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PAPER TITLE

There is a growing recognition that parking is an essential contributor to the function of the transport system. Widely adopted "conservative" parking provisions have resulted in undesirable parking outcomes at significant social, environmental and economic cost.

This paper describes a parking demand model developed specifically to assess the requirements for dense mixed-use City Centres. This model extends best-practice by taking into account the synergies between land-use components of the City that arise from both time-of-use and internal trip capture in a way that is independent of external mode share.

The results of the model can be confirmed and calibrated to observed behaviours for the existing land-use scenario, taking into account additional factors such as mode choice, park 'n' ride and parking pricing mechanisms. Outputs can then assist policy makers, planners and engineers in the early stages of City Centre planning to ensure that an optimal parking supply is provided, and to establish the necessary funding to construct public parking facilities through developer contributions or cash-in-lieu mechanisms.

1. Introduction

The current trend in Australian land-use planning is for a network of Activity Centres that provide dense local inner-city environments for residents, employees and visitors.

The viability of these Activity Centres is inextricably linked to the provision of a variety of transport modes. Given the highly car-dependent nature of the Perth region and most other Cities in Australia; car parking provision is a primary factor in determining the viability of a future Centre.

Cardno have developed an improved method for determining the demand for car parking within a dense mixed-use development that extends current best-practice. This method includes consideration of both shared use of public parking for uses with different peak demand profiles and also quantifies the reduction in car parking requirement as a result of synergies between residential, office and other land uses, where parking is usually considered to be exclusive.

The results of analysis integrate well with the assessment of a road capacity-based parking cap and can identify where parking demand is likely to exceed the available supply. This information, provided in the early stages of planning, also assists in determining how public and private parking can be delivered, requisite parking rates by land use, cash-in-lieu contributions and more.

This paper will discuss the general methodology and provide case-study examples of its utility in determining parking supply for future scenarios.

2. Nomenclature

2.1 Shared parking

For the purpose of this analysis, ***shared parking*** refers to bays that permit use by multiple land uses. The peak parking occupancy is reduced as a result of different parking profiles across different months (seasonal or monthly effects) and the day (time of day effects).

Figure 1 shows the theoretical parking demand profiles for a range of land-uses. The differences in relative parking demand peaks create opportunities for more efficient use of a given parking quantum.

