DEVELOPMENT OF A SHARED PARKING MODEL FOR MIXED USE DEVELOPMENTS IN THE SOUTH AFRICAN DEVELOPMENT LANDSCAPE

J SCHEEPERS and C VENTER*

Novus3 (Pty) Ltd, Postnet Suite 406, Private Bag X025, Lynnwood Ridge, 0040
Tel: +27 12 364-2546; Email: jamess@novus3.co.za
*University of Pretoria, Centre of Transport Development / Department of Civil Engineering, Pretoria, 0002, South Africa
Tel: +27 12 420-2184; Email: christo.venter@up.ac.za

ABSTRACT

Worldwide, parking provision is required at minimum rates typically prescribed by municipal ordinances or in national policy documents. Litman (2011) argues that inherent problems with **minimum parking requirements**, their predictive variables, demand ratio estimation processes and the application of dated parking standards within an ever-changing development landscape typically **results in** the **oversupply of parking**.

In the South African context, minimum parking rates are specified in the South African Parking Standards – 2nd Edition (Van Zyl et al., 1985). The development landscape throughout the world and in South Africa has changed dramatically over the past decades, and research of Hitge and Roodt (2006) concluded that "current South African parking standards do not support current land use and transport policies [and that] policy of providing parking at a minimum rate [has limited application] and should be revised". One specific trend has been an increase in mixed-use developments, which raises the potential for sharing parking between land uses with different peaking characteristics. However more information is needed on both the demand and supply characteristics of parking in this context, if more rational planning is to result.

The aim of this research is to investigate the development of a new method of shared parking demand estimation, by assimilating best practice shared parking model components from international literature, and to test the shared parking model by systematically adjusting conventional parking parameters according to shared parking principles to parking demand for high-density, mixed use developments within a South African context case study.

1. INTRODUCTION

1.1 Background

Parking is a critical, but often ignored, element in the transport system. The act of travelling (trip making) and the mode of travelling (mode choice) often dominate the focus of transportation system studies, with the trip ends (parking) and particularly their associated cost, being ignored. However, the availability and accessibility of parking often strongly influence private transport system users' decision to undertake a trip in the first place as well as the mode choice for that trip – or as Manville and Shoup (2005) suggest, parking is a ubiquitous entity which is only noticed when it is absent.

Worldwide, parking provision is required at minimum rates typically prescribed by municipal ordinances or in national policy documents, which prescribe the minimum number of parking bays that must be supplied by a development for each land-use type (expressed in terms of some predictive demand-side or supply-side variable such as Gross Leasable Area (GLA), number of seats, occupied rooms etc.). In the South African context, these rates are specified in the South African Parking Standards – 2nd Edition policy document (Van Zyl et al., 1985) which is echoed by the requirements and policy documents of local authorities throughout the country.

The development landscape throughout the world has changed dramatically over the past decades and Litman (2011) argues that inherent problems with **minimum parking requirements**, their predictive variables, demand ratio estimation processes and the application of dated parking standards within an ever-changing development landscape typically **results in** the **oversupply of parking**. Similar South African research by Hitge and Roodt (2006) concluded that "current South African parking standards do not support current land use and transport policies [and that] policy of providing **parking at a minimum rate** [has limited application] and **should be revised**".

Given the changes in the global and domestic development landscapes, it is evident that the approach and guidelines governing parking provision are no longer adequate to respond to a changing development reality and one could argue that there is a growing 'disconnect' between the standards governing parking provision today and the demand for parking driven by ever changing user needs.

The extent of this 'disconnect' or disparity is difficult to determine as parking demand changes from single-purpose to multi-purpose parking demand; however, it is clear that a new approach to parking demand estimation and parking provision is needed to respond to the changing development landscape. Litman (2009) suggests that shared parking schemes could reduce the parking requirements of mixed use developments by 10 to 30%, provided that shared parking schemes are applied alongside other parking management strategies, whereas **shared parking** applied in isolation could account for **10% reduction** in **parking requirements**.

1.2 Aim of the paper

The aim of this research study is to investigate the development of a new method of parking demand estimation, by assimilating best practice shared parking model components from international literature, and to test the shared parking model by systematically adjusting conventional parking parameters according to shared parking principles to parking demand for high-density, mixed use developments within a South African context case study.
This new method of parking demand estimation will draw on international best practice shared parking methodologies employed as demand management strategies in mixed-use land-use districts where different land-uses exhibit complementary parking demand profiles across the day.

1.3 Research Objectives

This research has the following specific objectives:

- Identifying locally applicable variables which influence parking supply and demand within high-density mixed-use developments with a view towards development or assimilation of a parking demand estimation model.

- Adapting and assimilating existing mathematical models for estimating parking demand of high-density mixed-use developments, by including variables not commonly considered during parking demand estimation calculations.

- Measuring the extent of multi-use trip making and the nature of trip chains within the case study development with a view to estimating single-use and multi-use parking adjustment factors as part of calibrating the mathematical model for estimating parking demand of high-density mixed-use developments.

- Testing the models ability to estimate parking demand at high-density mixed-use developments and quantifying the over-supply of parking based on the application of minimum parking rates predicted by conventional parking demand estimation techniques for a case study area.

2. DOMESTIC AND INTERNATIONAL ADVANCEMENTS IN PARKING ESTIMATION METHODS

Advancements have been made both domestically and internationally to adjust for multi-purpose trips associated with mixed-use development, as well as the phenomenon of shared parking at mixed-use development where certain land-use parking demand profiles offer the opportunity to share parking space during different times of the day.

2.1 South African Committee of Transport Officials (COTO)

The South African Committee of Transport Officials has in recent years developed a number of policy documents aimed at developing a uniform set of requirements, uniform approaches and uniform data sets for municipalities and road authorities in South Africa to undertake and evaluate Traffic Impact Assessments (TIA) and Site Traffic Assessments (STA) throughout the country, namely:

- National Policy for Traffic Impact Assessments and Site Traffic Assessments in South Africa (Version 0.02), 2009 (Draft)

- Trip Data Manual (TMH17, Volume 1.), 2012 (Final Draft)

Both these documents introduce the concept of mixed-use developments into their calculations, thereby recognizing that these types of development have different trip generation and parking demand characteristics. The National policy on TIAs and STAs states in paragraph 14.3.3 that parking requirements may be reduced (but not overstated) for factors such as low vehicle ownership, transit availability and shared parking and continues in paragraph 14.3.4 by stating that parking may also be reduced in multi-use developments when the peak parking demand for the different land-uses occurs at different hours or days of the week and parking can be shared between different developments.

2.2 United States of America Urban Land Institute (ULI)

The ULI Urban Development / Mixed-use Council first recognized the need to a study on the shared-parking phenomenon in 1981. The need for the study emanated from preliminary observations at mixed-use or multiuse developments that a combination of land-uses required less parking space than the same land-uses in freestanding locations.

