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Kerbside Parking Assessment Using a Simulation Modelling Approach for Infrastructure Planning—A Metropolitan City Case Study

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Abstract: The main purpose of this research is to investigate the effect of kerbside parking demand and provision on short-term parking (STP) and freight activity space (FAS) as a benchmark for infrastructure planning, considering the impacts of expected future growth and capacity changes. In this study, we adopted a mixed-methods approach of quantitative analysis including a spatial view of parking using manual and video-captured camera data from the majority of STP and FAS parking bays covering a diverse range of loads/tasks with different levels of elasticity and substitutes, as well as simulation of current demand influenced by various factors, as a basis for the development of strategies and prioritisation of the allocation of limited kerbside spaces in Parramatta, a rapidly transforming/growing CBD city centre environment. Parking demand consisted of a diverse range of FAS and STP categories. Spatial analysis showed a non-homogeneous distribution of parking demand and loads across several sections of the city. A large proportion of short-term parking spaces is attributed to two peak periods during the day and increased traffic volumes at peak times. Comparatively lower average parking times in the northern and western regions compared to those in the city centre indicate the potential to reduce peak parking periods and therefore traffic congestion in the city centre by changing parking limits. The presented simulation model can be used as a reliable benchmarking model for the simulation of future impact scenarios and to make recommendations with respect to infrastructure planning and to develop travel demand management strategies. This research is based on a case study and is therefore subject to limitations in its applications in other contexts. Extension of the baseline simulation with future impact scenarios is planned for the next stage of this research. A simulation model is presented and illustrated as a reliable benchmarking tool for the simulation of future impact scenarios through a case study of a rapidly changing city environment.

Keywords: kerbside parking; baseline scenario; short-term parking (STP); freight activity space (FAS)

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1. Introduction

Parking is a broad topic that has been investigated from different perspectives, mainly considering parking assessment and infrastructure planning across a range of parking demands and facilities, including off-street and kerbside parking in urban city environments, policies, and parking limits. Parking infrastructure relates to current facilities, requirements and usage in urban cities and other large established areas such as university campuses, business parks and sporting venues. Parking infrastructure comprises a range of facilities, including kerbside parking in metropolitan city centres and private multistorey carparks. Furthermore, parking policy, as well as urban planning and space policy, is an integral parts of parking assessment. Therefore, the provision of parking and space for communities under urban planning is a main question for policymakers at the local government/council level, focusing on types of kerbside parking space/allocation, parking time limits, pricing of parking, and space for people [1].

Parking assessment is a continuing area of interest for various stakeholders due to the changing environment in many urban/metropolitan cities. For example, the difference between supply and demand has increased over the years, and most local/city governments are behind and institutionally unprepared for planning, regulation. and management of parking [1]. At the same time, parking assessment is becoming a complex and challenging task when cities are being planned with the concept of "car-free cities" or "planning for people, not for cars". Most local authorities (and states) are proposing a reduction in parking provisions in cities to provide more places for people (than vehicles). Main changes include increasing the level of infrastructure, commercial and residential developments, increasing level of demand for scarce space for different types of parking and daily temporal patterns, and changes to existing parking infrastructure.

Access and kerbside parking assessment are critical for any future infrastructure development, particularly when existing parking infrastructure is affected during the construction stage and given expected changes to existing parking facilities. Some of the changes impacting the availability of kerbside parking include (i) increasing public space and pedestrian prioritisation, (ii) possible closure of existing kerbside parking due to new public transport infrastructure such as light rail, (iii) increasing demand due to population growth, (iv) increasing freight and servicing activities, and (v) changes to other parking facilities (e.g., closure of existing multistorey carparks for the development of new residential and commercial buildings). Some studies have investigated the impact of changes in specific factors on overall parking capacity and needs/behaviour, including the provision of a minimum number of parking spaces, taking into consideration historical relationships between specific land uses and parking needs [2], as well as parking pricing and kerbside allocation when the private sector provides garage parking [3]. Although parking needs and capacity, which are impacted by several factors (e.g., population growth and public transport infrastructure) is a well-studied/-reported area, segmentation of kerbside assessment of FAS is less defined/studied. In this context, there is a lack of science supporting the understanding of different segments of demand and providing useful guidance for policymakers in making decisions on parking limits and schemes.

Thus, the main purpose of this research is to propose a simulation modelling approach for kerbside parking assessment. The key objectives of this research are to (i) assess the current kerbside demand during regular peak periods using a survey of parking events based on manual and camera data and (ii) model and simulate current kerbside parking demand (baseline scenario) as the basis for modelling and simulation of future kerbside parking impact scenarios. Camera data are collected using video of kerbside parking events. Simulation modelling of the baseline (current demand and capacity/supply) scenario based on comprehensive camera data and analysis of future parking demand growth forms the basis for simulation modelling of kerbside impact scenarios, which are influenced/generated by potential future changes to parking capacity and potential increases in demand due to construction activities, population growth, and increased freight and serving activities.

This study was carried out as a kerbside parking case study of a rapidly changing city centre within metropolitan Sydney. The remainder of the paper is structured as follows. First, the research background and an overview of the research methodology are presented. The case study background and data collection are outlined under the research methodology, followed by simulation modelling, results, and analysis. In this case, results and analysis include verification of camera data using manual survey data, simulation model-based analyses, and analysis of the growth of kerbside parking demand and future changes to parking capacity. Finally, findings, discussion, and conclusions are presented by outlining recommendations for policymakers regarding kerbside parking, limitations, and practical implications.

2. Research Background

Kerbside parking provision and management is a major area of focus of city planning for various stakeholders, including local councils and local government transport agencies. Key areas of consideration include kerbside parking infrastructure (e.g., capacity perspective), kerbside parking policy (e.g., pricing perspective), current practices (e.g., demand, utilisation, trends, etc.), future impacts, and policy objectives for urban centres [4]. All these areas are very broad and have been considered in various research projects, including the planning of infrastructure in different settings [2], setting of policies at local government and council levels, and operational issues and challenges from demand and utilisation perspectives [5]. Research studies on parking assessment cover a range of aspects and have investigated parking assessment from a range of viewpoints, including evaluation of parking facilities and infrastructure from the perspective of constraints and/or opportunities for urban development [2], energy management for a large-scale electric vehicle (EV) charging-enabled municipal parking facility [6], a cost–benefit analysis of inner-city parking using network optimisation [7], and the effectiveness of off-street parking pricing schemes under changing conditions [5]. Studies investigating kerbside parking demand from the perspective of influencing factors have considered changes in parking cost, shifting demand, and their interaction with cruising for parking [8,9]; a tradeoff between cruising and walking cost [10]; pricing elasticity of parking occupancy and associated parking supply restrictions [11]; and management of freight capacity in the context of a major CBD transformation while accommodating business growth with reduced kerbside capacity [12]. Furthermore, studies of demand modelling have considered latent demand (e.g., unrealised demand and drivers searching/cruising for an available spot), showing that it accounts for a significant proportion of overall demand [13,14]. In addition, factors affecting the level of satisfaction of commuters can also be used as a key input for the promotion of sustainable modes of transport to solve parking problems in rapidly growing urban cities [15].

Based on a range of research studies around these key areas, it is clear that most of studies cover long-term planning and short-term operations. These areas are related and interconnected through the planning/management process and involve many stakeholders, including local government for the planning of infrastructure, councils for setting of parking policies, and users from a demand and utilisation perspective. Because most research is driven by the parking assessment context, key areas of kerbside parking are discussed from both theoretical and practical perspectives herein.

2.1. Kerbside Parking Infrastructure—Capacity Perspective

Every metropolitan city is facing the challenge of balancing kerbside parking infrastructure with various spatial and usage demands. Demand is changing at a rapid rate due to various influencing factors, such as growth in e-commerce, increasing numbers of share economy providers, and shorter delivery windows [2,5,16], as well as changes to supply due to rapidly changing city infrastructure, particularly with popular light rail transit projects [17]. These changes are dynamic and need to be considered as part of a holistic approach when dealing with planning for parking infrastructure needs. These changes are common in high-growth cities such as the Sydney CBD and Parramatta [18] due to minimum development requirements [2]. This is exacerbated by the increasing rate of changes to existing infrastructure and changes to the mix of demand needs, among many factors.

