al. (2020), Cho et al. (2017), B. Li et al. (2017), Sutjarittham et al. (2019), pandey & Hanchate Author (2018), Mao et al. (2019), Gong et al. (2013), Caliskan et al. (2007), Hong et al. (2013), Debath & Serpen (2015), S. Li et al. (2012), Ma et al. (2017), Guo et al. (2018), Chukwu & Mahajan (2014), Jung & Lee (2014), Millard-Ball et al. (2014), Abhishek et al. (2012), Senapati & Khilar (2020), Kawakami et al. (1994), Larson & Sasanuma (2007), Chiara & Cheah (2017), Sukmana & Lesmono (1999), Du & Gong (2016), Cějka & Šedivý (2021), Fuentes et al. (2017), Guo (2020), Klappenecker et al. (2014), Xiao et al. (2018), Tamber (2015), Zhu et al. (2018), Shahzad et al. (2015), Min & Shidong (2015), Setiawani et al. (2020), Abdel-Aal (2020), Chiara & Cheah (2017) |
MG & Putrada (2020) Keren & Hadad (2021), Pypno & Sierpi (2013)

MD Dowling et al. (2018), X. Li et al. (2015), Abdel-Aal (2020) Maršanić et al. (2010)

GM Zhao et al. (2020) Others Ahda et al. (2019), Nugraha & Tanamas (2017) Mohd Bukari et al. (2019), Hauer & Templeton (1972)

Where, MM – The arrival process is Poisson distribution (M), service process is exponential distribution (M), MG – The arrival process is Poisson distribution (M), service process is generally shifted distribution (G), MD – The arrival process is Poisson distribution (M), service process is fixed-length distribution (D), GM – The arrival process is generally shifted distribution (G), service process is exponential distribution (M), GG – The arrival process is generally shifted distribution (G), service process is c shifted distribution (G).

6. CONCLUSION

In this paper, applications of queueing theory in modeling parking processes have been reviewed and categorized. Since parking is an essential component of today’s transportation system, improving system performance is a very important goal. Queueing theory provides an effective and powerful modeling technique that can assist managers in achieving the aforementioned goal.

We presented a review of 65 papers searched in the database of Google scholar. We collected high-quality papers that were peer-reviewed and published between 1972 and 2021 using structured keywords search and cross-referencing. Our objective was to identify the leading areas of parking problems as modeled by queueing theory. This paper reviewed the use of queueing theory for the analysis and design of different types of parking systems. Also, we have reviewed the simulation-based queueing models that have been presented. From this review, we found that most queueing theory application articles in parking management were published after 2000. Another possible reason for the upward trend since 2000 is the advancement in computational power and software availability.

REFERENCES

[1] Abdeen, M. A. R., Nemer, I. A., & Sheltami, T. R. (2021). A Balanced Algorithm for In-City Parking Allocation: A Case Study of Al Madinah City. Sensors, 21(9), 3148. https://doi.org/10.3390/s21093148

[2] Abdel-Aal, M. M. M. (2020). Survey-based calibration of a parking entry as a single-server mathematical queuing model: A case study. Alexandria Engineering Journal, 59(2), 829–838. https://doi.org/10.1016/j.aej.2020.02.016

[3] Abhishek, N., Legros, B., & Fransoo, J. C. (2021). Performance evaluation of stochastic systems with dedicated delivery bays and general on-street parking. Transportation Science, 1–41.

[4] Adan, I., & Resing, J. (n.d.). Queueing Systems. 182.