The first edition of the Shared Parking Study released in 1983, yielded the following information for each of the 161 development projects observed:

- Peak parking demand factors

- Hourly accumulation of parked vehicles (time differentials)

- Seasonal variations

The second edition of the Shared Parking Study offered a number of improvements in the shared parking estimation model (Smith, 2005):

- Data on a more complex mix of different potential land-uses that could be combined at mixed-use developments.

- Separate parking ratios for visitor and customer parking, employee and resident parking, as well as reserved parking.

- Hourly parking accumulation was also delineated into weekday and weekend periods with weekdays defined from Monday at 06:00 to Friday at 17:00 and weekends from Friday evening (after 17:00), all day Saturday.

2.3 Shared Parking Turn-time Model (SPaTT)

The Shared Parking Turn-Time system was adopted from the AUCoP model, which is an acronym for "Available, under construction, completed and planned [parking] space" and was implemented in Malaysia as a mechanism for parking demand management, whereby members of the public who wish to access busy commercial and services zones where limited parking is provided, need to share parking on a rotational basis (Iman, 2006). The SPaTT model seeks to achieve parking supply-demand equilibrium using a systematic mathematical framework (quantitative techniques) and geographic information (spatial analytical techniques) to identify areas where the parking space imbalances occur.

The parking space equilibrium concept of the SPaTT model hinges on the spatial mobility of parking choice, which presupposes that insufficient parking space at one point can be compensated by additional parking space at another points within conveniently accessible parking zones in respect to the intended point of destination.

3. ASSIMILATION OF A SHARED PARKING MODEL FOR THE SOUTH AFRICAN LANDSCAPE

The rationale of shared parking models is therefore to systematically adjust (reduce) parking rates to account for multiple business visits or multi-use trips for customers for each car trip to a centre or mixed use land use development as well as adjusting for variations in the accumulation of vehicles by hour, by day or by season at the individual land uses, as all land uses do not have the same parking demand profile throughout the day or throughout the year.

Assessment of the structure and application examples of each of these models has indicated that there is a fair degree of overlap between them, as they share a number of parameters and adjustment factors by which systematic reduction of parking demand is achieved. Each model does however have unique parameters and adjustment factors which have merit, which have been combined into a new shared parking model here named the **"Non-Captive Turn-time Time Period Utilisation Adjusted"** shared parking model (**$NC_{TT}TP_{UA}$** shared-parking model).

In order to understand the $NC_{TT}TP_{UA}$ model and the unique elements which have been assimilated to create this more comprehensive approach to shared parking estimation, a process flow diagram was developed to identify the various model parameters (refer to

Figure 1). Based on the above process flow, the following steps are required to calculate a more balanced parking supply and demand based on the $NC_{TT}TP_{UA}$ shared-parking model:

- Step 1: Determine Land use Mix / Composition
- Step 2: Determine the Predictive Variables per Land use Type
- Step 3: Estimate or Survey Parking Supply
- Step 4: Determine Daily Person Trip Rate per Land use
- Step 5: Calculate Maximum or Peak Hour Employees and Customers per Land-use
- Step 7: Calculate (observed) Day of Week and Time of Day Adjustments
- Step 8: Land Use Occupancy Rate Adjustment (Only required for developments in ramp-up phase)
- Step 9: Calculate the Car Ownership Population for Employees and Customers per Land use
- Step 10: Peak Hour Employees and Customers Car Sharing Adjustment
- Step 11: Non-Captive (Customer) Short Stay Single- and Multi-use Trip Turn-time Adjustment
- Step 13: Calculate the Total Development Parking Space Demand
- Step 14: Shared Parking Demand Reduction Assessment

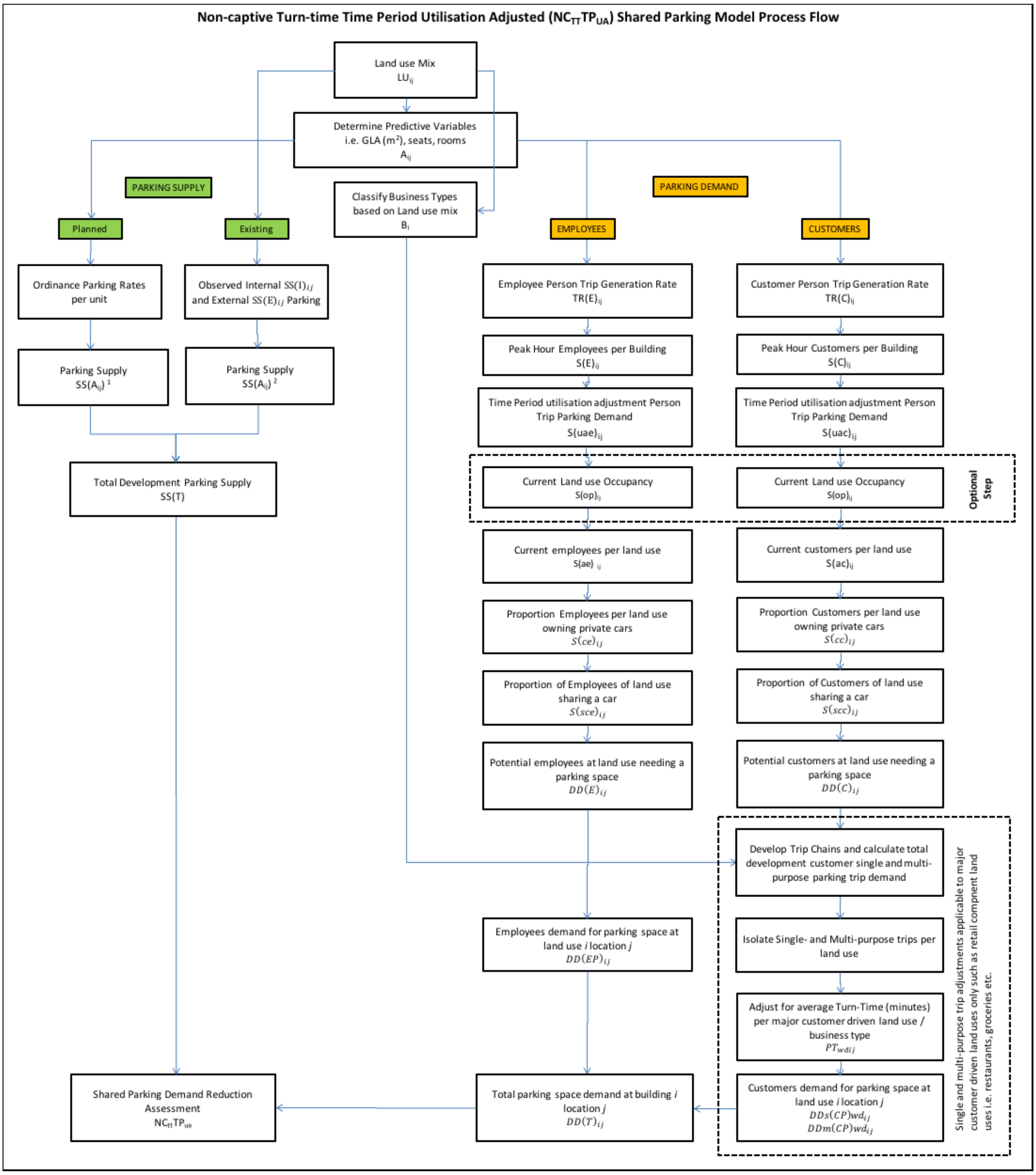


Figure 3-1: NC$_{TT}$TP$_{UA}$ Shared-Parking Model Process Map

Shared parking demand reduction represents the total number of parking spaces which can be eliminated from the development or precinct given that all parking spaces in the calculation are accessible to everyone and that no exclusive use or reserved parking is included in the NC$_{TT}$TP$_{UA}$ shared parking model calculation. A comprehensive overview of the method is provided in Scheepers (2016).