Parking infrastructure in urban centres consists of a diverse range of parking spaces, including kerbside parking, available for a range of users under different parking categories, time limits, and pricing conditions. An assessment of paid parking in an urban city environment [1] indicated that off-street parking facilities are growing much faster than kerbside parking. According to [1], off-street parking spaces now account for more than 90% of the total parking spaces in Beijing—a more than 290% increase since 2008. However, parking infrastructure assessment studies are very limited, particularly with respect to changes to the composition of various parking facilities from the perspective of urban city settings. Although the growth of kerbside parking is decreasing in some urban settings [1], it represents critical infrastructure in an urban city environment and serves various users with increasing demand due to increasing residential and commercial activities. Thus, kerbside parking facilities are considered to be a significant part of the overall parking space, especially in urban centres. The rapid growth of residential and commercial activities in urban centres has led to the need for assessment of current parking supply, demand, location, and duration/limits, among many other factors, as the basis for improving current parking practices and setting appropriate parking policy to meet future demand under changing conditions. Several research studies have focused on various aspects of parking in urban centres, including parking infrastructure [2], parking policy [16,19,20], and environmental assessment of parking [21] and parking requirements [22].

Parking infrastructure is another area of investigation, mainly due to the direct connection to the source of the major problem of shortage of parking spaces and the increasing gap between supply and demand [1]; increasing demand for parking spaces due to growth in residential living in association with increasing car ownership and commercial activity in urban centres [23]; and the very important influence of infrastructure development, resulting in changes to existing parking infrastructure [2]. Parking infrastructure studies are mainly focused on the assessment of parking requirements based on zoning regulations and future developments, including the assessment of the extent and location of parking infrastructure within metropolitan areas [2], setting of minimum parking requirements using cost–benefit analysis [22], and policy shifts towards setting maximum limits for buildings (off-street) for general parking to encourage active and public transport. On the other hand, some scholars and planners suggest multiple ways to reduce parking requirements and even suggest additional parking for other users, such as cyclists, carpoolers, and transit users [22]. As evident from the literature, a reduction in parking requirements can address some of the issues caused by kerbside parking infrastructure (e.g., abundant "free" and low-cost parking), such as traffic congestion, poor air quality, more household spending on mobility, equity issues, and underused land [24–26]. This suggests that addressing parking infrastructure issues not only reduces the gap between demand and supply but also societal benefits, such as by promoting more space for people than cars in populated cities. Recently, addressing a key issue associated with minimum parking requirements set by historical relationships between specific land use and parking needs [27] has emphasised the importance of considering remaining incentives for auto use created by the existing parking infrastructure when reforming parking policies.

2.2. Kerbside Parking Policy

Parking policy can cover a range of perspectives, including barriers to the emergence of off-street parking markets [28], on-street parking pricing [29], non-residential parking policies [30], kerbside parking time limits [16], time-varying parking prices [31], and user-attitude-driven pricing [32]. There is a considerable literature on parking policy-related studies, mainly focusing on the investigation of the supply of parking and parking price [29,32,33]. At the same time, the supply of parking in urban centres covers a range of parking spaces including kerbside parking and public and private parking facilities. Thus, broader parking policy covers the pricing and supply of various parking spaces.

Recently, kerbside parking policy has received considerable interest, in particular from the perspective of parking time limits [16] and pricing schemes [16,33–35]. According to [16], underpricing of kerbside parking leads to wasteful cruising for parking. Similarly, based on the survey method of comparing parking occupancy, the objective of parking policy to increase the ease of finding a vacant parking place is evident from underutilised parking spaces in city centres [33]. However, these studies are limited to developing kerbside parking policies subject to only economic factors. Shortage of parking spaces is a major issues, particularly in urban centres, and has been exacerbated by an increase in traffic and associated demand in recent times [33]. It is emphasised that the increase in Internet shopping due to the COVID-19 pandemic has contributed to an increase in freight-related traffic, particularly in urban centres. According to [36]:

"We've entered an entirely new way of buying goods and services, but our infrastructure is only adapting incrementally."

Studies on parking policy can be divided into two categories: studies on the supply of parking and studies on parking price. Most studies on parking policy are case-study-based, as policies are area-specific, given the very specific nature of the supply of parking and its price. In this context, the authors of [28] emphasise the need for a more rigorous policy effort, taking into consideration both market fostering and regulation. Recently, [20] highlighted the importance of adopting new planning practices of "maximum provision codes", limited parking development, and demand pricing over traditional practices. Based on the case study approach, a few studies have suggested new policy frameworks, including spatial distribution and usage of parking in Melbourne, Australia [19], and the strong need for reform in urban parking management to promote urban transportation and maximise social welfare [1]. In the specific parking policy of pricing downtown parking, many research studies have reported different perspectives, [16] recommending underpricing of kerbside parking as a sound policy response to the free parking provided by suburban shopping centres, in particular with respect to heterogeneous individuals using the parking. However, this approach limits the parking policy to differences in individuals using parking but does not consider types of vehicles.

2.3. Parking Usage and Behaviour

Parking presents several challenges, particularly in metropolitan areas, due to limited supply and demand/usage by a range of users [37]. With limited parking in the metropolitan city environment, vehicles searching for parking create an environmental and economic impact [38]. Thus, parking usage is considered a central part of parking assessment studies, taking into consideration various parking demand and supply scenarios, including kerbside parking assessment, the impact of varying user and parking load categories, the impact of expected growth and changes in parking behaviour, and the variety of assessment situations in suburban cities and large centres such as university campuses [39]. The underlying principles of all these assessments are changing demand and supply situations, with a range of dynamic conditions impacting demand and supply [30] and various characteristics of supply and demand, including specific differences between commercial parking and other parking facilities [39]. From the perspective of optimum parking facilities, the authors of [40,41] proposed modelling approaches to determine the optimum number of park-and-ride facilities as a way to reduce traffic congestion in the considered urban cities.

Kerbside parking assessment studies mainly focus on the assessment of current demand for various purposes, including the impact of the parking price change on demand [42], parking slot allocation subject to dynamic conditions [37], the evaluation of parking demand for policy assessment [20], and assessment of pricing impact [43]. From the perspective of usage and impact, studies have focused on the source of knowledge for car parking strategies, emphasising the need to develop and implement staff car parking strategies [44], environmental and economic impact due to searching for parking [38], the concept of freight landscape, and requirements for different city logistics strategies [45], in addition to highlighting limited parking capacities with increased demand and intensity in metropolitan cities.

The impact of price changes on kerbside parking usage has shown mixed results in different contexts, including a reduction in double parking and cruising for parking and improved driver experience [43], determining optimal parking price, taking into consideration users' attitudes [32] and optimal parking rate/price to achieve the desired level of parking occupancy. The authors of [37,42] proposed an approach for public parking slot assignment using advances in parking sensing and communication technologies, which rely on eliciting truthful private information from drivers while maximising social welfare.

Furthermore, a few research studies on parking assessment and allocation of limited parking capacity have reported on the application of advanced technologies, smart parking management systems to increase effective capacity [46], and potential benefits of using intelligent parking guidance systems, mainly using electronic signage systems that direct drivers to vacant parking lots [20].

These studies have mainly focused on assessing current kerbside/off-street parking, taking into consideration pricing/rate changes and/or application of technologies to improve effective parking usage/behaviour. In this case, effective parking usage/behaviour is achieved by minimising the gap between demand/requirements and supply across a diverse range of parking spaces and loads and under different conditions, including parking limits and/or pricing schemes. It is also evident from these research studies that kerbside parking infrastructure, kerbside parking policy, and parking usage are inter-related. Rapidly changing cities are most likely to influence changes to all or most of these aspects. Therefore, the need for parking assessment taking into consideration all of these aspects is imperative, particularly when cities are subject to the rapid growth of infrastructure development, population growth, and changes to existing parking infrastructure. In this context, parking assessment taking into consideration all of these aspects is considered with respect to a case of the fastest-growing cities in Australia.

2.4. Background of Current Parking Infrastructure—Parramatta CBD

One of the rapidly changing urban cities in Australia is Parramatta CBD. The increase in development in Parramatta CBD aims to support more employment and residents [47]. Parramatta is recognised as one of several major cities in Sydney as part of A Metropolis of Three Cities—the Greater Sydney Region Plan prepared concurrently with Future Transport 2056 and the State Infrastructure Strategy [48]. Parramatta light rail and the Sydney Metro West rail line are two major infrastructure projects currently in progress. In the case of Parramatta CBD as the focus of this research, the proposed light rail project will have a major impact on the current kerbside parking facilities. Figure 1 shows a map of the planned route of light rail infrastructure and the parking study area in Parramatta CBD on a 2 km × 2 km map. The parking study area of short-term parking (STP) and freight activity space (FAS) defined by the boundaries of the area is about 0.78 km^2 (i.e., 0.91 km × 0.86 km) and is shown in Figure 1 (blue colour).