[5] Ahda, F., Abdurohman, M., & Putrada, A. G. (2019). Evaluation of Active RFID as Vehicle Identification at Parking Gates Using Queuing Theory. 2019 Fourth International Conference on Informatics and Computing (ICIC), 1–6. https://doi.org/10.1109/ICIC47613.2019.8985936

[6] Amari, A., Moussaid, L., & Tallal, S. (2019). A Smart Parking for Invisible Disabilities. In Y. Farhaou & L. Moussaid (Eds.), Big Data and Smart Digital Environment (pp. 1–6). Springer International Publishing. https://doi.org/10.1007/978-3-030-12048-1_1

[7] Aronu, C., Okoh, J., Onyeka, E., & Ikemefuna, S.-A. (2021). The Assessment of Bank Service Performance in Delta State, Nigeria: A Queuing Theory Approach. 10–25.

[8] Atif, Y., Kharrazi, S., Jianguo, D., & Andler, S. F. (2020). Internet of Things data analytics for parking availability prediction and guidance. Transactions on Emerging Telecommunications Technologies, 31(5), e3862. https://doi.org/10.1002/ett.3862

[9] Babic, J., Carvalho, A., Ketter, W., & Podobnik, V. (2015). Economic Benefits of Smart Parking Lots. 1–9.

[10] Bajpai, P., & Maneesha. (2015). Analysis of Parking Lots While Dubai Prepares for Expo 2020. In Z. Zhang, Z. M. Shen, J. Zhang, & R. Zhang (Eds.), LSS 2014 (pp. 969–974). Springer. https://doi.org/10.1007/978-3-662-43871-8_139
[11] Basarić, V., Mitrović, J., & Papić, Z. (2013). Passenger Car Usage for Commuting to Work As A Function of Limited Stay at Car Parks. Promet - Traffic & Transportation, 25(4), 323–330. https://doi.org/10.7307/ptt.v25i4.322

[12] Belkhala, S., Benhadou, S., & Medromi, H. (2019). Real-Time Intelligent Parking Entrance Management. International Journal of Advanced Computer Science and Applications, 10(8), 402–405. https://doi.org/10.14569/IJACSA.2019.0100854

[13] Benenson, I., Martens, K., & Birfir, S. (2008). PARKAGENT: An agent-based model of parking in the city. Computers, Environment and Urban Systems, 32(6), 431–439. https://doi.org/10.1016/j.compenvurbsys.2008.09.011

[14] Bhat, U. N. (1969). Sixty Years of Queueing Theory. Management Science, 15(6), B-280. https://doi.org/10.1287/mnsc.15.6.B280

[15] Bhat, U. N. (2015). Introduction. In An Introduction to Queueing Theory: Modeling and Analysis in Applications (pp. 1–14). Birkhäuser.

[16] Bitran, G. R., & Dasu, S. (1992). A review of open queueing network models of manufacturing systems. Queueing Systems, 12(1), 95–133. https://doi.org/10.1007/BF01158637

[17] C, L., & Appa Iyer, S. (2013). Application of queuing theory in health care: A literature review. Operations Research for Health Care, 2(1), 25–39. https://doi.org/10.1016/j.orhc.2013.03.002

[18] Cai, Y., Chen, J., Zhang, C., & Wang, B. (2018). A Parking Space Allocation Method to Make a Shared Parking Strategy for Appertaining Parking Lots of Public Buildings. Sustainability, 11(1), 1–20.

[19] Caliskan, M., Barthels, A., Scheuermann, B., & Mauve, M. (2007). Predicting Parking Lot Occupancy in Vehicular Ad Hoc Networks. 2007 IEEE 65th Vehicular Technology Conference - VTC2007-Spring, 277–281. https://doi.org/10.1109/VETECS.2007.69

[20] Cejka, J., & Šedivý, J. (2021). Discussion of Operational Transport Analysis Methods and the Practical Application of Queuing Theory to Stationary Traffic. Transportation Research Procedia, 53, 196–203. https://doi.org/10.1016/j.trpro.2021.02.026

[21] Cherian, J., Luo, J., Guo, H., Ho, S.-S., & Wisbrun, R. (2016). ParkGauge: Gauging the Occupancy of Parking Garages with Crowdsensed Parking Characteristics. 2016 17th IEEE International Conference on Mobile Data Management (MDM), 1, 92–101. https://doi.org/10.1109/MDM.2016.26