4. CASE STUDY

4.1 Site Selection

In order to test the proof of concept of the $NC_{TT}TP_{UA}$ shared parking model, the Lynnwood Bridge development, developed by the Atterbury Property Group, was selected as a case study development exhibiting mixed-use high density land-use. The following primary land use categories are located within the precinct:

- Banks, Building Societies
- Gymnasium
- Hotel
- Neighbourhood / Local Convenience Stores
- Offices (General Offices)
- Places of refreshment / Restaurants
- Retail / Shops
- Social Hall / Theatre

The following section will demonstrate the practical application of the $NC_{TT}TP_{UA}$ shared parking model and the empirically researched model parameters within the Lynnwood Bridge case study environment.

4.2 Parking Supply Assessment

Development parking supply was calculated in two ways, namely by counting the number of parking bays indicated on the parking layout plans, which were sourced from the developer / owner , and by applying the minimum parking rates as per the City of Tshwane Ordinance to the various predictive variables to calculate the parking supply.

Table 1: Parking Bay Provision for Lynnwood Bridge Development

Parking Level	**Offices**		**Hotel**		**Retail**		**Total Development**	
Bay Classification	Std	Dsbl	Std	Dsbl	Std	Dsbl	Std	Dsbl
Total Bays	1376	21	141	2	625	8	2142	31

Note: *Std = Standard Parking Bays; Dsbl = Disabled Parking Bays (Reserved bays)*

The ordinance parking supply requirements of the development can be calculated by applying the minimum parking rates to the independent or predictive variables (i.e. GLA, number of seats and number of beds).

Table 2: Ordinance Parking Supply Requirements calculated by means of Minimum Parking Rates

Land use (LU_{ij})	Ordinance Parking Ratio	Rate	Total GLA m^2	Rooms / Seats	%	*Ordinance Parking Supply $SS(A_{ij})_1$	Observed Reserved Parking	Observed Non-reserved Parking Supply $SS(A_{ij})_2$
Retail / Shops	4 bays / $100m^2$ GLA	4	4,614	N/A	10%	185	8	625
Places of refreshment / Restaurants**	0.5 bays / seat	0.5	2,499	1362	6%	681		
Neighbourhood / Local Convenience	4 bays / $100m^2$ GLA	4	1,721	N/A	4%	69		
Banks, Building Societies	4 bays / $100m^2$ GLA	4	15	N/A	0%	1		
Gymnasium / Health Club	8 bays / $100m^2$ GLA	8	2,244	N/A	5%	180		
Social Hall / Theatre**	11 bays / $100m^2$ GLA	11	724	400	2%	80		
Office Block (General Offices)	4 bays / $100m^2$ GLA	4	32,504	N/A	73%	1,300	21	1376
Hotel (Business)***	0.67 bays / room	0.67	N/A	205	N/A	137	2	141
TOTAL						2,633	31	2,142

Notes:
** denotes that parking ratios and minimum parking rates were sourced from the City Council of Pretoria, Guidelines on Parking Requirements for the Pretoria Area (November 2004)*
*** Minimum parking rate predictive variable based on number of seats of the place of refreshment or restaurant*
**** Minimum parking rate predictive variable based on number of rooms in the hotel*

It is evident from the tables above that the development is slightly over-supplied with parking with respect to the office and hotel land uses. However, the retail land use component, and the development as a whole, appears to be undersupplied based on the calculation methodology and minimum parking rates per land use category as provided for in the city council ordinance.

4.3 Person Trip Rates and Peak Hour Factor Rates per Land use

The person trip rate is defined as the number of person trips generated by land use per predictive variable (typically Gross Leasable Area (m^2)). The peak hour factor rate is the rate by which the daily person trips are factored down to reflect the maximum or peak person trip demand for a development.

Within the South African environment, person trip rates (whether daily or peak hour) are not readily available for land-uses as vehicle trip generation rates are more commonly used for traffic impact determination. Vehicle trip rates can be used as a proxy for person trip rates by applying a vehicle occupancy factor to the daily vehicle trip rate.

Given the lack of person trip rates in South Africa, the most recent vehicle trip rates from the TRH17 South African Trip Data Manual (Committee of Transport Officials (COTO), 2012) was used for the various land use categories for Lynnwood Bridge in order to estimate the daily and peak hour person trips for each land use category.

The $NC_{TT}TP_{UA}$ shared parking model requires person trips to be estimated for both employees and customers of each land use as the parking demands of these two segments are considered separately in the model. Given that vehicle trip rates are not provided according to these segments, best practice assumptions were made to calculate these values.

Table 3: Vehicle Trip Rates per Land Use Category for Lynnwood Bridge Development

						$AADT_D$	**F_{QD}**	**F_{QD} x $AADT_D$**	
Land use (LU_{ij})	**Class**	**Total GLA m^2**	**Rooms / Seats**	**Ratio***	**Land use Code**	**Employees and Customers**			**Unit**
Retail / Shops	Retail	4,614	N/A	1 : 5	820	35.00	0.085	2.98	/100m^2 GLA
Places of refreshment / Restaurants	Retail	2,499	1,362	1 : 12	932	140.00	0.100	14.00	/100m^2 GLA
Neighbourhood / Local Convenience	Retail	1,721	N/A	1 : 15	820	35.00	0.085	2.98	/100m^2 GLA
Banks, Building Societies	Retail	15	N/A	N/A	N/A	2.00	0.150	0.30	/m^2 GLA
Gymnasium / Health Club	Retail	2,244	N/A	1 : 20	492	32.50	0.300	9.75	/100m^2 GLA
Social Hall / Theatre	Retail	724	400	1 : 20	780	1.00	0.300	0.30	/seat
Office Block (General Offices)	Office	32,504	N/A	10 : 1	710	8.50	0.250	2.13	/100m^2 GLA
Hotel (Business)	Hotel	N/A	205	1 : 7	310	3.25	0.150	0.49	/ room

Source: Committee of Transport Officials (COTO), 2012. TMH17 Vol 1 South African Trip Data Manual, Pretoria: South African National Roads Agency Limited (SANRAL).
Notes:
$AADT_D$ denotes the average annual daily vehicle trip rate per land use category
F_{QD} denotes the peak hour rate factor which converts daily vehicle trips to peak hour trip
** Ratio refers to the Employee-Customer ratio*

4.4 Maximum Employee and Customer Person Trips per Land-use

The maximum employee and customer person trips generated by each land use over a daily period is typically calculated by applying the person trip rates to the predictive variables for various land use categories.