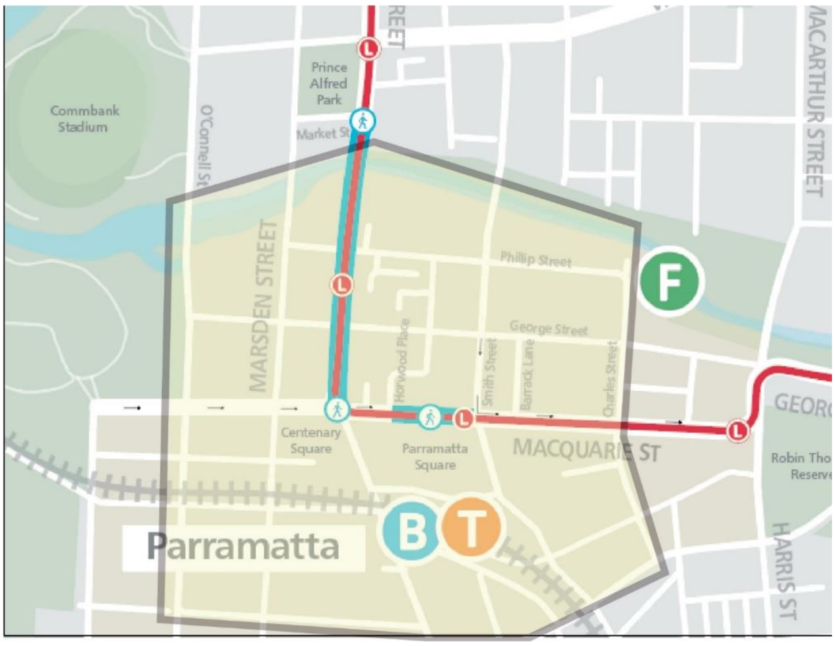

Figure 1. Planned route of light rail infrastructure (red) and the parking study area (shaded) of Parramatta CBD [49].

The second major change expected in the Parramatta CBD is ongoing infrastructure development, which also impacts the current kerbside parking infrastructure [50]. There are also several other residential and commercial infrastructure projects that are in the pipeline, including a large number of applications for commercial office development in the Parramatta CBD [51]. Impact on kerbside parking due to these projects are in two stages. First, there is an immediate impact on kerbside parking requirements due to increased demand by various vehicles such as construction workers' vehicles and freight services. Secondly, there would be additional demand and varied demand composition once the development is complete and buildings are occupied by residents and businesses.

The next major change is the reduction in existing parking facilities due to other developments in the Parramatta CBD. In Central Parramatta, there are three public multistorey carparks, two of which are flagged for demolition to make way for other developments. Commuter carparks on the fringe of the CBD are likely to replace this infrastructure. While this scenario can be approached from a land value perspective, a uniform profile of commuter parking may be required. However, tradespersons who used the carpark on Horwood Place (now demolished for future development) may be using kerbside parking due to its convenient proximity to the large city centre developments such as Parramatta Square, particularly if workers are carrying tools to the site [50]. The relationship between the Horwood carpark and Parramatta Square should be considered as one of the critical factors when parking behaviour is further investigated within the city infrastructure development planning framework, particularly in the context of the scale of change in Parramatta CBD. All of these expected changes and the resulting impact on overall kerbside parking behaviour from the perspective of usage (e.g., different loads/tasks, vehicles) with time and bottleneck are complex to visualise and need to be investigated to develop travel demand management strategies for all stakeholders. Therefore, the broader aim of this research is to provide a holistic kerbside parking assessment with a spatial view of parking distribution and an analysis/forecast of expected changes, taking into consideration current parking demand, non-homogeneous distribution of parking loads, and overall utilisation as the basis for investigation of expected future changes and developing travel demand management strategies for all stakeholders. The key research question investigated in this paper is: What is the current kerbside demand in terms of parking distribution and utilisation, and how can potential changes to kerbside parking demand be modelled as a basis for evaluating the impact on kerbside parking, taking into consideration of all possible supply and demand changes in the future? To answer this research question and achieve the main purpose of this study, the following aims/objectives are set:

- Investigate current kerbside parking capacity, demand, and utilisation patterns, including a spatial view of parking and behaviour;
- Model current kerbside parking demand and capacity using simulation modelling as a basis for modelling kerbside impact scenarios, taking into consideration the non-homogeneous distribution of parking loads, future demand increases, and changes to kerbside capacity due to infrastructure development;
- Illustrate, forecast and analyse expected future kerbside parking demand due to population and construction growth, as well as capacity reduction due to infrastructure development, as the basis for investigating various kerbside impact scenarios to be carried out in the next stage of the research;

Because the proposed light rail infrastructure and expected increased demand due to rapid growth in construction activities are expected to directly impact parking spaces in the Parramatta CBD, this study focuses on kerbside parking within Parramatta CBD. Thus, the scope of the research includes:

- Kerbside parking spaces for short-term parking (STP) and freight activity space (FAS) in the Parramatta CBD, as defined by the boundaries of the area of about 0.78 km^2 (i.e., 0.91 km $\times$ 0.86 km) (Figure 2);
- Video data collection of kerbside parking events at selected locations as a representation of Parramatta CBD over one week;

- Manual data collection of parking events using a survey at selected locations in Parramatta CBD during peak periods over two days. Each parking event is recorded with time in/out, type of vehicle/load, and the type of parking space the vehicle occupies;
- Analysis of manually captured data to verify the camera dataset first, followed by setting of input parameters for a baseline traffic/parking simulation model using the camera dataset.

Figure 2. Area of Parramatta CBD (2021) kerbside parking spaces for assessment.

This research was carried out using a combination of experimental and simulation modelling approaches based on real manually collected and camera data. Details of the research methodology are presented next.

3. Research Methodology

In this study, we adopted a mixed-methods approach of (i) analysis of parking in terms of load distribution; (ii) a spatial view of parking in five regions/areas, including the centre of the CBD; and (iii) simulation modelling of the current parking scenario for prioritisation of the allocation of limited kerbside spaces in a rapidly changing city environment due to increasing population growth and rapid infrastructure development. The research methodology involves three stages: (i) analysis of current kerbside parking demand and a spatial view of parking loads using video camera data; (ii) simulation modelling of current parking demand, taking into consideration expected searching for parking; and (iii) estimation of key model input variables using expected population and construction growth as a benchmarking for modelling and simulation of four future kerbside impact scenarios. The research was carried out by assessing current kerbside parking demand/usage using real data, simulation modelling of current kerbside parking demand/usage, and illustration using a case of an urban centre/city in Sydney, Australia. The benchmarking of current parking demand using simulation modelling forms a basis for the development of strategies and prioritisation of the allocation of limited kerbside spaces in a rapidly changing city environment. The first stage of parking assessment involves data collection and associated analysis. This is followed by traffic/parking simulation modelling of the current demand/usage (baseline) scenario using input parameters from a comprehensive kerbside parking dataset. The baseline (benchmarking) traffic/parking simulation model using key parameters forms a basis for investigating the impact of future increased demand, changes to parking capacity, and infrastructure development Expected population growth and construction growth forecast are evaluated as key model inputs for the development of four kerbside impact scenarios for the next stage of this research project.

3.1. Data Collection

Kerbside parking data collection was carried out using a combination of manual survey data collection over two working days and video-captured camera data over one week at selected parking spaces in respective parking segments. Parameters of kerbside data collection are outlined in Table 1.

Table 1. Parameters of kerbside data collection in Parramatta CBD.

Data Collection Method	Number of Parking Spaces Used		Dates and Times of Data Collection	Parking Time Slots
	STP: 5M, 1/4P, 1/2P, 1P & 2P	**FAS:** LZ, TZ, DR		
Manual kerbside survey (8 segments)	26	20 (15 LZ, 3 TZ and 2 DR)	19–20 October 2017; 7 a.m.–4 p.m.	PT6 = before 0700, PT7 = 0700–0800, PT8 = 0800–0900, PT9 = 0900–1000, PT10 = 1000–1100, PT11 = 1100–1200, PT12 = 1200–1300, PT13 = 1300–1400, PT14 = 1400–1500, PT15 = 1500–1600
Camera dataset using video capture (19 segments)	84	28 (All LZ)	16–20 October 2017; 24 h	24 h; Hour of day: 0 (12 a.m. to 12:59 a.m.) to 23 (11 p.m. to 11:59 p.m.)

Total kerbside parking spaces in Parramatta CBD (Figure 2) include 501 STP and 46 FAS spaces. STP and FAS are the two main parking zone types; STP consists of five different types (5M (5 min), 1/4P (1/4 h), $\frac{1}{2}$ P (half an hour), 1P (1 h), and 2P (2 h)), and FAS consists of three categories (loading zones (LZ),truck zones (TZ), and driveways (DR)). LZ spaces have a maximum dwell time of 30 min. STP can be used by FAS vehicles. LZ spaces can legitimately be used by any vehicle for the purpose of pick-up and drop-off. Manual data collection was carried out for all parking types subject to different usage depending on the time (e.g., LZ spaces have a maximum dwell time of 30 min (parking time limit), and STP can also be used by FAS vehicles), whereas camera data capture was limited to STP and LZ parking zones.