[22] Chiara, G. D., & Cheah, L. (2017). Data stories from urban loading bays. European Transport Research Review, 9(4), 1–16. https://doi.org/10.1007/s12544-017-0267-3

[23] Cho, Y., Seo, Y. G., & Jeong, D.-Y. (2017). LoRa Network based Parking Dispatching System: Queuing Theory and Q-learning Approach. Journal of Digital Contents Society, 18(7), 1443–1450. https://doi.org/10.9728/dcs.2017.18.7.1443

[24] Chowdhury, M. S. R. (2013). Queuing Theory Model Used to Solve the Waiting Line of a Bank—A Study on Islami Bank Bangladesh Limited, Chawkbazar Branch, Chittagong. Asian Journal of Social Sciences & Humanities, 2(3), 11.

[25] Chukwu, U. C., & Mahajan, S. M. (2014). V2G Parking Lot With PV Rooftop for Capacity Enhancement of a Distribution System. IEEE Transactions on Sustainable Energy, 5(1), 119–127. https://doi.org/10.1109/TSTE.2013.2274601

[26] Cooper, R. B. (1990). Chapter 10 Queueing theory. In Handbooks in Operations Research and Management Science (Vol. 2, pp. 469–518). Elsevier. https://doi.org/10.1016/S0927-0507(05)80174-4

[27] Debnath, J. K., & Serpen, G. (2015). Real-Time Optimal Scheduling of a Group of Elevators in a Multi-Story Robotic Fully-Automated Parking Structure. Procedia Computer Science, 61, 507–514. https://doi.org/10.1016/j.procs.2015.09.202

[28] Dowling, C., Fiez, T., Ratlif, L., & Zhang, B. (2018). How Much Urban Traffic is Searching for Parking? Simulating Curbside Parking as a Network of Finite Capacity Queues. ArXiv:1702.06156 [Cs], 1–11.

[29] Du, L., & Gong, S. (2016). Stochastic Poisson game for an online decentralized and coordinated parking mechanism. Transportation Research Part B: Methodological, 87, 44–63. https://doi.org/10.1016/j.trb.2016.02.006

[30] Erlang, A. K. (1909). The Theory of Probabilities and Telephone Conversations. Nyt Tidsskrift for Matematik B, 20.

[31] Erlang, A. K. (1917). Solution of some Problems in the Theory of Probabilities of
Significance in Automatic Telephone Exchanges. Post Office Electrical Engineering Journal, 10, 189–197.

[32] Fuentes, A., Heaslip, K., D’Antonio, A., Khalilikhah, M., & Soltani-Sobh, A. (2017). Evaluation of Vehicle Parking Queueing in a National Park: Case Study of the Laurnance S. Rockefeller Preserve in Grand Teton National Park. Transportation Research Record, 2654(1), 1–10. https://doi.org/10.3141/2654-01

[33] Geng, Y., & Cassandras, C. G. (2012). A new “Smart Parking” System Infrastructure and Implementation. Procedia - Social and Behavioral Sciences, 54, 1278–1287. https://doi.org/10.1016/j.sbspro.2012.09.842

[34] Geng, Y., & Cassandras, C. G. (2013). A New “Smart Parking” System Based on Resource Allocation and Reservations. IEEE Transactions on Intelligent Transportation Systems, 14(3), 1129–1139. https://doi.org/10.1109/TITS.2013.2252428

[35] Geng, Y., & Cassandras, C. G. (2011a). A new “smart parking” system based on optimal resource allocation and reservations. 2011 14th International IEEE Conference on Intelligent Transportation Systems (ITSC), 979–984. https://doi.org/10.1109/ITSC.2011.6082832