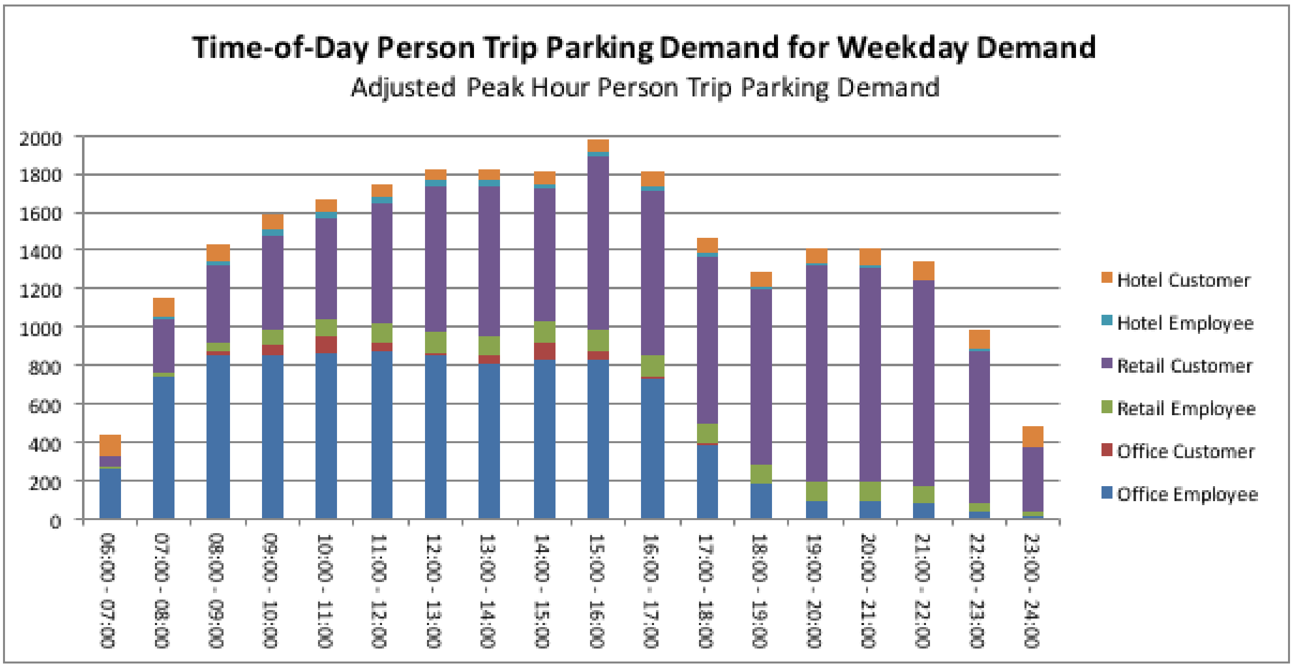
Table 4: Maximum Peak Hour Employee and Customer Person Trips per Land use for Lynnwood Bridge

					Daily Trips AADT Split (vehicle trips)		**Peak Hour Trips Split (vehicle trips)**		**Peak Hour Trips Split (person trips)**	
Land use (LU_{ij})	Class	Total GLA m^2	Rooms / Seats	Ratio	Employees	Customers	Employees	Customers	Employees	Customers
Retail / Shops	Retail	4,614	N/A	1 : 5	323	1,292	27	110	38	154
Places of refreshment / Restaurants	Retail	2,499	1,362	1 : 12	292	3,207	29	321	41	449
Neighbourhood / Local Convenience	Retail	1,721	N/A	1 : 15	40	562	3	48	5	67
Banks, Building Societies	Retail	15	N/A	N/A	N/A	30	N/A	5	N/A	6
Gymnasium / Health Club	Retail	2,244	N/A	1 : 20	36	693	11	208	15	291
Social Hall / Theatre	Retail	724	400	1 : 20	20	380	6	114	8	160
Office Block (General Offices)	Office	32,504	N/A	10 : 1	2,487	276	622	69	870	97
Hotel (Business)	Hotel	N/A	205	1 : 7	133	533	20	80	28	112
	Total				**3,331**	**6,973**	**719**	**954**	**1,006**	**1,335**

It is evident from the table above that the development is dominated by restaurant and convenience stores from a customer perspective and dominated by offices from an employee perspective.

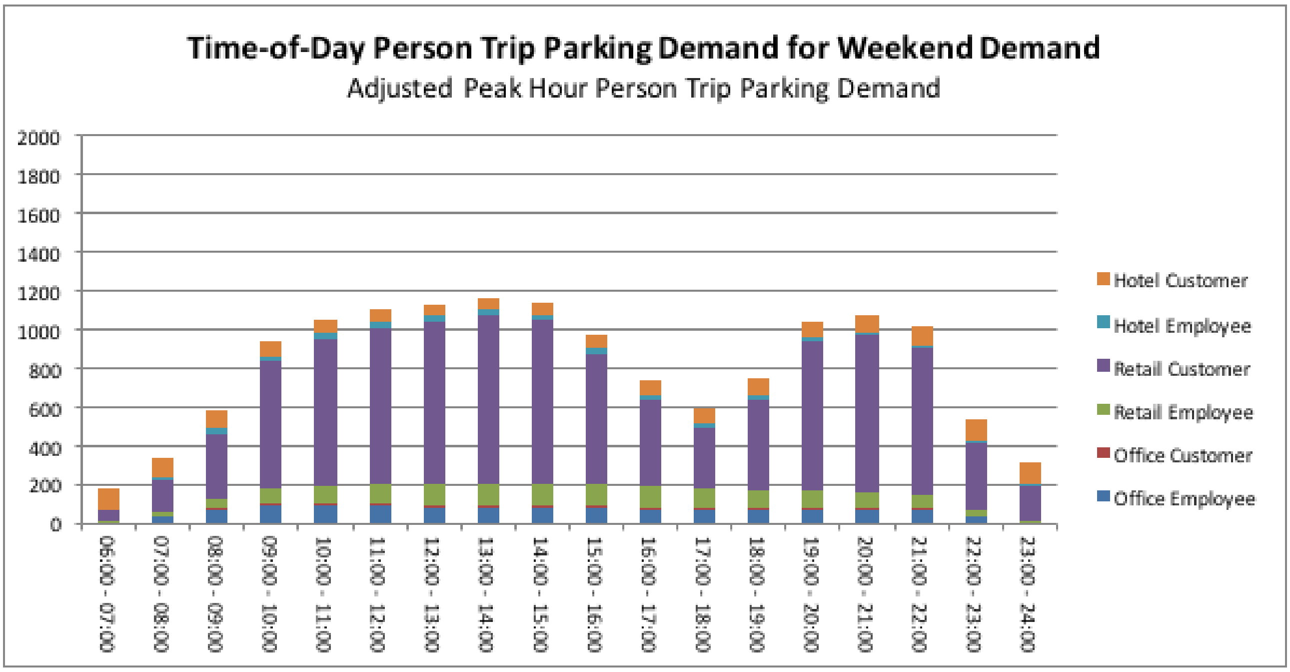
4.5 Day of Week and Time of Day Utilisation Adjustment