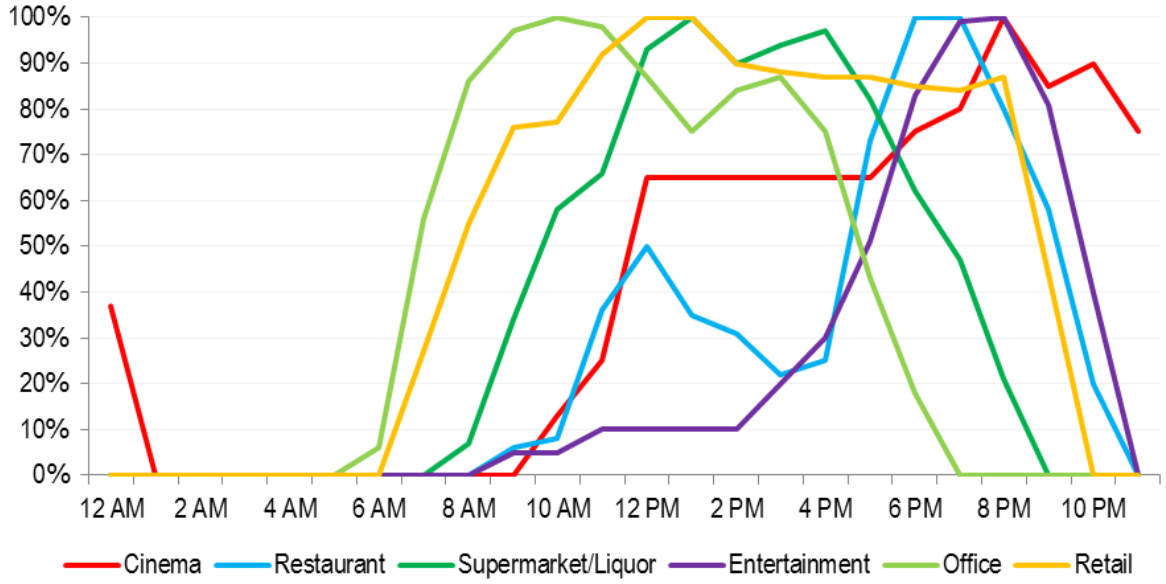

Figure 1 **Example of a weekday parking demand profile**

Shared parking rates are generally extracted from baseline suburban demand studies such as those described in the Urban Land Institute's *Shared Parking* (Smith, 2005), or *Parking Generation* (Institute of Transportation Engineers, 2010). These sources generally neglect the influence of transport mode share reductions and internal trip capture, allowing the model to determine the influence of these factors.

2.2 Reciprocal parking

Reciprocal parking (also referred to as ***captive parking***) occurs when a visitor has more than one purpose within an area and hence only one parking bay is required to serve two or more purposes. This primarily occurs where there is a mix of retail and office uses surrounded by a primarily residential catchment. As a result of the synergies between these uses, there is likely to be a degree of internal trip capture and an associated reduction in parking demand.

The degree of captive parking occurring depends on the type of land use in the vicinity and the time of day. For the purpose of this model, the likelihood of internal trip capture has been determined from the *NCHRP Report 684: Enhancing Internal Trip Capture Estimation for Mixed-Use Developments* (Bochner et al, 2011).

In this model, NCHRP internal trip capture rates are considered to be applicable for all land-use pairs determined to be within a reasonable walking catchment. The effect of internal trip capture only ***reduces*** local parking occupancy where cars are parked outside of the internal 'shared' quantum. That is, where cars are parked at businesses, residences or other exclusive parking locations (internal-internal reciprocity), or outside of the Precinct (internal-external reciprocity).

By including the effects of parking reciprocity, the peak parking requirement is reduced and a lower total parking supply will be required to satisfy demand. It should be noted that the reduction in parking supply associated with internal trip capture is not reliant on shared or public parking provision, as it instead leverages vehicles parking in exclusive bays.

3. Parking Demand Methodology

The following describes the general methodology used to determine the existing and future theoretical parking demand.

3.1 Precinct choice

This parking model is suitable for analysis across many development scales. It has been used successfully for small mixed-use developments within a local residential catchment, and for moderately-sized City Centre environments. Fundamentally, precincts are chosen according to two metrics:

> In which area do I care about the parking demand? (i.e. the **Internal Zone**)
> To what distance can we reasonably assume will choose to walk, rather than drive (i.e. the **External Zone**)

These factors will determine the scale of the precinct and its area of influence. It is important to consider factors such as pedestrian severance effects (e.g. the location of a freeway or railway line that restricts pedestrian movements), or public transport accessibility (e.g. the free CAT system in Perth which significantly extends the reasonable travel distance).

Some City Centres are too large to be aggregated into a single precinct zone. To address this issue, Cardno has developed a spatial assessment that allows for an understanding of parking demand across multiple precincts with overlapping 'areas of influence'.

3.2 Existing gross peak demand calculation

Existing precinct land uses are disaggregated fine-grained land use designations as described in parking demand guidelines (e.g. *Parking Generation (ITE), Shared Parking (ULI), Guidelines for Traffic Generation Developments (RTA) etc.*). Peak parking demands are extracted from these document, for the most applicable category. The summation of each land use peak parking demand value results in the calculation of the **Gross Peak Demand** for the site.

This value does not consider shared or reciprocal parking, and is therefore overly conservative. That is, where the parking demand for each land use is considered separately, the result is a significant oversupply of parking.

3.3 Shared parking calculation

The basic assessment for shared parking assumes that all bays are available for all uses. This is a simplification of the actual operation of on-site parking, but provides an idealized benchmark for further analysis.

There is a significant difference in parking behaviour between weekdays and weekends, requiring two related but separate parking demand assessments, as shown in **Figure 2** below.