[36] Geng, Y., & Cassandras, C. G. (2011b). Dynamic resource allocation in urban settings: A “smart parking” approach. 2011 IEEE International Symposium on Computer-Aided Control System Design (CACSD), 1–6. https://doi.org/10.1109/CACSD.2011.6044566

[37] Gong, Q., Midlam-Mohler, S., Serra, E., Marano, V., & Rizzoni, G. (2013). PEV charging control for a parking lot based on queueing theory. 2013 American Control Conference, 1124–1129. https://doi.org/10.1109/ACC.2013.6579887

[38] Guo, Y. (2020). Evaluation on Optimization of Traffic Organization of Xiangfang Wanda Parking Lot. IOP Conference Series: Earth and Environmental Science, 587, 012078. https://doi.org/10.1088/1755-1315/587/1/012078

[39] Guo, Y., Zhang, Y., Zhao, Y., Jia, Q., Jing, Z., Ren, Y., Li, R., & Luo, X. (2018). Traffic Congestion Evaluation and Management Optimization Based on Queueing Model and VISSIM Simulation. 2018 IEEE 22nd International Conference on Computer Supported Cooperative Work in Design (ICSCWD), 672–676. https://doi.org/10.1109/CSCWD.2018.8465175

[40] Hauer, E., & Templeton, J. G. C. (1972). Queuing in Lanes. Transportation Science, 6(3), 247–259. https://doi.org/10.1287/trsc.6.3.247

[41] Hong, T. P., Soh, A. C., Jaafar, H., & Ishak, A. J. (2013). Real-Time Monitoring System for Parking Space Management Services. 2013 IEEE Conference on Systems, Process Control (ICSPC), 149–153. https://doi.org/10.1109/SPC.2013.6735122

[42] Ji, Y., Tang, D., Blythe, P., Guo, W., & Wang, W. (2015). Short-term forecasting of available parking space using wavelet neural network model. IET Intelligent Transport Systems, 9(2), 202–209. https://doi.org/10.1049/iet-its.2013.0184

[43] Jung, H., & Lee, H. (2014). A Study on the Re-examination of Parking Requirements for Discount Stores and the Utilization Plan of Parking Space. KSCE Journal of Civil and Environmental Engineering Research, 34(6), 1863–1871. https://doi.org/10.12652/Ksce.2014.34.6.1863

[44] Kawakami, S., Takayama, H., & Liu, Z. (1994). A Study on Parking Place Choice and Parking Demand Forecast by Traffic Assignment Models. IFAC Proceedings Volumes, 27(12), 943–948. https://doi.org/10.1016/S1474-6670(17)47595-1

[45] Kendall, D. G. (1951). Some Problems in the Theory of Queues. Journal of the Royal Statistical Society, 13, 151–185.

[46] Keren, B., & Hadad, Y. (2021). Using queuing models to set the right parking price. International Journal of Process Management and Benchmarking, 11(2), 271–289. https://doi.org/10.1504/IJPMB.2021.113739

[47] Klappenecker, A., Lee, H., & Welch, J. L. (2014). Finding available parking spaces made easy. Ad Hoc Networks, 12, 243–249. https://doi.org/10.1016/j.adhoc.2012.03.002

[48] Koenigsberg, E. (1982). Twenty Five Years of Cyclic Queues and Closed Queue Networks: A Review. Journal of the Operational Research Society, 33(7), 605–619. https://doi.org/10.1057/jors.1982.136

[49] Kokolaki, E., Karaliopoulos, M., & Stavrakakis, I. (2012). Opportunistically assisted parking service discovery: Now it helps, now it does not. Pervasive and Mobile Computing, 8(2), 210–227. https://doi.org/10.1016/j.pmcj.2011.06.003
[50] Krpan, L., Maršanić, R., & Milković, M. (2017). A model of the dimensioning of the number of service places at parking lot entrances by using the queuing theory. Tehnički Vjesnik, 24(1), 231–238. https://doi.org/10.17559/TV-20160128161848

[51] Larson, R. C., & Sasanuma, K. (2007). Congestion Pricing: A Parking Queue Model. 1–48.