As demonstrated by the ULI Shared Parking Model (Smith, 2005), time of day (as well as day of week and month of year) variations in parking demand is by far the most significant determinant of potential shared parking. Given that the parking utilisation surveys for this research was only undertaken over a limited period of time, only day of week (i.e. weekday or weekend) and time of day adjustments profiles were developed for each land use category for the $NC_{TT}TP_{UA}$ shared parking model, in order to identify the critical peak period of parking demand of the development.



Notes: *The weekday and weekend time of day parking utilisation adjustment tables calculated from observed utilisation values during Lynnwood Bridge parking utilisation survey and adapted from Smith, Mary S. Shared Parking (2005), is available in the full research paper.*

Figure 4-1: Weekday Time of Day Adjusted Person Trip Parking Demand per Land use



Notes: *The weekday and weekend time of day parking utilisation adjustment tables calculated from observed utilisation values during Lynnwood Bridge parking utilisation survey and adapted from Smith, Mary S. Shared Parking (2005), is available in the full research paper.*

Figure 4-2: Weekend Time of Day Adjusted Person Trip Parking Demand per Land use

The critical analysis period was then selected based on the composite highest parking demand scenario. It should be noted that the critical peak demand analysis period does not necessarily mean that all land uses are at their maximum parking demand time period. Given that some land use parking demands may peak when others are low means that one should identify the highest combined parking demand across all land uses in the development.

Time of day adjustments for employees and customers were calculated by adjusting time periods (typically expressed in hourly intervals) throughout the day against the maximum observed parking demand for each type of land use. This would result in the maximum of peak demand time period reflecting 100% of parking demand and all other parking demand time periods reflecting a percentage relative to this maximum.

It is evident from the graphs that the weekday peak person trip parking demand analysis period is from 15:00 to 16:00 and the weekend peak person trip parking demand analysis period is from 13:00 to 14:00.

Table 5: Weekday Adjusted Peak Period Parking Requirements

Weekday Peak Period		**15:00 - 16:00**					
Class	**Segment**	**Unadjusted Peak Hour Parking Demand (Person Trips)**	**Adjusted Peak Hour Parking Demand (Person Trips) $S(uae)_{ij}$ $S(uac)_{ij}$**	**Mode Choice / Car Ownership**	**Extent of Population Owning a Car $S(c)_{ij}$**	**Car Sharing / Occupancy S(cp)**	**Potential Vehicles Needing Parking $DD(E)_{ij}$ $DD(C)_{ij}$**
Office	Employee	871	836	95%	795	1	795
Office	Customer	97	44	100%	44	1	44
Retail	Employee	108	108	70%	76	1	76
Retail	Customer	1,127	897	100%	897	1	897
Hotel	Employee	28	28	70%	20	1	20
Hotel	Customer	112	68	80%	55	1	55
Total	Both	2,343	1,981		1,887		1,887
% Reduction			15%		5%		0%

Table 6: Weekend Adjusted Peak Period Parking Requirements adjusted for Car Ownership and Car Sharing

Weekend Peak Period		**13:00 - 14:00**					
Class	**Segment**	**Unadjusted Peak Hour Parking Demand (Person Trips)**	**Adjusted Peak Hour Parking Demand (Person Trips) $S(uae)_{ij}$ $S(uac)_{ij}$**	**Mode Choice / Car Ownership**	**Extent of Population Owning a Car S(c)ij**	**Car Sharing / Occupancy S(cp)**	**Potential Vehicles Needing Parking DD(E)ij DD(C)ij**
Office	Employee	871	83	95%	79	1	79
Office	Customer	97	10	100%	10	1	10

Weekend Peak Period		**13:00 - 14:00**					
Class	**Segment**	**Unadjusted Peak Hour Parking Demand (Person Trips)**	**Adjusted Peak Hour Parking Demand (Person Trips) $S(uae)_{ij}$ $S(uac)_{ij}$**	**Mode Choice / Car Ownership**	**Extent of Population Owning a Car S(c)ij**	**Car Sharing / Occupancy S(cp)**	**Potential Vehicles Needing Parking DD(E)ij DD(C)ij**
Retail	Employee	108	108	70%	76	1	76
Retail	Customer	1,127	874	100%	874	1	874
Hotel	Employee	28	28	70%	20	1	20
Hotel	Customer	112	62	80%	50	1	50
Total	Both	2,343	1,165		1,109		1,109
% Reduction			50%		5%		0%

It is evident from the table above that the time of day adjustment has reduced person trip parking demand by 15% from 2,343 person trips to 1,981. The weekend time of day adjustment was much more pronounced, given that the majority of office land uses do not conduct business over the weekend, resulting in weekend person trip parking demand reducing by 50% from 2,343 person trips to 1,165.

4.6 Alternative Mode, Car Ownership and Car Occupancy Adjustments

Parking demand is further affected by the propensity of using alternative modes, car ownership, and car occupancy figures. The demand surveys undertaken for this study provided some information on mode splits, which was used in Tables 5 and 6, but this is largely for illustration purposes as more reliable data is needed. The net effect was a downward adjustment of the total development car owning population (and consequently the parking demand) by approximately 5% for both weekday and weekend periods.

4.7 Turn-time Adjusted Customer Parking Demand

Another important aspect of parking demand is the duration of stay, as land uses generating short duration trips can use their parking bays more efficiently by accommodating more trips per hour per parking bay. The $NC_{TT}TP_{UA}$ shared parking model makes adjustments (either up or down) for turn-time (duration of stay) only to those land uses which exhibit a high turnover with shorter stay durations by customers. Furthermore, the turn-time adjustment is only made to major customer focused land uses in order not to overestimate the parking reduction based on turn times (emanating from small land uses with very short turn-time values, largely only visited as part of multi-use trip chains). Turn-time adjustments should be made separately for different time of day periods (such as morning, lunch-time, afternoon and evening periods) as well as day of week periods (such as weekday and weekend periods) as turn-times will differ between these periods, and turn-time adjustments should be separated into single-use and multi-use turn-time adjustments.