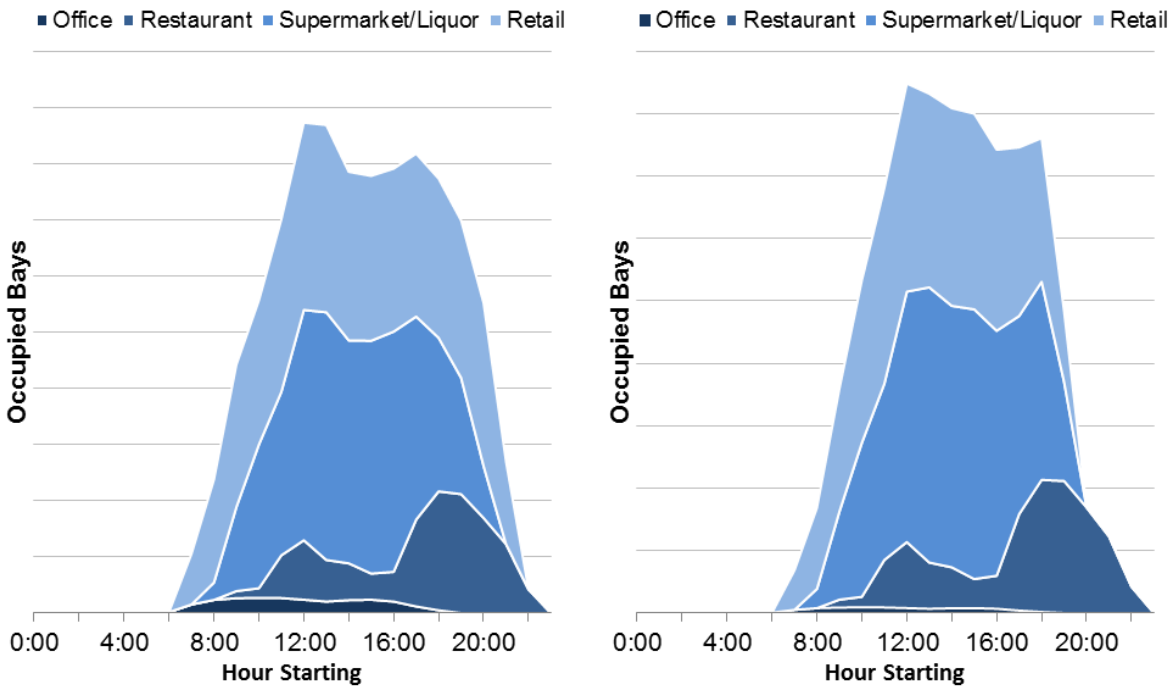

Figure 2 **Example of a weekday (left) and weekend (right) precinct parking demand profile**

3.4 Reciprocal parking

Research undertaken by the NCHRP and described in *Report 684* used survey data to identify the rates of internal trip capture between six main land use types. These rates have been used as the primary mechanism to calculate the effect of mixed-use synergies on parking demand.

For this purpose, the individual land uses on-site are aggregated into "Office", "Retail", "Restaurant", "Residential", "Hotel" and "Entertainment" categories.

The reciprocity rates extracted from *NCHRP Report 684* are shown as a matrix in **Table 1**:

Table 1 **Internal Trip Capture Rates (AM Period)**

	To						
From		Residential	Office	Retail	Restaurant	Hotel	Entertainment
	Residential	-	2%	1%	20%	-	-
	Office	1%	-	28%	63%	-	-
	Retail	14%	29%	-	*13%*	-	-
	Restaurant	4%	31%	*14%*	-	*3%*	-
	Hotel	-	75%	*14%*	*9%*	-	-
	Entertainment	-	-	-	-	-	-
	From						
To		Residential	Office	Retail	Restaurant	Hotel	Entertainment
	Residential	-	-	2%	5%	-	-
	Office	3%	-	4%	14%	3%	-
	Retail	17%	32%	-	*8%*	*4%*	-
	Restaurant	20%	23%	*50%*	-	*6%*	-
	Hotel	-	-	-	*4%*	-	-
	Entertainment	-	-	-	-	-	-

Several aspects of this data should be noted:

> Reciprocity rates are given for AM and PM periods, but there is a step-change transition at Midday. Therefore, the worst-case of the AM and PM calculation should be given as the midday peak.