3.2. Data Collection Methods

Manual kerbside data collection was carried out at eight predetermined segments within eight subsections of the CBD; each parking event was recorded in a spreadsheet, identifying key attributes such as bay number, parking zone at the start of parking, arrival time, vehicle type, load type, and departure time. Because data collection methods involve different locations and numbers of parking spaces, details of kerbside segments available and used for both types of data collection are outlined in Table 1. To overcome the limitations of manual kerbside data and the limited number of parking spaces surveyed, camera data collection was carried using video capture of parking events for selected parking segments over five workdays (16–20 October 2017).

The camera (video-captured) dataset was carefully checked for any missing data, overlapping data, and outliers (e.g., parking events with more than 24 h parking durations) and was cleaned before analysis for kerbside hourly arrival rates and parking duration of parking events for each hour over the selected period. The refined kerbside parking demand dataset was used as the main kerbside demand input for the baseline simulation model. The refined kerbside dataset for the assessment and baseline model is based on measures and parameters outlined in Table 1.

The main assumptions and limitations of kerbside parking using camera data include:

- Removing outliers, duplicate data, and events with overlapped parking times in the same parking space of camera data are assumed to be a good representation of all parking events [50];
- Limitations of kerbside camera data include (i) data captured in a small scope (61% of LZs and only 17% of STP, as most STP is in locations unlikely to be used for freight and servicing activity) of parking spaces (84 STP and 28 LZ) compared to the full scope of Parramatta CBD kerbside parking (501 STP and 46 LZ), (ii) the fact that FAS parking spaces are limited to the LZ category only (i.e., no data capture for TZ and DR parking spaces), and (ii) removal of some records due to missing data.

3.3. Modelling and Simulation of Kerbside Baseline (Current) Scenario

Because manual data are limited (only two days from 7 a.m. to 4 p.m.), the kerbside parking demand data captured using video cameras over 5 days were used. Hence, model inputs on arrival rates and parking durations for kerbside modelling were obtained from the camera dataset outlined in Table 1. The parking duration was modelled by evaluating all available weekday kerbside parking data according to the parking duration distribution for parking events in each hour. The resulting parking distributions determined and reported in [50] were used in the simulation of the baseline scenario.

Because kerbside video data collection had some gaps due to likely video recording errors, a "typical day" parking scenario was constructed by considering the highest hourly parking arrivals. Kerbside usage during the week (16–20 October 2017) and usage of a typical day are shown in Appendix A (Table A1). Using Flexsim [52], a simulation model was first constructed using the typical day scenario, which consisted of 31 STP and 8 LZ parking spaces. The typical day scenario was then verified against the expected parking usage and arrivals to verify the kerbside parking model and the procedure.

The typical day scenario was then extended to the baseline scenario simulation model by appropriately evaluating hourly arrival rates to reflect the baseline (current) kerbside scenario. The baseline scenario kerbside model takes into consideration a kerbside capacity of 501 STP and 46 LZ parking spaces. Details of data analysis, results, and findings are presented in the following section and categorized into the key areas of analysis of an intercept survey, kerbside and carpark data, and analysis/results of traffic/parking simulation models.

4. Results and Analysis

Kerbside parking assessment is presented in five stages: (i) assessment of manual kerbside data, (ii) assessment of camera data, (iii) spatial analysis of parking demands and loads, (iv) baseline modelling of current kerbside demand, and (v) evaluation of future impact scenarios as the basis for simulation modelling of kerbside impact scenarios.

4.1. Analysis of Manual Kerbside Data

The first stage of data collection involved a small-scale kerbside parking survey to verify the validity of camera data. The purpose of validation is to ensure no significant discrepancy between manual data and camera data before incorporating the camera data into simulation modelling. The preliminary analysis found that camera data closely aligns with the manual dataset. Therefore, the camera dataset is valid and reliable for use in the development of the traffic/parking baseline scenario simulation model.

Key analysis of manual data collected at several kerbside parking sections of Parramatta CBD over two days (19–20 October 2017) includes descriptive statistics of key measures (number of parking events and length of stay) and analysis of those measures using key variables/parameters, including (i) time slots/zones and (ii) parking zones/categories. Key analyses are illustrated using column/bar charts for visualization of peak/valley points and trends.

Based on the analysis of parking events in three parking time zones (morning: before 0700 to 1200; mid-day: 1200 to 1400; and afternoon: 1400 to 1600), the distribution of parking events in three categories of parking zones (STP, FAS, and other) (Figure 3) shows a fairly uniform distribution. For example, STP parking events are distributed in proportion of 44%, 42%, and 46% over the three parking time zones (morning, mid-day, and afternoon, respectively), whereas FAS parking events are distributed in proportions of 44%, 46%, and 45% over the three parking time zones. Furthermore, both distributions of STP and FAS parking events show similar percentages of parking events (44% and 45%, respectively), whereas the percentage of parking events in other parking zones show a very low percentage of 11% of the parking load during the considered period.

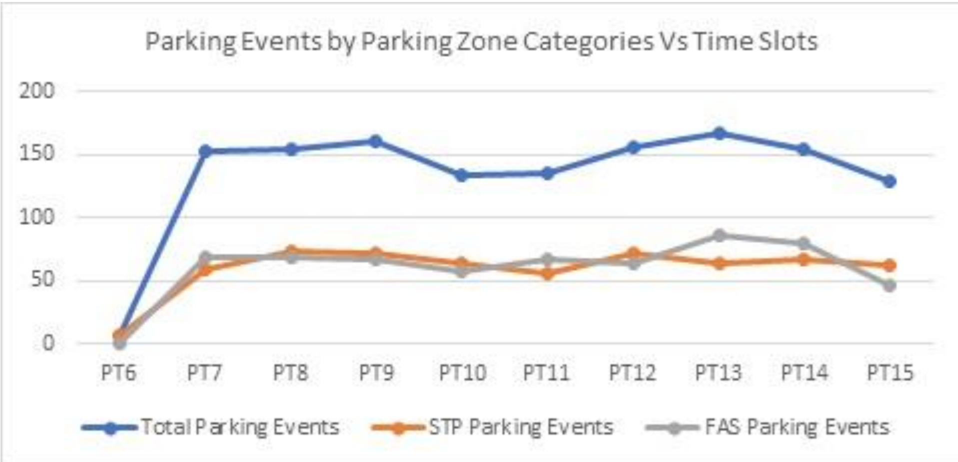

Figure 3. Number of parking events by parking zone category vs. time slots.

The above results show that time zone 2 (mid-day) is the busiest period across both parking zone categories (STP and FAS) when the number of parking events per parking zone is considered. For example, the average (mean) number of parking events per parking zone in STP parking zones is 55, 68, and 65 for time zones 1, 2, and 3, respectively, with the highest average number of parking events recorded for time zone 2. Similarly, the average number of parking events during time zone 2 (Mid-day) is 75 for FAS. This means that the demand for parking during mid-day is at its peak across both categories of parking zones.

Table 2 presents descriptive statistics of the length of stay, as well as a detailed profile of each time slot, using the number of parking events. Overall, the average length of stay of parking events over individual time slots (PT6 to PT15) is within a range of 15 min to 38 min, suggesting a fairly uniform distribution over the considered period, including a peak of an average of 38 min during the unrestricted period (before 0700) and a low average of 15 min during the last period/slot (1500–1600). Figure 4 shows a boxplot of the length of stay by time slot, and Figure 5 shows a 95% confidence interval of mean by time slot, indicating potential implications concerning the differences in length of stay across those time slots. It is interesting to note that between 0700 and 1400, the 95% confidence is tightly contained around the 30-minute mark, which is very close to the average length of stay (27 min). Furthermore, an Anderson–Darling normality test is presented to confirm the distribution of each category, leading to a better assessment of the length of stay of the studied sample and supporting these conclusions. It is evident from the results that none of the distributions of individual lengths of stay are normally distributed except for PT6 (before 0700).

Table 2. Descriptive statistics of length of stay (minutes) of parking events during two days (19–20 October 2017).