Adjusting for single and multi-purpose trip turn-times would entail development of trip chains to estimate the probability of patrons undertaking single- or multi-purpose trips within the mixed-use development. Typically, questionnaires have to be circulated to estimate the extent of single and multi-purpose trips across the range of different land use types within a development. The respondents to the questionnaires indicated the sequence of land use visits associated with each car trip to the development as well as the duration of stay (turn time) associated with each land use visited. This information should then be converted into trip chains for each car visit to the development. The proportion of single and multi-purpose trips from the sample should then be applied to the population to determine the proportion of single- and multi-purpose trips within the development, and the average turn-time for each land-use component of the trip chain should be isolated for weekday and weekend trip chains as well as for morning, lunch-time, afternoon and evening periods.

The parking space demand for customers based on single- and multi-use turn-time adjustments for customer-focussed land uses is calculated by dividing the number of peak hour customers for major customer-focussed land uses by the product of the parking turn-time in minutes for single and multi-use trips and the maximum business hours of operation of each the land use in question for the analysis period.

It is important to note that turn-times for similar land-uses for similar time periods and day of week periods would vary around the average. In order to account for this variation, turn-time distributions were simulated by means of Monte Carlo simulation using the Palisade @RISK simulation software.

Monte Carlo simulation performs risk analysis by building models of possible results by substituting a range of values—a probability distribution—for any factor that has inherent uncertainty, such as the turn-time variable. It then calculates results over and over, each time using a different set of random values from a probability function and produces distributions of possible outcome values.

Trip chains and associated turn-times per land-use per time period and day of week were observed for 268 customers providing sufficient data to define the minimum, most likely and maximum turn-time values for land-uses where turn-time observations were observed to exhibit short-stay high-turnover parking for different time periods as well a day of week periods.

Based on the Monte Carlo simulations, a data table and distribution functions were prepared for each short-stay high-turnover parking land-use (i.e. Grocery / Supermarket / Butchery, Restaurant / Deli and Sport, Outdoor, Goods and Gear) for morning, lunch-time, afternoon and evening time periods for weekday and weekends. This data is presented graphically in Figure 4-3, Figure 4-4 and Figure 4-5below.

The turn-time adjustment is applied to the identified short-stay land uses according to the 85th percentile of the turn-time probability distribution per land-use per time periods per day of week, as simulated from the observed minimum, most likely and maximum turn-times for single- and multi-use trips for both weekdays and weekends.

Weekday turn-time adjustments were adjusted as follows:

- Weekday short-stay (customer) peak hour parking demand increased from 491 to 552 for single-use trips and from reduced 406 to 390 for multi-use trips. The nett effect is a 2,4% increase in short-stay (customer) parking from 897 parking spaces to 942 (45) parking spaces for the combined single- and multi-use trips. This increase is primarily as a result of the longer turn-slot requirements at restaurants during the weekday afternoon peak.

Weekend turn-time adjustments were adjusted as follows:

- Weekend short-stay (customer) peak hour parking demand reduced from 441 to 421 for single-use trips and increased from 433 to 441 for multi-use trips. The net result accounts for a 1.1% reduction in short-stay parking from 874 parking spaces to 862 parking spaces for the combined single- and multi-use trips.

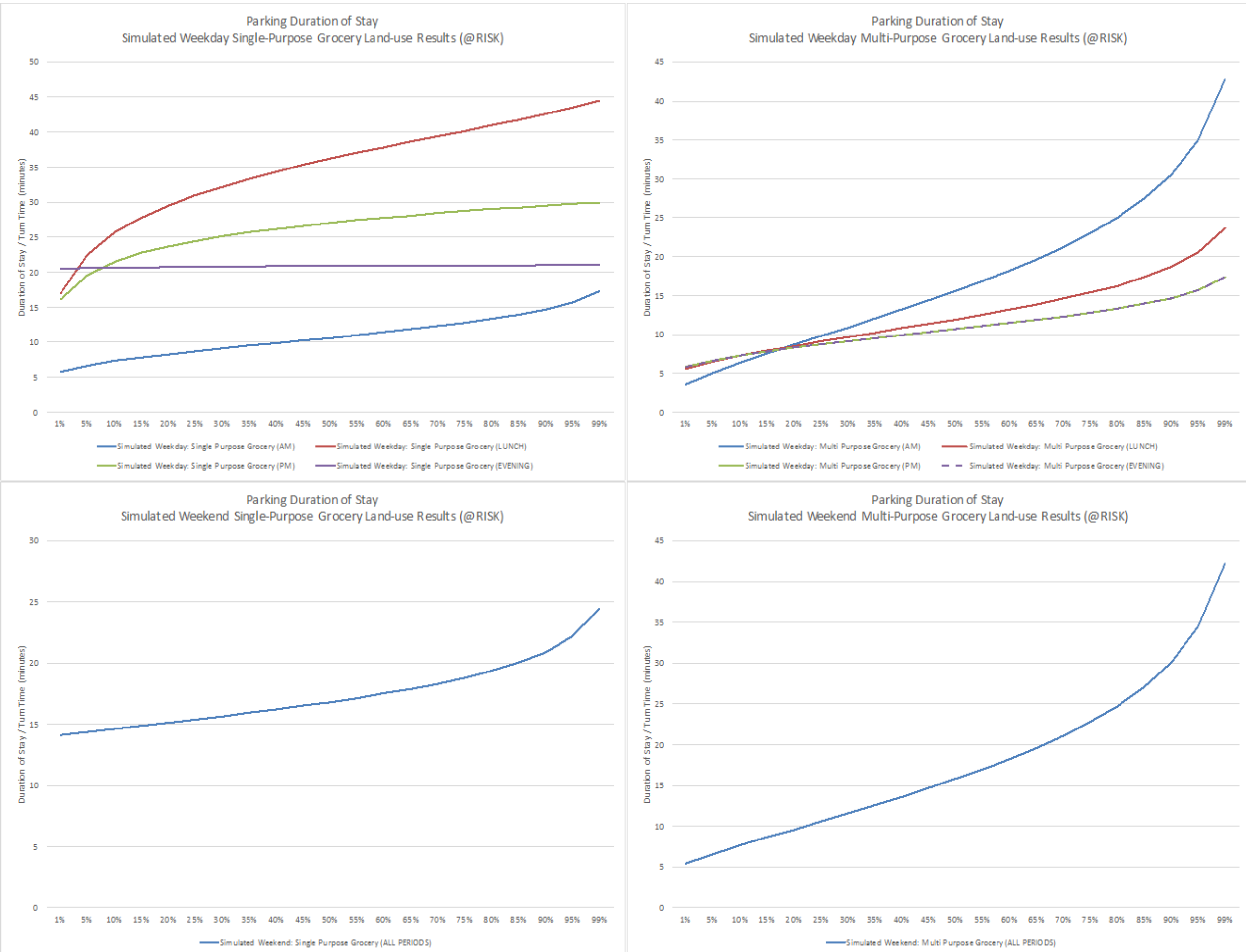


Figure 4-3: Parking Duration of Stay: Simulated Weekday and Weekend Grocery Land-use