[52] Li, B., Pei, Y., Wu, H., & Huang, D. (2017). MADM-based smart parking guidance algorithm. PLOS ONE, 12(12). e0188283. https://doi.org/10.1371/journal.pone.0188283

[53] Li, S., Li, H. R., Zhang, X. B., & Ji, M. F. (2012). Scheduling Optimization for Parking and Taking Car about the Vertical Circulation Type Stereo Garage. Applied Mechanics and Materials, 214, 52–57. https://doi.org/10.4028/www.scientific.net/AMM.214.52

[54] Li, X., Liu, S., Yu, Y., & Lai, H. (2015). Research on vehicle scheduling strategy of “non-shaped” tower parking garage. 2015 IEEE International Conference on Communication Problem-Solving (ICCP), 149–152. https://doi.org/10.1109/ICCPS.2015.7454113

[55] Li, Z., & Miao, L. (2020). Automated stereo-garage with multiple cache parking spaces—Structure, system and scheduling performance. Automation in Construction, 119, 103377. https://doi.org/10.1016/j.autcon.2020.103377

[56] Lu, R., Lin, X., Zhu, H., & Shen, X. (2010). An Intelligent Secure and Privacy-Preserving Parking Scheme Through Vehicular Communications. IEEE Transactions on Vehicular Technology, 59(6), 2772–2785. https://doi.org/10.1109/TVT.2010.2049390

[57] Lu, R., Lin, X., Zhu, H., & Shen, X. (2009). SPARK: A New VANET-Based Smart Parking Scheme for Large Parking Lots. IEEE INFOCOM 2009, 1413–1421. https://doi.org/10.1109/INFOCOM.2009.5062057

[58] Ma, J., Clausing, E., & Yimin, L. (2017). Smart On-Street Parking System to Predict Parking Occupancy and Provide a Routing Strategy Using Cloud-Based Analytics. 9. https://doi.org/10.4271/2017-01-0087

[59] Mandelbaum, M., & Hlynka, M. (2009). History of Queueing Theory in Canada Prior to 1980. INFOR: Information Systems and Operational Research, 47(4), 335–353. https://doi.org/10.3138/infor.47.4.335

[60] Mao, X., Yuan, C., Gan, J., & Zhou, J. (2019). Optimal Evacuation Strategy for Parking Lots Considering the Dynamic Background Traffic Flows. International Journal of Environmental Research and Public Health, 16(12), 2194. https://doi.org/10.3390/ijerph1612194

[61] Marchi, B., Zanon, S., Pasetti, M., Zavanella, L., & Ferretti, I. (2018). A queuing theory decision support model and discrete event simulations for the smart charging of electric vehicles. 1–7.

[62] Maršanić, R., Zenzerović, Z., & Mrnjavac, E. (2010). Planning Model of Optimal Parking Area Capacity. Promet - Traffic&Transportation, 22(6), 449–457. https://doi.org/10.7307/ptt.v22i6.210

[63] Maršanić, R., Zenzerović, Z., & Mrnjavac, E. (2011). Application of the Queuing Theory in the Planning of Optimal Number of Servers (Ramps) In Closed Parking Systems. Economic Research-Ekonomiska Istråživanja, 24(2), 26–43. https://doi.org/10.1080/1331677X.2011.1151745

[64] Medhi, J. (1997). Single Server Queueing System with Poisson Input: A Review of Some Recent Developments. In N. Balakrishnan (Ed.), Advances in Combinatorial Methods and Applications to Probability and Statistics (pp. 317–338). Birkhäuser. https://doi.org/10.1007/978-1-4612-4140-9_19

[65] Millard-Ball, A., Weinberger, R. R., & Hampshire, R. C. (2014). Is the curb 80% full or 20% empty? Assessing the impacts of San Francisco’s parking pricing experiment. Transportation Research Part A: Policy and Practice, 63, 76–92. https://doi.org/10.1016/j.tra.2014.02.016

[66] Min, Z., & Shidong, F. (2015). Study on Performance and Scheduling Strategy for Lift-sliding Solid Garage based on Queuing Theory. 184–186. https://doi.org/10.2991/iea-15.2015.45

[67] Mohd Bukari, S., binti Abdul Rahman, N., & Md. Rohani, M. (2019). Car Park Availability Assessment in Muar Town Using GIS. 11(9), 110–114.