Parking Time Slot	Number (N)	Mean (Minutes)	Median (Minutes)	Standard Deviation (Minutes)	1st Quartile	3rd Quartile	95% Confidence Interval for the Population Mean (Lower; Upper)	Anderson–Darling (A-Squared Normality Test)	Skewness	Kurtosis
PT6	7	38.57	35.00	25.59	15.00	62.00	14.90; 62.24	0.39	0.31	−1.92
PT7	153	33.00	12.00	67.62	5.00	33.00	22.21; 43.81	26.11	4.49	22.95
PT8	155	31.40	7.00	71.75	3.00	25.00	21.02; 42.78	30.92	4.17	19.04
PT9	159	35.66	13.00	56.95	4.00	38.00	26.74; 44.58	19.35	3.38	15.91
PT10	133	23.31	10.00	32.72	5.00	27.00	17.70; 29.92	13.80	3.15	12.90
PT11	135	27.78	15.00	42.14	5.00	31.00	20.61; 34.95	15.17	3.77	17.78
PT12	156	30.20	14.00	41.44	5.25	37.75	23.65; 36.75	14.73	2.88	10.28
PT13	167	26.90	14.00	35.25	5.00	32	21.52; 32.29	17.06	2.13	4.14
PT14	154	19.15	12.50	21.34	3.75	30.0	15.75; 22.55	9.67	1.69	2.88
PT15	129	15.30	11.00	13.89	5.00	22.00	12.88;17.72	5.26	1.18	0.80
All	1348	27.32	12.00	47.21	5.00	30.75	45.49; 49.06	173.62	4.76	31.15

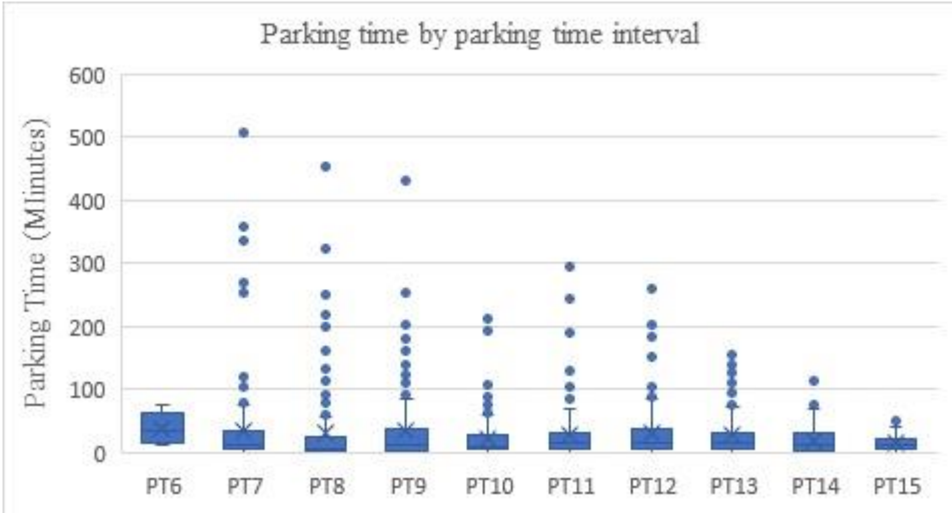

Figure 4. Boxplot of parking time (length of stay) of all parking events on FAS and STP spaces by parking time slot.

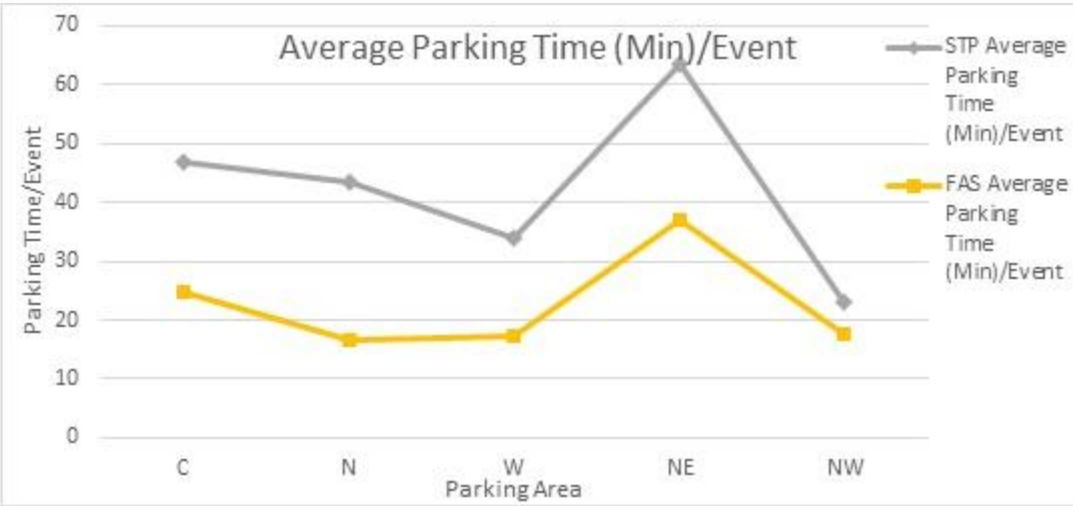

Figure 5. Average parking time in STP and LZ spaces across five areas/regions.

Although some parking events span two or more periods, in particular freight and services (FAS)-related parking events, the average length of stay of parking events in each time slot is less than 60 min (duration of the time slot). However, the range of length of stay (indicated by standard deviation) is significantly large across several parking time slots, including 72 min for time slot PT8 (0800–0900). Analysis of manual data includes a comprehensive analysis of the following aspects:

- Define the peak time of day activity and the average length of stay for parking events in short-term and loading zone bays;
- Define the use of short-term parking by the freight and servicing vehicle classifications;
- Examine the use of "freight activity spaces" by other types of vehicles;
- Define the current state minimum short-term or loading zone bays required to meet service demands.

In summary, the following results are noted from the comprehensive analysis of kerbside assessment using a manual dataset. The peak time of day activity across two categories of parking zones (STP and FAS) is the mid-day (1200 to 1400) period. The average length of stay for parking events is 27 min and within an average range of 15 min to 38 min, with a fairly uniform distribution over the studied period (0700–1600).

The analysis shows that there is a considerable amount of FAS loads/tasks (11% of all parking events) performed in STP zones. On the other hand, more than half of all parking events in STP (i.e., 52%) are associated with FAS loads/tasks. Additionally, passenger vehicles not only use STP zones but also FAS parking zones. This indicates that parking usage by various users is not fully matched with the parking zone categories.

A considerable (if not significant) difference was found between the average length of stay in FAS (23 min) and the average length of stay in STP zones (13 min). This emphasises the need for further research to determine whether the difference is significant, as well as practical implications for prioritising parking allocation in the future.

Kerbside assessment using analysis of current capacity and actual demand shows that there is spare capacity for short-term parking zones. In this case, the spare capacity of time is around 27% of total short-term parking time (i.e., only around 74% of the total short-term parking time available during the considered period was used). Because full capacity utilisation is assumed to be around 90% of total capacity, taking into consideration lost time between events and a large number of events with a short length of stay [18], the current spare capacity is only around 17%.

It can be noted from the above analysis of current kerbside parking that overall parking assessment is limited by (i) the scope of the dataset (parking events over two days of the week from 7 a.m. to 4 p.m.) and (ii) analysis using two key variables/parameters: (a) time slots/zones and (b) parking zones/categories. In order to use camera data for the development of a baseline traffic/simulation model, kerbside camera data were validated using a representative sample of data, details of which are presented in Appendix A (Table A1).

The kerbside usage shown based on the validation of camera data (Appendix A) is closely aligned with the results of the manual data analysis reported earlier. By considering 90% of utilisation as full-capacity usage, overall, kerbside STP parking reaches full capacity over three time periods (8:30 a.m.–9:30 a.m., 10:30 a.m.–3:30 p.m. and 7 p.m.–8 p.m.). Kerbside usage of around 77% between 10 a.m. and 11 a.m. is somewhat lower than expected. This could be due to (i) a small sample size of 39 spaces compared to a total of 547 kerbside (510 STP and 46 LZ) spaces, (iii) usage based on a simple method of hourly arrivals and departures, and (iii) possible errors when the recording camera data from video capture. Therefore, for simulation modelling of baseline kerbside parking (current demand and capacity) as the basis for the testing of kerbside impact scenarios, we adopted kerbside camera data gathered in 2017. In addition, key inputs of the model are hourly arrival rates and parking duration of hourly events. In this case, parking duration distributions of each hour based on a synchronised camera dataset are determined by best-fit distribution functions within simulation software (Flexsim) based on the approach adopted for distribution of kerbside parking manual data [50].

The kerbside usage/behaviour considered in this analysis is mainly focused on benchmarking current demand/requirements and supply under given economic conditions, such as parking limits and pricing schemes set by the local council. Because the parking demand for STP is at full capacity at three different time intervals and there could be unnoticed demand during these times, it is suggested that there is a need for further investigation into kerbside parking demand as part of promoting car-free city principles and providing more space for sustainable mobility in future studies.