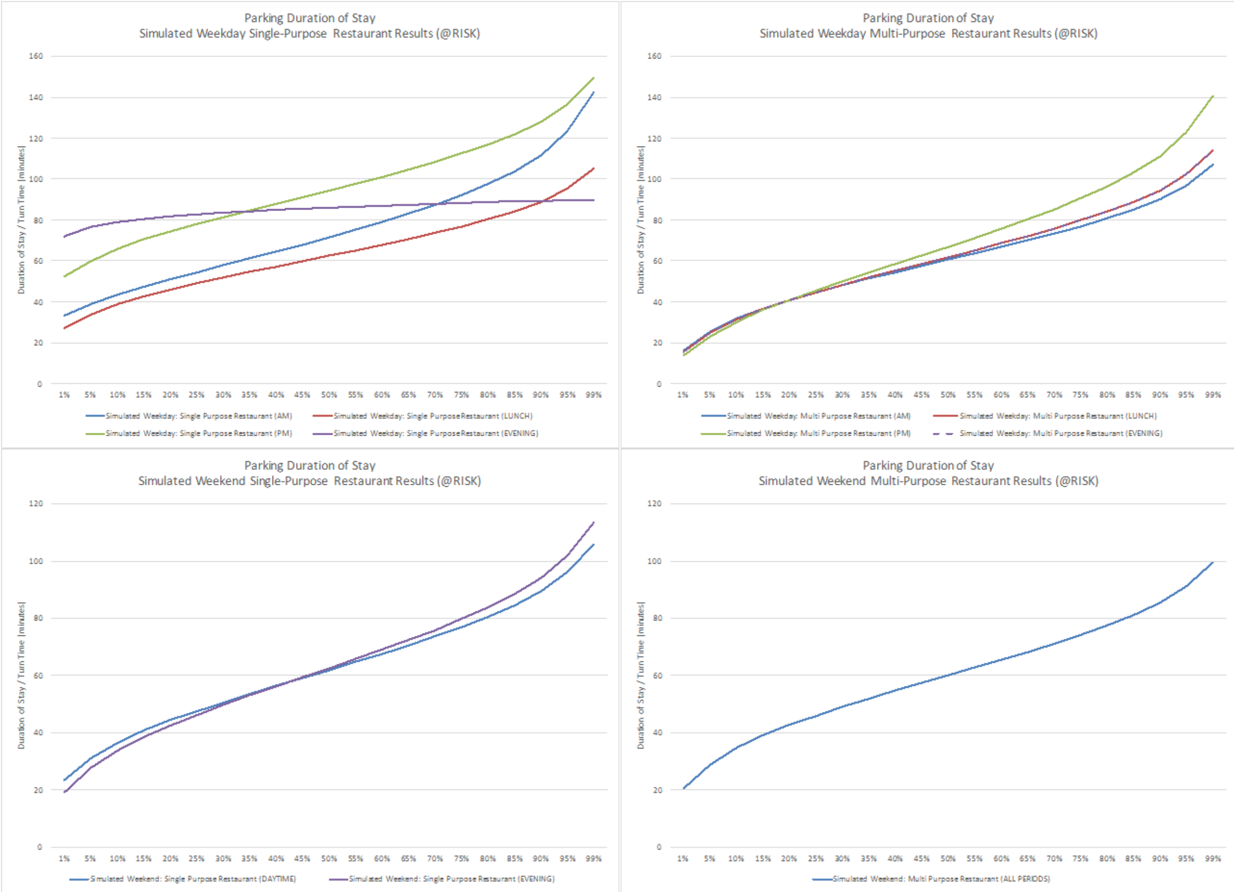


Figure 4-4: Parking Duration of Stay: Simulated Weekday and Weekend Restaurant Land-use

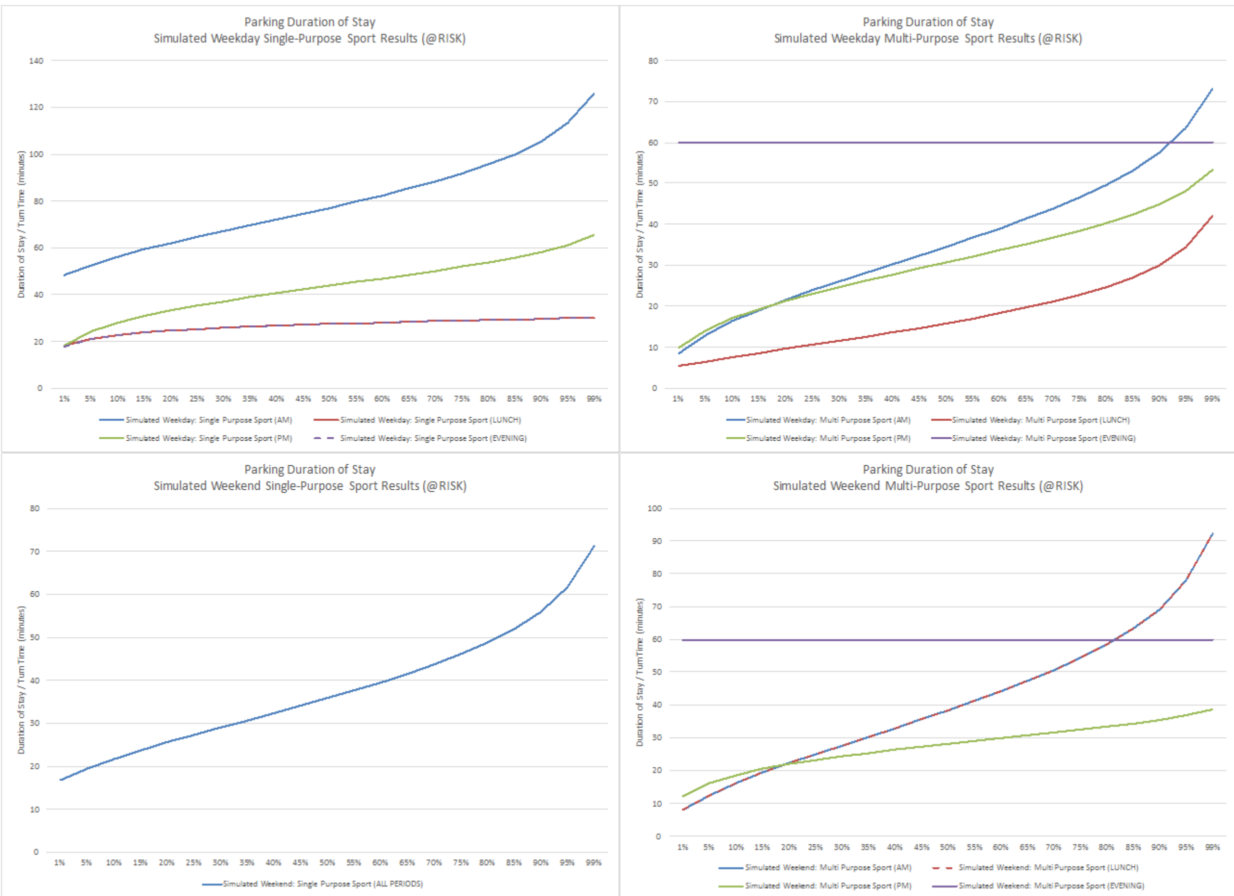


Figure 4-5: Parking Duration of Stay: Simulated Weekday and Weekend Sport Land-use

4.8 Shared Parking Demand Reduction Assessment

Shared parking demand reduction is the total number of parking spaces which can be removed from the development whilst still ensuring that there is sufficient shared parking provided for the peak period demand. It is critical that all parking spaces in the calculations are accessible to everyone and that no exclusive use or reserved parking is included in the $NC_{TT}TP_{UA}$ shared parking model calculation.