> The data is presented in the form of an 'ordered trip' (i.e. a trip that goes From Office-To Retail is different From Retail-To Office).

> Reciprocity is calculated in both directions (i.e. From Office-To Retail is the same as To Retail-From Office), with the minimum value taken.

> Reciprocal parking effects only occur where a trip might be feasibly taken by private car modes. Therefore, all calculations are hypothecated to 'parked cars', rather than modelling person-trips directly.

Applying these percentages pair-wise to the parking profiles of the six land-use categories creates a reciprocal parking profile for the Precinct.

Two types of reciprocal parking are considered in this analysis, internal-internal reciprocity and internal-external reciprocity. These differ in the land uses that can reasonably be considered as eligible for reciprocal parking.

3.5 Internal-Internal reciprocity

The internal trip catchment is calculated based on parking bays within the Internal Zone (the Precinct), occupied by a car associated with two land categories, both located within the Internal Zone. For the purpose of determining the benefit of internal-internal reciprocity on parking consumption, only exclusive bays are included in the analysis (e.g. all residential and any dedicated office bays).

Shared parking is assumed for all retail, restaurant, hotel, entertainment, off-site residential visitors, park 'n' ride and non-reserved office uses. Internal trips between these land uses may result in a reduction in private vehicle *trips*, but has no impact on *parking demand.*

Reciprocity has been defined to occur in the manner illustrated in **Figure 3** below. That is, reciprocity only reduces the total parking requirement where parking is provided in exclusive bays.

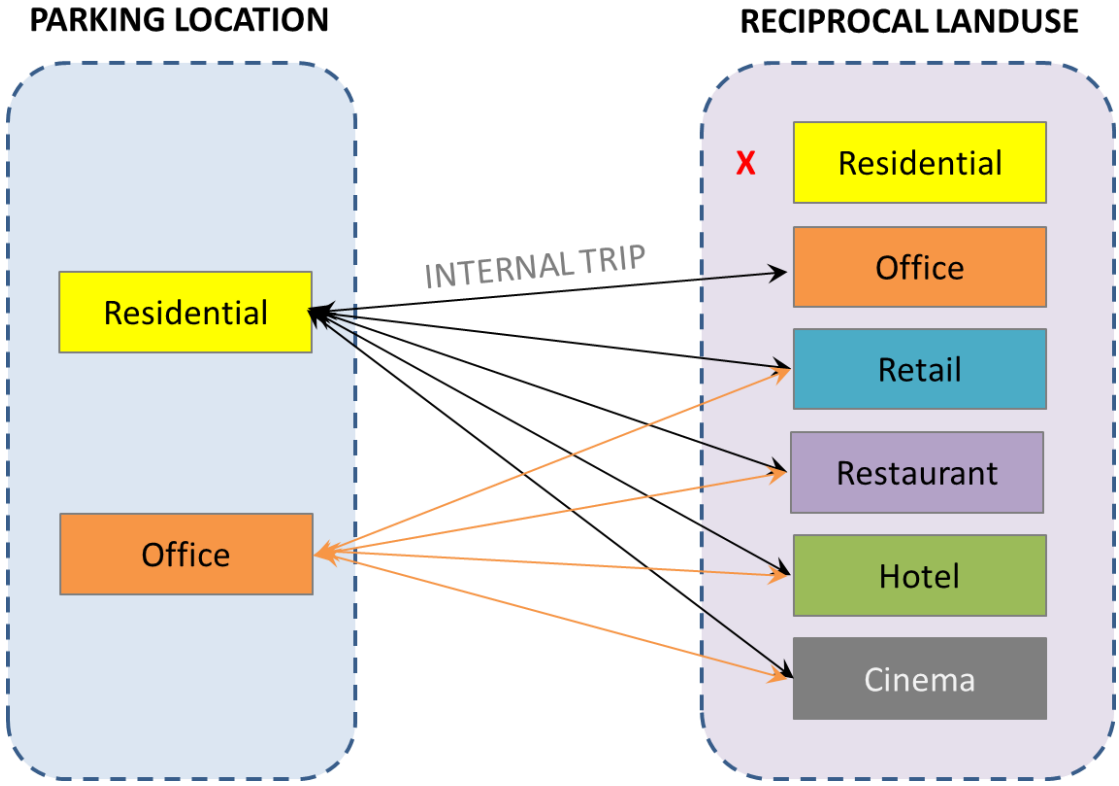

Figure 3 **Reciprocity Relation Between Constituent Land Use Pairs**

Assumptions:

> Parking location choice is based on a hierarchy of land uses as follows:
  - Residential ←→ All other uses (i.e. any parking associated with residential will preferentially use residential parking bays)
  - Office ←→ All non-residential uses (i.e. any non-residential parking associated with office will preferentially use office parking bays)
> No synergies are calculated within a land-use category (i.e. walking trips from one office to another). This is considered conservative under the assessed scenario.
> Residential visitors do not generate reciprocal parking benefits as they are considered unlikely to use other Precinct facilities during their visitation.

> Office parking is divided into dedicated office parking and shared office parking. The model assumes that office users will prefer to park within dedicated spaces (where available), rather than use the public supply. Only dedicated office parking demand is considered in the reciprocal parking calculation.

> Park 'n' ride demand is assumed to be unrelated to internal land use and users of park 'n' ride bays do not contribute to activity or reciprocal parking benefits.

3.6 Internal-External reciprocity

The interaction between the land uses in the surrounding walkable catchment (the External Zone) and the Precinct (the Internal Zone) are captures by the internal-external reciprocity.

In this calculation, all potential interactions are included, with impacts determined by application of **Table 1** percentages for every land use pair involving the External Zone)

This interaction is defined as follows:

> External residents are assumed to walk to and from the Internal Zone with their cars parked at their homes

> External employees are assumed to park in their allocated parking space at their office premises and walk to and from the Internal Zone to access non-residential land uses

> For all other land use pairs, parking is consumed within the Internal and External Zones according to the ratio of internal versus external development. This is described by the following equation:

Parking occupancy expected within the internal development is adjusted by a factor ***F*** to account for the allocation of reciprocal parking across the Internal and External Zones.

$$F = (1 - 2Z), \qquad with\ Z = \frac{D_{int}}{D_{tot}}$$

Where;

> *F* is the adjusting **Factor** to allocate reciprocal parking across the Internal and External Zones.

> *Z* is the **Proportion of Parking Occupancy** expected within the Internal Zone at a particular time of the day;

> D_{int} is the Parking Demand of non-residential/office for Internal land uses;

> PD_{tot} is the combined Parking Demand of non-residential/office for both Internal and External land uses.

3.7 Calibration

The above methodology creates a useful baseline for demand assessment based solely upon land-use inputs. However, it does not include any understanding of local parking demand or supply management, public transport provision or other external effects.

To account for these impacts, the model must be re-run using transport mode share reduction factors for each land use category and then calibrated to parking demand observations including identification of park 'n' ride and residential visitor parking.

This creates a robust model of the existing scenario that captures aspects of the local parking system including:

> Availability of public transport
> Spatial distribution of catchment
> Parking supply management effects such as timing restrictions or reduced parking rates
> Parking pricing and other demand management effects
> Environmental and social effects

3.8 Investigation and future assessment

The calibrated model can then be extended to account for development within the Precinct and surrounding catchment area. This future assessment is, by nature, a reflection of the existing system and attitudes and should be adjusted manually to reinforce or supplement the policy direction of the Local Government area.

Additional factors may also be included in the application of the above demand assessment:

> consideration for parking efficiency within the various types of parking
> the need for and impact of park 'n' ride and residential visitor parking on public provision; and
> the potential for future mode shift either as a consequence of improved public transport or enforced by parking supply restrictions

Some of the applications of this model are described below, with reference to a single case study for the Midland Oval Redevelopment.

4. Application of Methodology

This methodology for parking demand assessment has been used in a variety of City Centre areas and mixed-use developments. One of these developments, the Midland Oval Redevelopment, is discussed below as a case study examples for the type of information that can be extracted from the model and the use of this information to drive physical infrastructure and policy.