4.2. Spatial View of Parking Spaces and Utilisation

Because the parking assessment is based on parking data (spaces and loads) across a relatively small area (0.78 km^2) but with a diverse range of parking spaces/limits, it is expected that parking utilisation is not only non-uniform but also non-homogeneously distributed. To understand this non-homogeneous distribution of parking utilisation as a basis for the development of guidelines for changes to parking infrastructure, the representative dataset of manual data collected over two days was further analysed in terms of average parking times in both STP and FAS spaces, as well as distance from the centre of the CBD. Details of parking utilisation from the perspective of distance from the centre of the CBD are presented in Table 3.

Table 3. Spatial view of kerbside parking using camera data.

Area	Total (FAS&STP) Spaces	Distance from Carpark (m)	Collected STP Parking Space Data	Collected FAS (Only LZ) Parking Space Data	STP Average Parking Time (Min)/Space	STP Average Parking Time (Min)/Event	FAS Average Parking Time (Min)/Space	FAS Average Parking Time (Min)/Event
NW	75	342.12	10	5	321.30	23.12	300.6	17.68
N	174	211.70	24	8	631.67	43.44	326.875	16.55
NE	116	325.75	6	2	740.33	63.46	631	37.12
W	86	294.97	18	3	666.72	33.90	366.33	17.17
C	25	0.00	9	6	474.89	46.97	493.5	24.88

As shown in Table 3, there is a non-homogeneous distribution of parking in the CBD in terms of parking limits and times across two major groups of parking spaces (STP and LZ of FAS). In this case, the centre section of the CBD has (i) the highest average FAS parking time per space and (ii) the second highest parking time per event for both FAS and STP parking. Although the northern section is the closest to the centre section of the CBD, it has the lowest FAS parking time per parking event and space. Furthermore, when the average parking time per space is compared across the range of several areas, the average STP parking time/event ranges from 23.12 min in the NW section to 63.46 min (Figure 4). Similarly, the highest average parking time of 37.12 min in FAS spaces (LZ) is also associated with the NE area/region.

As shown in Figure 5, it is interesting to note that both STP and FAS average parking times in the NW and N regions are shorter than those in the NE region. Based on this parking behaviour, increasing parking spaces and/or increasing limits on existing spaces in the northern section first, followed by the western section, could alleviate the current parking demand for the centre and thereby reduce congestion in the CBD.

Because the metropolitan city associated with this study is changing very rapidly with several infrastructure development projects and the planned demolition of two out of three multistorey carparks, parking assessment requires incorporation of these expected changes if the assessment is to be current and used to plan for future needs. To model various kerbside impact scenarios influenced and generated by these developments to plan for future kerbside demand, an analysis of kerbside parking demand using the baseline simulation model is presented next. Analysis of simulation modelling of impact scenarios is not presented here because it is beyond the scope of this research paper.

4.3. Analysis of Kerbside Parking Demand Using the Baseline Simulation Model

The baseline model captures the current (2019) kerbside parking demand in Parramatta CBD. Kerbside parking demand is modelled using model inputs and parameters including parking capacity, hourly arrival rates, and parking usage/dwell times of parking events derived from the camera dataset.

The traffic/parking baseline scenario simulation model is developed as a discrete-event simulation using hourly parking duration distributions, hourly parking arrival rates, and parking capacities as the main inputs. The kerbside parking logic of the simulation modelling of kerbside parking assumes two distinct routes of parking upon arrival and searching for parking for two minutes and leaving if a parking space is not available. The parking logic model with key events and associated paths is shown in Figure 6.

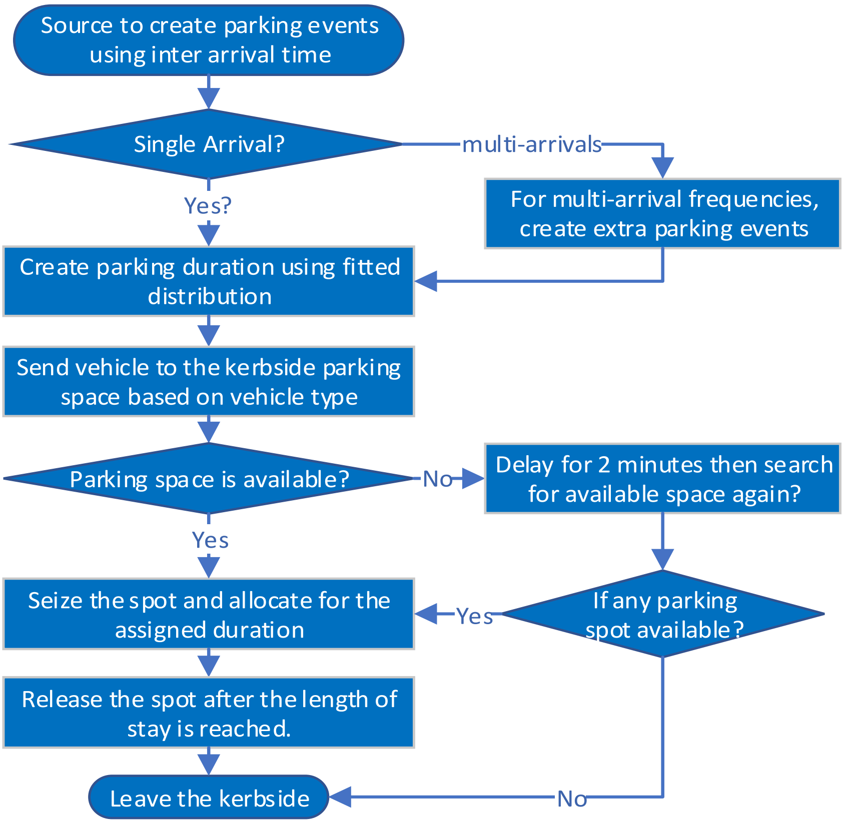

Figure 6. Kerbside parking logic model (Source: [50]).

The simulation modelling platform used is Flexsim [52], and the analysis of results was performed using MATLAB [53] and Microsoft Excel. The kerbside parking events and percentage of parking events reproduced by the baseline simulation model are shown in Figures 7 and 8, respectively.

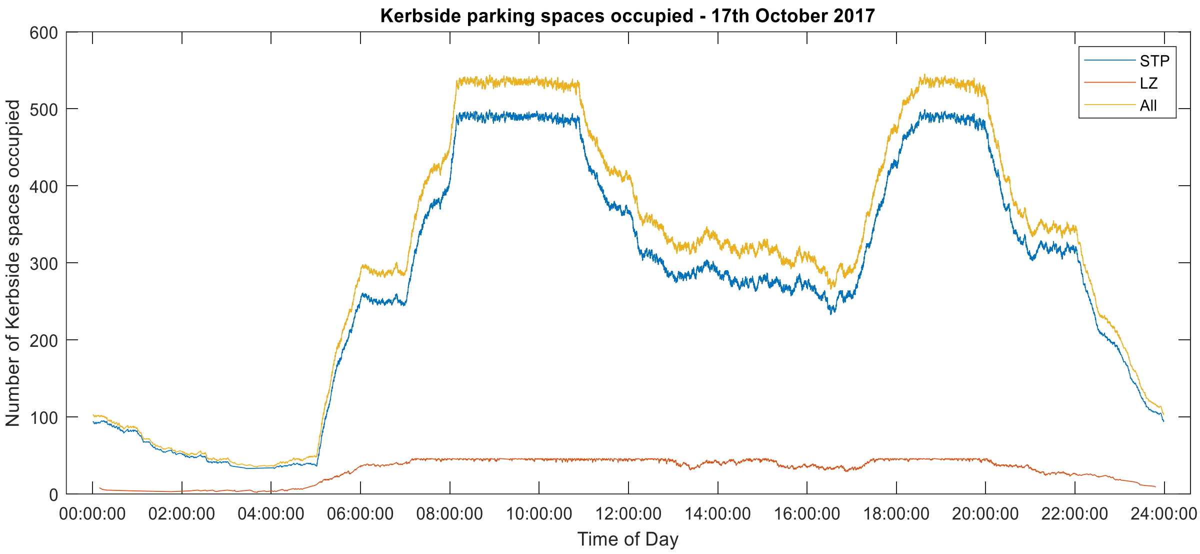

Figure 7. Kerbside parking events using the baseline simulation model (17 October 2017).