[68] Nugraha, I. G. B. B., & Tanamas, F. R. (2017). Off-street parking space allocation and reservation system using event-driven algorithm. 2017 6th International Conference on Electrical Engineering and Informatics
[69] Pandey, D., & Hanchate, S. (2018). Navigation-based Intelligent Parking Management System using Queuing theory and IOT. 2018 Second International Conference on Green Computing and Internet of Things (ICGCIoT), 159–165. https://doi.org/10.1109/ICGCIoT.2018.8753053

[70] Pel, A. J., & Chaniotakis, E. (2017). Stochastic user equilibrium traffic assignment with equilibrated parking search routes. Transportation Research Part B: Methodological, 101, 123–139. https://doi.org/10.1016/j.trb.2017.03.015

[71] Portilla, A. I., Oreña, B. A., Berodia, J. L., & Díaz, F. J. (2009). Using M/M/∞ Queueing Model in On-Street Parking Maneuvers. Journal of Transportation Engineering, 135(8), 527–535. https://doi.org/10.1061/(ASCE)TE.1943-5436.0000016

[72] Pypno, C., & Sierpi, G. (2013). Modelling of The Operation of The Multi-Storey Automated Garage with A Big Capacity. 10.

[73] Ratliff, L. J., Dowling, C., Ma, Pypno, C., & Sierpi, G. (2013). Modelling of The Operation of The Multi-Storey Automated Garage with A Big Capacity. 10.

[74] Saaty, T. L. (1966). Seven more years of queues. A lament and a bibliography. Naval Research Logistics Quarterly, 13(4), 447–476. https://doi.org/10.1002/nav.3800130407

[75] Sattayhatewa, P., & Smith, R. L. (2003). Development of Parking Choice Models for Special Events. Transportation Research Record, 1858(1), 31–38. https://doi.org/10.3141/1858-05

[76] Senapati, B. R., & Khilar, P. M. (2020). Automatic Parking Service Through VANET: A Convenience Application. In H. Das, P. K. Pattnaik, S. S. Rautaray, & K.-C. Li (Eds.), Progress in Computing, Analytics and Networking (Vol. 1119, pp. 151–159). Springer Singapore. https://doi.org/10.1007/978-981-15-2414-1_16

[77] Setiawani, S., Hidayatni, N., & Suharto. (2020). The analysis of queue model on a motorcycle parking area. Journal of Physics: Conference Series, 1490, 012008. https://doi.org/10.1088/1742-6596/1490/1/012008

[78] Shahzad, G., Ahmad, A. W., Yang, H., & Lee, C. (2015). Sensor fusion based energy efficient and sustainable smart parking system. 2015 17th International Conference on Advanced Communication Technology (ICACT), 100–104. https://doi.org/10.1109/ICACT.2015.7224766

[79] Shao, W., Zhang, Y., Guo, B., Qin, K., Chan, J., & Salim, F. D. (2019). Parking Availability Prediction with Long Short Term Memory Model. In S. Li (Ed.), Green, Pervasive, and Cloud Computing (pp. 124–137). Springer International Publishing. https://doi.org/10.1007/978-3-030-15093-8_9

[80] Shortle, J. F., Thompson, J. M., Gross, D., & Harris, C. M. (2018). Fundamentals of Queueing Theory. John Wiley & Sons.