4.1 Midland Oval Redevelopment

The Midland Oval Redevelopment is a significant project within the Midland Activity Centre, defined to be a Strategic Metropolitan Centre in *State Planning Policy 4.2: Activity Centres for Perth and Peel (SPP4.2)* (PlanningWA, 2010). This redevelopment is intended to create a dense mixed-use zone in the heart of the Centre, and provides a test-bed for application of long-term policy direction for the City.

Midland Oval is planned to include a wide range of activities including:

> Medium-High density residential
> Office
> Library, Museum and Local Government Administration
> Retail shopping
> Small bars, restaurants and cinemas
> Serviced apartment and hotels

Being a mixed use development in the City Centre, there are opportunities for trip chaining and parking reductions that could substantially impact the economic viability and the overall function of the site.

The model described above was employed to identify the potential future requirement for parking on-site, and the extent to which this parking could be provided in public bays for the benefit of employees and visitors.

For the purpose of the assessment, nine constituent land uses have been re-classified broadly into the six land use categories (as shown in **Figure 4**) based on their function.

Source: City of Swan, Midland Oval Master Plan

Figure 4 **Midland Oval Redevelopment Plan land use classification**

4.2 Summary of parking demand assessment

Table 2 summarises the results obtained from parking demand analysis.

Table 2 **Theoretical peak weekday parking demand assessment for Midland Oval**

		Visitor/Employee Parking		
	Theoretical Parking Demand	**Total**	**Reduction**	
Isolated Site	Un-Restrained Exclusive Parking Demand	**5,642**		%
	Shared Parking Demand	4,485	1,157	**21**
	Parking Demand: Shared+Reciprocal	3,924	1,718	**30**
Site with Internal - External Interaction	With Internal-External Reciprocity (Existing)	3,339	2,304	**41**
	With Internal-External Reciprocity (2031)	3,308	2,352	**41**

Several outcomes should be noted from the above assessment results:

> The traditional best-practice method which include supply reductions due to shared parking only (temporal use of communal bays) results in the largest component of the calculated benefit.
> The additional benefit resulting from internal trip capture for land uses within the site area (the Isolated Site model) is relatively small, in the order of 10 percent. This is consistent with rule-of-thumb measures for the impact of mixed-use sites.
> By calculating synergies with the surrounding City Centre, the total impact of reciprocity is approximately 20% - over 1,000 parking bays less than the 'shared parking only' result.
> There is very little reduction as a result of the future Activity Centre growth. This is because the External Zone is restricted to a 400m catchment and is largely made up of nearby shopping centre and residential land uses. While the shopping centre floor area is proposed to increase substantially, this growth will occur outside of the walkable catchment and is therefore not captured in this analysis. Residential growth in the External Zone is also minimal.

From this assessment it can be inferred that once the effects of shared parking and reciprocity are accounted for, both within the development and for a reasonable external walking catchment, a reduction of approximately **40%** in the parking supply can be justified, when compared with standard suburban rates.

That is, if the Midland Oval Precinct were to provide exclusive parking for every constituent land use, then approximately **5,642** visitor/employee parking bays would be required in addition to the residents' bays. However, in this analysis the peak demand for parking is expected to be in the order of **3,339** visitor/employee bays at full build-out, reducing to **3,308** bays by 2031, with an additional **713** bays provided for exclusive residential use.

4.3 Summary of calculated parking supply

The parking supply within the Midland Oval Precinct can be disaggregated into three main types:

> Private, exclusive parking – All resident bays and some office bays

> Public parking – On-street and multi-deck parking bays available for all users at all times. These should be priced to ensure that the supply is used primarily for Precinct parking and limits the attractiveness for parking by external land uses.

> Shared Parking – parking within development boundaries which is available for use by all land uses in the precinct. It is acknowledged that parking provided by office developments will be used primarily for their own staff during business hours, but this quantum would be available after-hours for use by retail/entertainment uses.