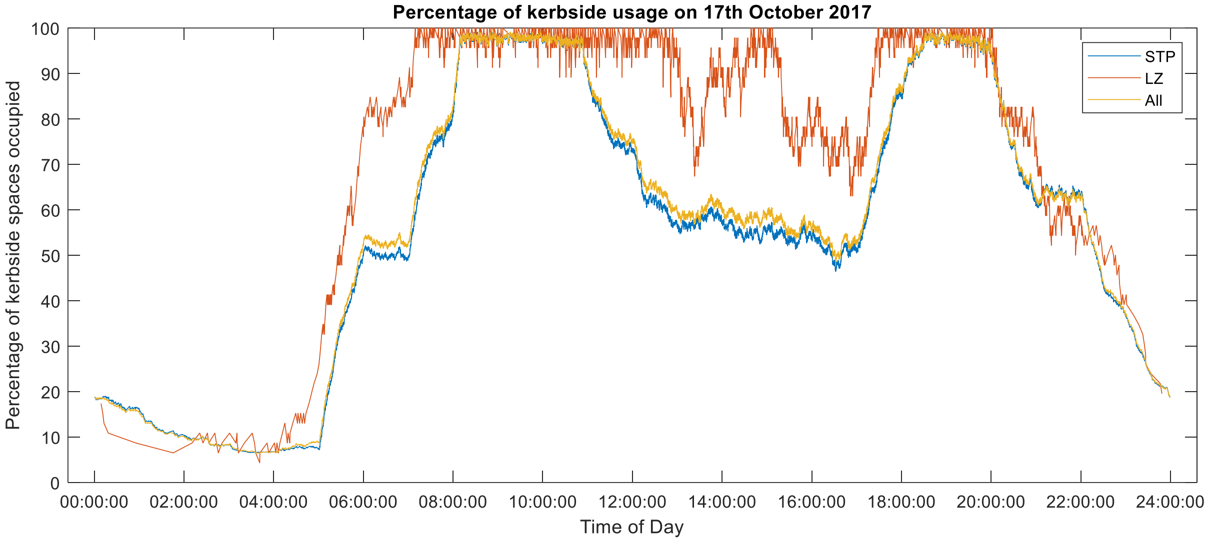

Figure 8. Percentage of kerbside parking events using the baseline model (17 October 2017).

As shown in Figures 7 and 8, kerbside parking reaches full capacity at two-time intervals (from around 8:08 a.m. to 10:54 a.m. and from 6:00 p.m. to 8:00 p.m. Because kerbside parking is expected to reach full usage over a considerable period during the peak period (7 a.m. to 4 p.m.) rather than spikes (just small peaks), the method used in the simulation modelling is more accurate. The baseline model was tested using data collected in 2019 to simulate impact scenarios (e.g., population growth and changes to parking infrastructure) and was found to be a reliable modelling approach to test current and expected changes to parking demand and supply [50].

Because the actual kerbside usage is closely reproduced by the baseline scenario simulation model using hourly arrivals and best-fit distributions of parking duration, with some variations (e.g., possible underestimation of usage) between parking usage using data analysis and simulation modelling, typical weekday usage is assumed, using the maximum usage of each hour. Kerbside usage during the week (16–20 October 2017) and usage of a typical day are shown in Appendix A. Because kerbside parking demand is closely reproduced by the baseline model using weekly data including a typical day, the baseline model can reliably be used to model future kerbside scenarios, incorporating various kerbside impact situations depending on assumed demand and capacity changes [50].

4.4. Analysis of Growth of Kerbside Parking Demand and Future Changes to Parking Capacity

Because expected changes are critical for the development of travel demand management strategies, all the expected changes are investigated as the basis for modelling future kerbside impact scenarios.

Key areas of changes to kerbside parking capacity and requirements are outlined in Section 2.4. Because expected future changes to capacity and requirements are critical inputs for the development of traffic/parking simulation modelling and the development of travel demand management strategies for stakeholders, a preliminary analysis of those changes is presented here. In this case, changes include increased demand due to population and construction growth and reduction in kerbside capacity due to light rail infrastructure development. The forecasted population growth in Parramatta CBD is shown in Table 4. The year-to-year demand growth for kerbside parking is projected using the population growth rate.

Table 4. Predicted population growth for Parramatta.

Year	2019	2020	2021	2022	2023	2024	2025
Population	260,130	266,763	273,565	280,541	287,695	295,031	302,555
Cumulative Growth	0%	2.55%	5.16%	7.85%	10.60%	13.42%	16.31%
Year-to-Year Demand Growth		2.55%	2.55%	2.55%	2.55%	2.55%	2.55%

The increase in freight and servicing activity is assumed to be 10–15% annually from 2019 to 2025, which is based on the actual growth in Sydney CBD from 2017 to 2019 [4]. Therefore, a 12.5% increase in demand due to freight and serving is assumed for each year. Although this assumed increase in demand could be adjusted for COVID, no adjustments were made to the future parking demand in the modelling/simulation, considering that construction largely continued through COVID.

Year-to-year parking demand growth due to construction worker growth for 2020–2025 is based on the information provided by Transport for NSW supported by the following guidelines and forecast growth forecast using historical data as reported in [50] and outlined below.

i. It is assumed that the current estimation of construction workers at one of the major infrastructure developments in Parramatta CBD labelled "Parramatta Square" (PSQ) using a ratio of workers to the construction area is reliable for estimating future construction worker demand growth, using development application (DA) approvals for 2020–2025;
ii. It is assumed that the construction worker forecast for 2018–2020 can reliably be estimated using DA approvals during the corresponding period;
iii. The construction worker forecast for 2021–2025 is based on exponential smoothing of historical Parramatta construction activities during the period of 2010–2018 and estimated values of construction workers during the period of 2019–2020 (available from Transport for NSW).

Based on the above assumptions, the construction worker forecast was developed for the period 2020–2025 and is shown in Table 5 and Figure 9. The developed year-to-year growth rate was used to predict the number of construction workers who may use the carpark if available.

Apart from changes to parking demand, it is expected that existing kerbside parking spaces will be reduced from 501 to 436 for STP and from 46 to 44 for LZ in 2020. Four kerbside impact scenarios taking into consideration all of the above changes of kerbside capacity and demand over the next 6-year period are difficult to comprehend without visualization of those impacts using a time scale for better understanding of key points (e.g., peak period(s), percentage of utilisation, and the transition to full usage with changes). Therefore, the impacts outlined above are modelled in the next stage of the research project based on the baseline model, the modelling details of which are not presented here because they are beyond the scope of this paper.

Table 5. Forecasted construction worker growth.

Year	2019	2020	2021	2022	2023	2024	2025
Construction Workers (Forecasted)	6690	5890	6135	6304	6452	6749	7037
Year-to-Year Growth	N/A	−11.96%	4.17%	2.75%	2.33%	4.61%	4.27%

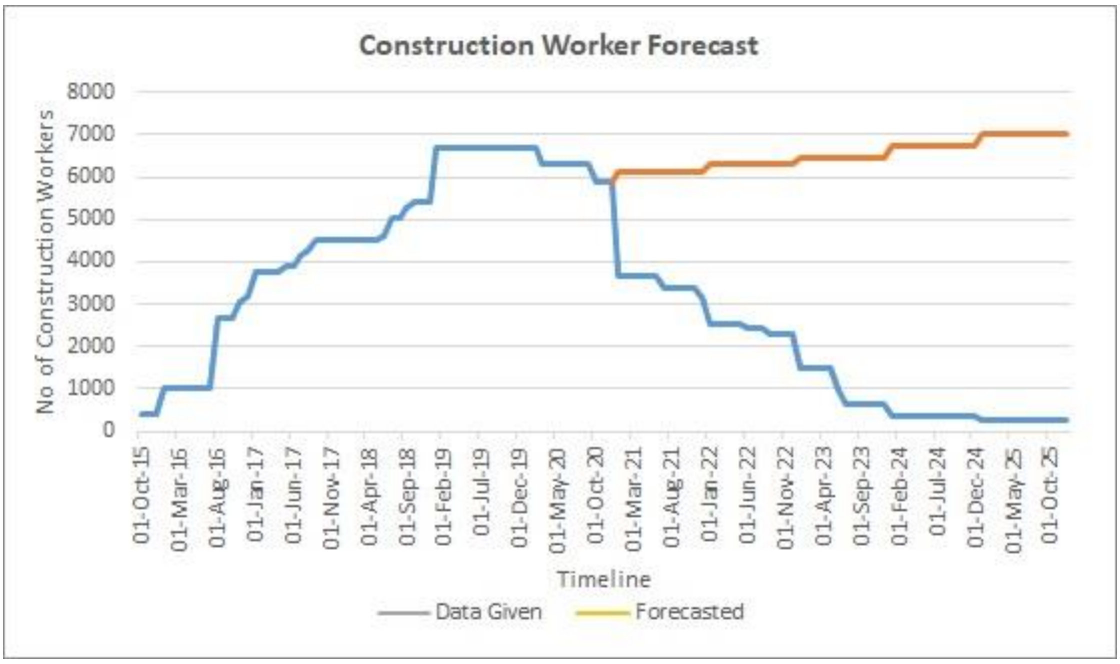

Figure 9. Construction worker forecast for 2021–2025. (Source: [50]).

5. Research Findings

5.1. Stage 1—Kerbside Assessment

The assessment is focused on providing evidence-based information on the current state of demand for kerbside parking for various activities for the planning of parking allocation in the future.