The Lynnwood Bridge case study was undertaken under the assumption that all parking spaces (except those allocated to disabled users) are available for public use and that no reserve parking restrictions apply. Although this is not strictly correct in terms of the way the Lynnwood Bridge development operates, this assumption was made to illustrate how the shared parking model reduces parking demand based on a number of parameters. In an actual assessment of a development, reserved parking will have to be isolated from other parking, and only those parking spaces which are accessible to everyone should be included in the calculation.

Table 7: Shared Parking Demand Reduction Assessment

<table>
<tr><th>Land use (LU_{ij})</th><th>Total GLA m^2</th><th>Rooms / Seats</th><th>Observed Parking Supply $SS(A_{ij})_2$</th><th>Single and Multi-use Turn Time adjusted Parking Demand DD(T)ij</th><th>Parking Space Reduction $NC_{TT}TP_{UA\ DR}$</th></tr>
<tr><td>Retail / Shops</td><td>4,614</td><td>N/A</td><td rowspan="6">625</td><td rowspan="6">1018</td><td rowspan="6">(393)</td></tr>
<tr><td>Places of refreshment / Restaurants</td><td>2,499</td><td>1362</td></tr>
<tr><td>Neighbourhood / Local Convenience</td><td>1,721</td><td>N/A</td></tr>
<tr><td>Banks, Building Societies</td><td>15</td><td>N/A</td></tr>
<tr><td>Gymnasium / Health Club</td><td>2,244</td><td>N/A</td></tr>
<tr><td>Social Hall / Theatre</td><td>724</td><td>400</td></tr>
<tr><td>Office Block (General Offices)</td><td>32,504</td><td>N/A</td><td>1376</td><td>839</td><td>537</td></tr>
<tr><td>Hotel (Business)</td><td>N/A</td><td>205</td><td>141</td><td>75</td><td>66</td></tr>
<tr><td></td><td colspan="2">**Total**</td><td>**2,142**</td><td>**1,932**</td><td>**210**</td></tr>
<tr><td colspan="4">*Note: Shared Parking Demand should be reflected for the peak parking demand period*</td><td>**Weekday PM**</td><td>**9.8% Over supply**</td></tr>
</table>

It is important to note that the modelled results yielded different results for different land uses, with retail requiring upward adjustment (undersupplied) and office requiring downward adjustment (oversupplied). This suggests that the overall shared parking demand adjustment might be very sensitive to the balance and sizes of land uses within the development.

Given the above, the $NC_{TT}TP_{UA}$ shared parking model parking demand adjustments suggests the total development parking supply (observed) can be reduced by 210 parking spaces for the peak analysis period (Weekday PM Peak from 15:00 to 16:00), which represents a 9,8% reduction in parking spaces. The reader may recall that based on the ordinance parking requirement assessment, the Lynnwood Bridge developed required a total parking supply of 2,633 spaces, and was already under-supplied with parking at the observed parking supply figure of 2,142. The $NC_{TT}TP_{UA}$ shared parking model parking demand adjustments shows an even greater reduction in parking (26%), if one uses the ordinance parking supply calculations.

5. CONCLUSIONS

The following key findings emanated from this research:

- A Non-captive Turn-time Time Period Utilisation Adjusted ($NC_{TT}TP_{UA}$) shared parking model was successfully assimilated from model parameter inputs from the ULI Shared Parking model (Smith, 2005) and the Shared Parking Turn-time model (SPaTT) (Iman, 2006) and was successfully calibrated and applied within the South African development environment.

- Litman (2009) suggested that shared parking schemes could reduce the parking requirements of mixed use developments by 10-30%, provided that shared parking schemes are applied in conjunction with other parking management strategies. The results from the illustrative application of the $NC_{TT}TP_{UA}$ shared parking model supported this finding by demonstrating that the parking supply, for the case study, could be reduced by approximately 10% for the development parking peak (Weekday PM from 15:00 to 16:00).

- This research has shown that time period specific utilisation adjustment factors have by far the greatest impact on reducing demand for parking in the $NC_{TT}TP_{UA}$ shared parking model than other model parameters such as non-captive trip-chain based turn-time, car ownership, car sharing etc.

- This research has shown that shared parking as a concept cannot simply be imposed on existing or new developments without taking account of critical design and parking management recommendations. Shared parking is applicable to environments where parking spaces are accessible to all development patrons with the absolute minimum exclusive use parking provision. The higher the exclusive use parking, the more compromised the shared parking scheme. Furthermore, parking spaces should be designed and positioned within the development to eliminate separation of parking structures as far as possible and “walkable” precincts should be characterized by centralized parking accessible to all precinct land use patrons.

- This research has found that the turn-time variable of the $NC_{TT}TP_{UA}$ shared parking model has the tendency to over-estimate the reduction in parking demand if the turn-time values associated with short-stay non-captive land uses are too low. The practical application of the model indicated that the turn-time adjustments for single- and multi-use trips should only focus on the large contributors of short-stay parking demand (irrespective whether they are single- or multi-purpose trips generators).

- The $NC_{TT}TP_{UA}$ shared parking model methodology has departed from standard traffic engineering practices of estimating vehicle trip generation of developments to an approach which rather focusses on estimating person trip generation for employees and customers per land use for mixed use developments. The reason for this departure is the $NC_{TT}TP_{UA}$ shared parking model systematically reduces parking demand through adjustments to person trip demand such as car ownership and car sharing.

In conclusion this research identified further research requirements, namely:

- Calculating person trip rates for per land use for employees and customers for different day of week time periods should be undertaken to obtain accurate person trip rates for South African conditions.

- Compilation of an extensive databank of time period specific parking utilisation adjustment factors for a range of land uses. The selected land uses for this research should be the same land use categorisations as those used in the person trip rates research referred to above.

- Isolate simultaneous trips and sequential trips (as identified in the ULI shared parking model (Smith, 2005)) from within the multi-use trip chains, as these could be an additional parking demand reduction parameters over and above the non-captive short stay parking turn-time parameter applied in the $NC_{TT}TP_{UA}$ shared parking model.

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