With respect to constituent quantum, preliminary assessment showed the following mix to be appropriate:

> Exclusive residential parking: ~700 bays (1 per unit)

> Exclusive office parking: up to 2,500 bays (2.3 bays per 100sq.m) *[note that the projected office demand is 3,200 bays; overflow demand will spill into shared parking]*

> Shared/public parking: 850 bays

- Public on-street parking: ~150 bays
- Shared Retail Parking: ~ 200 bays
- Public off-street parking: ~500 bays

4.4 Comparison of calculated and statutory supply rates

It is useful to compare the results of detailed parking supply calculations with the quantum defined in other statutory documents. The results of this comparison for employee/visitor bays are as follows:

> Existing *POL-TP-129 Vehicle Parking Standards* (City of Swan, 2014): **6,260** bays

> Calculated quantum (free and unrestrained): **3,339-3,308** bays (for existing and City Centre build-out scenarios, respectively).

This suggests that the existing City of Swan parking standards would significantly oversupply parking on this site, and that changes to City Centre Parking policy would be needed to ensure effective parking in the Precinct.

SPP4.2 establishes the concept of a parking cap as a way to manage the traffic generated by an Activity Centre. The calculated quantum for parking supply fits within the parking cap identified for this particular Centre, such that significant road improvements can be avoided.

4.5 Policy impacts of assessment

Through this process, the City of Swan recognized that the application of its suburban parking requirements within the Midland City Centre could jeopardise the viability of the development through consumption of valuable land assets and additional cost imposition. It was also important that mechanisms be put in place to ensure that public parking could be constructed for use by the constituent land uses, with any policy changes applied evenly across the entire City Centre

For this reason, a mandatory cash-in-lieu policy was recommended in the *Midland Activity Centre Transport Assessment* (Martin, 2013), equivalent to 25% of the statutory development parking requirement. This was combined with a set of simplified parking rates to be applied to new development across the City Centre, derived using the outcomes of the parking demand assessment.

The result allows for fine-grained analysis of infrastructure cost and staging in local areas to leverage cash-in-lieu to purchase land and build at-grade, and then multi-deck car parking as required.

In this particular case, parking was proposed to be constructed in two stages, allowing retail and residential development to lead the way, with office construction in accordance with the plan when demand increases.

Under this scenario, total parking provision is calculated at approximately 3,400 bays, comprising:

Stage 1:

- 850 bays publically accessible ‘private’ parking
- 150 bays public on-street parking
- 150 bays public at-grade parking
- 350 bays equivalent cash-in-lieu

Stage 2:

- 1,900 bays exclusive ‘private’ parking
- 500 bays replacement multi-deck parking (removing Stage 1 at-grade parking)
- 800 bays equivalent cash-in-lieu

The form of this parking, in large-scale lots easily accessible by multiple land uses, maximises parking efficiency and allows provision at close to demand rates.

It is noted that the projected office demand is higher than the ultimate supply for office parking. This can be accommodated through a private leasing arrangement with retail development, and/or by structuring public parking fees to support long-stay parking during office hours (e.g. concessional day rates).

Assuming land is purchased and at-grade parking is provided using the funds from Stage 1, and the multi-deck is constructed using the funds from Stage 2, a cost structure was determined that reduces the cost of parking for developers across both stages (when compared with private construction), while also funding the requisite public parking and providing an overall restraint on parking supply.

5. Conclusion

Parking management is an essential element to the successful operation of any City Centre. The model discussed herein is an innovative method of quantifying parking demand and determining the right parking supply to support the needs of the development and surrounding City Centre.

In this case study, it has been shown that a significant reduction in parking can be justified, based on a fine-grained understanding of demand and land-use interactions. The model outputs can also assist policy makers, planners and engineers in the early stages of City planning to ensure that an optimal parking supply is provided. Most importantly, the results of the model can be confirmed and calibrated to observed behaviors for the existing land-use scenario.

Further, policies for parking management can be accurately and appropriately framed on the basis of the model outputs.

6. Acknowledgements

Thank you to my colleagues at Cardno for their assistance in formulating the model and continually improving it through critical analysis.

Additional thanks to the City of Swan for their support throughout the process of establishing this method, evaluating its impact and applying it within the Midland City Centre.

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