Analysis (estimation) of the capacity of parking zones (measured by both time availability and the allowable number of parking events) and evaluation of the actual number of events and length of stays during the consider period show that there is a spare capacity for short-term parking zones. In this case, the spare time capacity is around 27% of total short-term parking time (i.e., only around 74% of the total short-term parking time available during the considered period was used) based on the data for 2017. However, this spare capacity is expected to be reduced, given an expected increase in demand and changes to parking capacity, as evidenced by the testing of impact scenarios [50].

5.2. Stage 2: Results of the Baseline Simulation Model Replicating the Refined Camera Data

It was found that the baseline simulation model using camera data provides a reliable representation of current demand over the entire kerbside scope using a selected set of kerbside spaces based on camera data. Kerbside impact can easily be modelled using parking usage duration and hourly arrival distributions determined from the camera dataset.

5.3. Stage 3: Results of Future Kerbside Capacity and Demand Changes

The predicted growth of kerbside demand due to infrastructure development to support more employment and residents shows that overall parking behaviour will be significantly different, resulting in daily temporal patterns, patterns of freight-related kerbside utilisation, and changing peak/saturation periods. These expected demand patterns could impact business and the community broadly due to limited parking access, leading to loose demand among several users. Furthermore, COVID interruption exacerbate parking demands due office workers preferring to drive a private car rather than use public transport. Kerbside impacts over the next six years are expected be widespread in terms of overall kerbside utilisation, peak periods, and saturation periods. This suggests that kerbside impact scenarios influenced/generated by such changes need to be investigated from the point of view of planning for future travel demand management strategies within a broader urban city infrastructure development planning framework. Therefore, the baseline model can be used as the basis to simulate all these impact scenarios by incorporating the growth and expected changes using key measures.

6. Findings, Discussion, and Conclusions

Kerbside parking assessment using a comprehensive camera dataset provides an opportunity for a better understanding of current parking behaviour in terms of peak demand and distribution of parking utilisation in different parking categories on weekdays. Results show that current kerbside parking capacity can meet the overall captured current demand with different utilisation of demand in a range of capacities of FAS and STP categories. However, the captured demand does not include the potential demand (e.g., searching for parking) not captured during full-capacity utilisation (e.g., peak periods) and potential demand increase due to the increasing construction workforce. Furthermore, peak periods, the profile of capacity utilisation by various loads and kerbside categories, and saturation periods are identified as key indicators of kerbside parking assessment for both the baseline and impact scenarios, which transport infrastructure planners can use to develop policies and travel demand management strategies. Peak periods, segmenting of demand, capacity utilisation profile, and saturation periods are critical measures from the perspective of economic analysis of parking assessment towards the development of policies, as reported in similar studies [3,7,20].

Modelling and simulation of current demand/utilisation using a comprehensive camera dataset were found to be a reliable approach for modelling and simulation of future impact scenarios, in particular kerbside impact from the perspective of saturation times over a 6-year period, taking into consideration all the factors affecting kerbside parking capacity and utilisation. Furthermore, kerbside parking assessment can be used to develop recommendations for travel demand management strategies, providing guidelines for several stakeholders in the metropolitan city considered in this research.

Modelling and simulation of kerbside parking demand and supply under dynamic conditions is a very effective approach for urban parking evaluation and policy assessment, as evidenced in some recent studies, including estimating the effectiveness of planned parking facilities under different development scenarios [20] and predicting parking utilisation/behaviour influenced by several factors, such as parking price and needs (e.g., desire to park for a long time) [24]. Furthermore, full-capacity utilisation at three time periods (accounting for 7 h between 8 a.m. and 8 p.m.) can have a direct impact on increased traffic volumes at peak times, partly caused by cruising for parking. Therefore, cruising for parking to evaluate unnoticed demand should be incorporated as part of future research studies to make parking assessment more realistic and consider all sustainability aspects. It is evident from previous research studies that cruising for parking contributes to other adverse outcomes, such as traffic congestion, increased air pollution, and accidents [24].

Overall, this research study provides evidence-based information on the current state of demand for kerbside parking, highlighting varying utilisation of demand in a range of capacities. This emphasises the need for more information campaigns on parking priorities and alternative options for parking (e.g., off-street parking around the CBD) as an integral part of planning for future infrastructure projects in Parramatta CBD.

Although the current kerbside capacity meets the overall captured demand, excluding potential demand above the full capacity and any demand increase due to the construction workforce, further analysis is required to determine whether utilisation is within the allocated time limits by testing the significance of the difference between the actual average length of stay and allocated time using an appropriate statistical test(s) (e.g., ANOVA or *t*-test). It is expected that a statistical test of the difference between the recorded average length of stay and allocated times of respective short-term parking will show a significant difference between these two sets of data. Similarly, differences between the actual length of stay and allocated times of other short-term parking zones can also be carried out using statistical testing as required.

In this research study, we identified potential improvements to the methodology, including improving candidate selection process (for manual data collection) using appropriate selection criteria, training of selected candidates by incorporating on-site training/pilot data collection, and monitoring of the data collection process with additional resources and quality assurance methods.

Future research directions include an extension of the baseline simulation model with future impact scenarios, taking into consideration future expected changes to parking infrastructure and demand growth, particularly demand impacted by the planned construction activities in Parramatta CBD and exacerbated parking demands due to people preferring to drive a private car rather than use public transport post COVID. Furthermore, parking assessment needs to consider not only the parking demand and supply but also the necessity to "plan for car-free cities", making space for people and vehicles that really need to be there (e.g., freight activity). However, achieving economically sound solutions to minimise the gap between demand and supply would be challenging while aiming for sustainable mobility principles with social benefits. Furthermore, in the examination of FAS, it can be determined that the substitution factor is lower and hence demand is less realistic. The current investigation is limited to lower substitution factors; therefore, future studies should consider different elasticities and substitutable moves, particularly when considering sustainable mobility principles. In this context, it is critical that modelling/simulation of impact scenarios incorporate all the key indicators, including economic factors and social conditions, and evaluate their interdependencies as a basis for development of travel demand management strategies and guidelines for broader stakeholders. However, the potential impact on parking demand due to COVID-19 interruption, particularly people preferring to drive rather than use public transport, is not incorporated into the current impact scenarios. Therefore, future work needs to consider these factors when modelling impact scenarios. Modelling and simulation of future impact scenarios can be used to provide guidelines for the development of travel demand management strategies to manage the rapidly changing and transforming infrastructure and demand landscape in Parramatta CBD, as influenced by several factors. Furthermore, simulation modelling of impact scenarios can be used to guide policymakers with the required information to address environmental and economic impacts due to vehicles searching for parking [38].

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Kerbside usage during the week (16–20 October 2017) and usage of a typical day (a sample of parking events in 39 parking spaces (31 STP and 8 LZ)).

Hour of Day	STP							LZ						
	16th	17th	18th	19th	20th	Typical Day	Max Capacity	16th	17th	18th	19th	20th	Typical Day	Max Capacity
0	1	2	2	4	1	4	31	0	1	0	0	0	1	8
1	0	2	2	3	1	3	31	0	0	0	0	0	0	8
2	0	3	2	1	0	3	31	0	0	0	0	0	0	8
3	1	2	3	0	1	3	31	0	1	1	0	2	2	8
4	2	3	2	2	3	3	31	0	1	0	0	0	1	8
5	13	19	14	14	12	19	31	2	6	3	3	4	6	8
6	22	22	15	15	21	22	31	3	4	1	3	4	4	8
7	14	17	16	12	15	17	31	2	1	3	3	1	3	8
8	20	23	24	17	22	24	31	4	4	2	3	0	4	8
9	25	30	29	20	29	30	31	6	3	5	4	4	6	8
10	22	22	30	22	30	30	31	6	6	5	5	5	6	8
11	25	28	27	21	25	28	31	6	3	3	6	6	6	8
12	21	31	27	22	31	31	31	5	4	4	4	4	5	8
13	24	28	28	17	29	29	31	7	2	3	2	6	7	8
14	31	27	26	19	26	31	31	6	6	4	5	5	6	8
15	25	23	22	20	28	28	31	4	4	2	0	5	5	8
16	22	18	18	18	16	22	31	6	2	3	5	4	6	8
17	22	24	11	14	18	24	31	5	4	3	3	3	5	8
18	29	22	25	10	25	29	31	7	4	4	3	5	7	8
19	28	29	25	11	27	29	31	7	5	4	3	4	7	8
20	27	20	22	9	28	28	31	5	5	2	3	3	5	8
21	18	14	13	7	24	24	31	3	2	3	1	1	3	8
22	10	8	5	3	10	10	31	1	3	2	2	1	3	8
23	6	0	6	1	8	8	31	1	0	0	0	0	1	8

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