[81] Stasiak, M. (2016). Queueing Systems for the Internet. IEICE TRANSACTIONS on Communications, E99-B(6), 1234–1242.

[82] Sukmana, A., & Lesmono, J. D. (1999). Stochastic approach for parking problems on Hoogstraat Rotterdam. 1–10.

[83] Sundarapandian, V. (2009). Queueing Theory. In Probability, Statistics and Queuing Theory (p. 686). PHI Learning Pvt. Ltd.

[84] Sutjarittham, T., Chen, G., Gharakheili, H. H., Sivaraman, V., & Kanhere, S. S. (2019). Measuring and Modeling Car Park Usage: Lessons Learned from a Campus Field-Trial. 2019 IEEE 20th International Symposium on “A World of Wireless, Mobile and Multimedia Networks” (WoWMoM), 1–10. https://doi.org/10.1109/WoWMoM.2019.8792972

[85] Sztrik, J. (2010). Queueing Theory and its Applications, A Personal View. International Conference on Applied Informatics, 1, 9–30.

[86] Sztrik, J. (2012). Fundamental Concepts of Queueing Theory. In Basic Queueing Theory (pp. 11–16).

[87] Tamber, A. (2015). Optimizing the Queueing System of a Fast Food Restaurant: A Case Study of Ostrich Bakery, 7–15.

[88] Wang, K., Li, N., & Jiang, Z. (2010). Queueing system with impatient customers: A review. Proceedings of 2010 IEEE International Conference on Service Operations and Logistics, and Informatics, 82–87. https://doi.org/10.1109/SOLI.2010.5551611
[89] Weant, R. A. (1978). Parking Garage Planning and Operation. https://doi.org/10.21949/1503647
[90] Willig, A. (1999). A Short Introduction to Queueing Theory. 41.
[91] Willson, R. (2013). Parking Reform Made Easy. 29–34.
[92] Worthington, D. (2009). Reflections on queue modelling from the last 50 years. Journal of the Operational Research Society, 60(sup1), S83–S92. https://doi.org/10.1057/jors.2008.178
[93] Wu, E. H.-K., Sahoo, J., Liu, C.-Y., Jin, M.-H., & Lin, S.-H. (2014). Agile Urban Parking Recommendation Service for Intelligent Vehicular Guiding System. IEEE Intelligent Transportation Systems Magazine, 6(1), 35–49. https://doi.org/10.1109/MITS.2013.2268549
[94] Xiao, J., Lou, Y., & Frisby, J. (2018). How likely am I to find parking? – A practical model-based framework for predicting parking availability. Transportation Research Part B: Methodological, 112, 19–39. https://doi.org/10.1016/j.trb.2018.04.001
[95] Xie, K., & Hlynka, M. (2019). Forward and Reverse Parking in a Parking Lot. ArXiv:1909.12941 [Physics]. 1–13.
[96] Yan, Q., Li, Y., & Wu, M. (2015). A Method to Determine the Number of Parking Spaces in a Taxi Station Based on the Queuing Theory. 1314–1321. https://doi.org/10.1061/9780784479384.165
[97] Yuan, L., Huang, R., Han, L., & Zhou, M. (2018). A Parking Guidance Algorithm Based on Time-Optimal Dynamic Sorting for Underground Parking. 2018 26th International Conference on Geoinformatics, 1–6. https://doi.org/10.1109/GEOINFORMATICS.2018.8557079
[98] Zhao, Y., Zhou, Z., Pan, Q., & Zhou, T. (2020). G/M/N Queuing Model-Based Research on the Parking Spaces for Primary and Secondary School. 1–7.
[99] Zhu, X., Lv, S., & Meng, J. (2018). Research on Access Speed of the Stereo Garage Based on Queuing Theory: Proceedings of the 2nd International Conference on Intelligent Manufacturing and Materials, 282–290. https://doi.org/10.5220/0007530602820290